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650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
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Foreword

This Technical Specification has been produced by the 3rd Generation Partnership Project (3GPP).

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1 Scope

The present document provides an overview and overall description of the NG-RAN and focuses on the radio interface protocol architecture of NR connected to 5GC (E-UTRA connected to 5GC is covered in the 36 series). Details of the radio interface protocols are specified in companion specifications of the 38 series.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document.*

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 36.300: "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2".

[3] 3GPP TS 23.501: "System Architecture for the 5G System; Stage 2".

[4] 3GPP TS 38.401: "NG-RAN; Architecture description".

[5] 3GPP TS 33.501: "Security Architecture and Procedures for 5G System".

[6] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification".

[7] 3GPP TS 38.322: "NR; Radio Link Control (RLC) protocol specification".

[8] 3GPP TS 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".

[9] 3GPP TS 37.324: "E-UTRA and NR; Service Data Adaptation Protocol (SDAP) specification".

[10] 3GPP TS 38.304: "NR; User Equipment (UE) procedures in Idle mode and RRC Inactive state".

[11] 3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities".

[12] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".

[13] 3GPP TS 38.133: "NR; Requirements for support of radio resource management".

[14] 3GPP TS 22.168: "Earthquake and Tsunami Warning System (ETWS) requirements; Stage 1".

[15] 3GPP TS 22.268: "Public Warning System (PWS) Requirements".

[16] 3GPP TS 38.410: "NG-RAN; NG general aspects and principles".

[17] 3GPP TS 38.420: "NG-RAN; Xn general aspects and principles".

[18] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone".

[19] 3GPP TS 22.261: "Service requirements for next generation new services and markets".

[20] 3GPP TS 38.202: "NR; Physical layer services provided by the physical layer"

[21] 3GPP TS 37.340: "NR; Multi-connectivity; Overall description; Stage-2".

[22] 3GPP TS 23.502: "Procedures for the 5G System; Stage 2".

[23] IETF RFC 4960 (2007-09): "Stream Control Transmission Protocol".

[24] 3GPP TS 26.114: "Technical Specification Group Services and System Aspects; IP Multimedia Subsystem (IMS); Multimedia Telephony; Media handling and interaction".

[25] Void.

[26] 3GPP TS 38.413: "NG-RAN; NG Application Protocol (NGAP)".

[27] IETF RFC 3168 (09/2001): "The Addition of Explicit Congestion Notification (ECN) to IP".

[28] 3GPP TS 24.501: "NR; Non-Access-Stratum (NAS) protocol for 5G System (5GS)".

[29] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification".

[30] 3GPP TS 38.415: "NG-RAN; PDU Session User Plane Protocol".

[31] 3GPP TS 38.340: "NR; Backhaul Adaptation Protocol (BAP) specification".

[32] 3GPP TS 38.470: "NG-RAN; F1 application protocol (F1AP) ".

[33] 3GPP TS 38.425: "NG-RAN; NR user plane protocol".

[34] 3GPP TS 23.216: "Single Radio Voice Call Continuity (SRVCC); Stage 2".

[35] 3GPP TS 38.101-2: "User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone".

[36] 3GPP TS 38.101-3: "User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios".

[37] 3GPP TS 37.213: "Physical layer procedures for shared spectrum channel access".

[38] 3GPP TS 38.213: "NR; Physical layer procedures for control".

[39] 3GPP TS 22.104 "Service requirements for cyber-physical control applications in vertical domains".

[40] 3GPP TS 23.287: "Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services".

[41] 3GPP TS 23.285: "Technical Specification Group Services and System Aspects; Architecture enhancements for V2X services".

[42] 3GPP TS 38.305: "NG Radio Access Network (NG-RAN); Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN".

[43] 3GPP TS 37.355: "LTE Positioning Protocol (LPP)".

[44] 3GPP TS 29.002: "Mobile Application Part (MAP) specification".

[45] 3GPP TS 23.247: "Architectural enhancements for 5G multicast-broadcast services; Stage 2".

[46] 3GPP TS 26.517: "5G Multicast-Broadcast User Services; Protocols and Formats".

[47] 3GPP TS 23.122: "Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode".

[48] 3GPP TS 23.304: "Proximity based Services (ProSe) in the 5G System (5GS)".

[49] 3GPP TS 28.541: "5G Network Resource Model (NRM)".

[50] 3GPP TS 38.423: "NG-RAN; Xn Application Protocol (XnAP)".

[51] NIMA TR 8350.2, Third Edition, Amendment 1, 3 January 2000: "DEPARTMENT OF DEFENSE WORLD GEODETIC SYSTEM 1984".

[52] 3GPP TS 38.211: "NR; Physical channels and modulation".

[53] 3GPP TS 24.587: "Vehicle-to-Everything (V2X) services in 5G System (5GS)".

[54] 3GPP TS 23.041: "Technical realization of Cell Broadcast Service (CBS)".

[55] 3GPP TS 24.554: "Technical Specification Group Core Network and Terminals; Proximity-services (ProSe) in 5G System (5GS) protocol".

[56] 3GPP TS 38.214: "Technical Specification Group Radio Access Network; NR; Physical layer procedures for data".

[57] 3GPP TR 38.835: "NR; Study on XR enhancements for NR".

[58] 3GPP TS 26.522: "5G Real-time Media Transport Protocol Configurations".

[59] 3GPP TS 38.215: "NR; Physical layer measurements".

[60] 3GPP TS 23.256: "Support of Uncrewed Aerial Systems (UAS) connectivity, identification and tracking; Stage 2".

[61] IETF RFC 9330: "Low Latency, Low Loss, Scalable Throughput (L4S) Internet Service: Architecture".

[62] IETF RFC 9331: "Explicit Congestion Notification (ECN) Protocol for Very Low Queuing Delay (L4S)".

[63] IETF RFC 9332: "Dual-Queue Coupled Active Queue Management (AQM) for Low Latency, Low Loss, and Scalable Throughput (L4S)".

[64] 3GPP TS 28.105: "Management and orchestration; Artificial Intelligence/ Machine Learning (AI/ML) management".

[65] 3GPP TS 38.351: "NR; Sidelink Relay Adaptation Protocol (SRAP) Specification".

[66] 3GPP TS 38.391: "Ambient IoT Medium Access Control Protocol specification".

[67] 3GPP TS 38.291: "Ambient IoT Physical Layer".

[68] 3GPP TS 23.369: "Architecture support for Ambient power-enabled Internet of Things".

[69] 3GPP TS 23.527: "Technical Specification Group Core Network and Terminals; 5G System; Restoration Procedures".

[70] 3GPP TS 33.545: "Security aspects of NR Femto".

[71] 3GPP TS 37.320: "Radio measurement collection for Minimization of Drive Tests (MDT); Overall description; Stage 2".

3 Abbreviations and Definitions

3.1 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1], in TS 36.300 [2] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1] and TS 36.300 [2].

5GC 5G Core Network
5GS 5G System
5QI 5G QoS Identifier

A2X	Aircraft-to-Everything
A-CSI	Aperiodic CSI
AGC	Automatic Gain Control
AI	Artificial Intelligence
AI/ML	Artificial Intelligence and Machine Learning
A-IoT	Ambient Internet of Things
AIOTF	Ambient IoT Function
AKA	Authentication and Key Agreement
AMBR	Aggregate Maximum Bit Rate
AMC	Adaptive Modulation and Coding
AMF	Access and Mobility Management Function
AR	Augmented Reality
ARP	Allocation and Retention Priority
ATG	Air to Ground
BA	Bandwidth Adaptation
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BFD	Beam Failure Detection
BH	Backhaul
BL	Bandwidth reduced Low complexity
BPSK	Binary Phase Shift Keying
BRID	Broadcast Remote Identification
C-RNTI	Cell RNTI
CAG	Closed Access Group
CAPC	Channel Access Priority Class
CBRA	Contention Based Random Access
CCE	Control Channel Element
CD-SSB	Cell Defining SSB
cellDTRX-RNTI	Cell Discontinuous Transmission and Reception RNTI
CFA	Contention Free Access
CFR	Common Frequency Resource
CFRA	Contention Free Random Access
CG	Configured Grant
CHO	Conditional Handover
CIoT	Cellular Internet of Things
CLI	Cross Link interference
CLTM	Conditional L1/L2 Triggered Mobility
CMAS	Commercial Mobile Alert Service
CORESET	Control Resource Set
CP	Cyclic Prefix
CPA	Conditional PSCell Addition
CPC	Conditional PSCell Change
D2R	Device to Reader
DAA	Detect And Avoid
DAG	Directed Acyclic Graph
DAPS	Dual Active Protocol Stack
DFT	Discrete Fourier Transform
DCI	Downlink Control Information
DCP	DCI with CRC scrambled by PS-RNTI
DCR	Direct Communication Request
DL-AoD	Downlink Angle-of-Departure
DL-SCH	Downlink Shared Channel
DL-TDOA	Downlink Time Difference Of Arrival
DMRS	Demodulation Reference Signal
DRX	Discontinuous Reception
DSR	Delay Status Report
DTX	Discontinuous Transmission
E-CID	Enhanced Cell-ID (positioning method)
EC	Energy Cost
EHC	Ethernet Header Compression
ePWS	enhancements of Public Warning System
ETWS	Earthquake and Tsunami Warning System

FS	Feature Set
FSA ID	Frequency Selection Area Identity
G-CS-RNTI	Group Configured Scheduling RNTI
G-RNTI	Group RNTI
GFBR	Guaranteed Flow Bit Rate
GIN	Group ID for Network selection
GNSS	Global Navigation Satellite System
GSO	Geosynchronous Orbit
GUAMI	Globally Unique AMF Identifier
H-SFN	Hyper System Frame Number
HAPS	High Altitude Platform Station
HRNN	Human-Readable Network Name
HSDN	High Speed Dedicated Network
IAB	Integrated Access and Backhaul
IFRI	Intra Frequency Reselection Indication
IoT	Internet of Things
I-RNTI	Inactive RNTI
INT-RNTI	Interruption RNTI
ISA	Intended Service Area
KPAS	Korean Public Alarm System
L2	Layer-2
L3	Layer-3
LBT	Listen Before Talk
LDPC	Low Density Parity Check
LEO	Low Earth Orbit
LO	LP-WUS Occasion
LP-RSRP	Low Power Reference Signal Received Power
LP-RSRQ	Low Power Reference Signal Received Quality
LP-SS	Low Power Synchronization Signal
LP-WUS	Low Power Wake-Up Signal
LR	Low Power Wake-Up Receiver
LTM	L1/L2 Triggered Mobility
MBS	Multicast/Broadcast Services
MCE	Measurement Collection Entity
MCCH	MBS Control Channel
MDBV	Maximum Data Burst Volume
MEO	Medium Earth Orbit
MIB	Master Information Block
MICO	Mobile Initiated Connection Only
MFBR	Maximum Flow Bit Rate
ML	Machine Learning
MMSID	Multi-modal Service ID
MMTEL	Multimedia telephony
MNO	Mobile Network Operator
MO-SDT	Mobile Originated SDT
MP	Multi-Path
MPE	Maximum Permissible Exposure
MR	Main Receiver
MRB	MBS Radio Bearer
MT	Mobile Termination
MT-SDT	Mobile Terminated SDT
MTCH	MBS Traffic Channel
MTSI	Multimedia Telephony Service for IMS
MU-MIMO	Multi User MIMO
Multi-RTT	Multi-Round Trip Time
MUSIM	Multi-Universal Subscriber Identity Module
N3C	Non-3GPP Connection
NB-IoT	Narrow Band Internet of Things
NCD-SSB	Non Cell Defining SSB
NCGI	NR Cell Global Identifier
NCL	Neighbour Cell List
NCR	Neighbour Cell Relation

NCRT	Neighbour Cell Relation Table
NES	Network Energy Savings
NGAP	NG Application Protocol
NGSO	Non-Geosynchronous Orbit
NID	Network Identifier
NPN	Non-Public Network
NR	NR Radio Access
NSAG	Network Slice AS Group
NTN	Non-Terrestrial Network
OD-SIB1	On-demand SIB1
OD-SSB	On-demand SSB
OFDM	Orthogonal Frequency Division Multiplexing
OOK	On-Off Keying
P-MPR	Power Management Maximum Power Reduction
P-RNTI	Paging RNTI
PCH	Paging Channel
PCI	Physical Cell Identifier
PDB	Packet Delay Budget
PDC	Propagation Delay Compensation
PDCCH	Physical Downlink Control Channel
PDRCH	Physical Device-to-Reader Channel
PDSCH	Physical Downlink Shared Channel
PEI	Paging Early Indication
PER	Packet Error Rate
PF	Paging Frame
PH	Paging Hyperframe
PLMN	Public Land Mobile Network
PNI-NPN	Public Network Integrated NPN
PO	Paging Occasion
PQI	PC5 5QI
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PRDCH	Physical Reader-to-Device Channel
PRG	Precoding Resource block Group
PRS	Positioning Reference Signal
PS-RNTI	Power Saving RNTI
PSDB	PDU Set Delay Budget
PSER	PDU Set Error Rate
PSI	PDU Set Importance
PSIHI	PDU Set Integrated Handling Information
PSS	Primary Synchronisation Signal
PTM	Point to Multipoint
PTP	Point to Point
PTW	Paging Time Window
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
PWS	Public Warning System
QAM	Quadrature Amplitude Modulation
QFI	QoS Flow ID
QMC	QoE Measurement Collection
QoE	Quality of Experience
QPSK	Quadrature Phase Shift Keying
R2D	Reader to Device
RA	Random Access
RA-RNTI	Random Access RNTI
RACH	Random Access Channel
RANAC	RAN-based Notification Area Code
REG	Resource Element Group
RIM	Remote Interference Management
RLM	Radio Link Monitoring
RMSI	Remaining Minimum SI
RNA	RAN-based Notification Area

RNAU	RAN-based Notification Area Update
RNTI	Radio Network Temporary Identifier
RQA	Reflective QoS Attribute
RQoS	Reflective Quality of Service
RS	Reference Signal
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSTD	Reference Signal Time Difference
RTT	Round Trip Time
RVQoE	RAN visible QoE
SBFD	Sub-Band Full Duplex
SCS	SubCarrier Spacing
SD	Slice Differentiator
SDAP	Service Data Adaptation Protocol
SDL	Supplementary Downlink
SDT	Small Data Transmission
SD-RSRP	Sidelink Discovery RSRP
SeGW	Security Gateway
SFI-RNTI	Slot Format Indication RNTI
SHR	Successful Handover Report
SIB	System Information Block
SI-RNTI	System Information RNTI
SLA	Service Level Agreement
SL-PRS	Sidelink Positioning Reference Signal
SL-RSRP	Sidelink RSRP
SMC	Security Mode Command
SMF	Session Management Function
SMTC	SS/PBCH block Measurement Timing Configuration
S-NSSAI	Single Network Slice Selection Assistance Information
SNPN	Stand-alone Non-Public Network
SNPN ID	Stand-alone Non-Public Network Identity
SpCell	Special Cell
SPR	Successful PSCell Addition/Change Report
SPS	Semi-Persistent Scheduling
SR	Scheduling Request
SRAP	Sidelink Relay Adaptation Protocol
SRS	Sounding Reference Signal
SRVCC	Single Radio Voice Call Continuity
SS	Synchronization Signal
SSB	SS/PBCH block
SSS	Secondary Synchronisation Signal
SSSG	Search Space Set Group
SST	Slice/Service Type
SU-MIMO	Single User MIMO
SUL	Supplementary Uplink
TA	Timing Advance
TB	Transport Block
TCE	Trace Collection Entity
TN	Terrestrial Network
TNL	Transport Network Layer
TPC	Transmit Power Control
TRP	Transmit/Receive Point
TRS	Tracking Reference Signal
TSS	Timing Synchronization Status
U2N	UE-to-Network
U2U	UE-to-UE
UAV	Uncrewed Aerial Vehicle
UCI	Uplink Control Information
UDC	Uplink Data Compression
UDM	Unified Data Management
UEIRI	UE Initiated Report Indicator

UE-Slice-MBR	UE Slice Maximum Bit Rate
UL-AoA	Uplink Angles of Arrival
UL-RTOA	Uplink Relative Time of Arrival
UL-SCH	Uplink Shared Channel
UPF	User Plane Function
URLLC	Ultra-Reliable and Low Latency Communications
VR	Virtual Reality
V2X	Vehicle-to-Everything
WAB	Wireless Access Backhaul
Xn-C	Xn-Control plane
Xn-U	Xn-User plane
XnAP	Xn Application Protocol
XR	eXtended Reality

3.2 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1], in TS 36.300 [2] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1] and TS 36.300 [2].

2Rx XR UE: two antenna port XR UE as specified in TS 38.101-1 [18].

A2X communication: A communication to support A2X services leveraging PC5 reference points. A2X services are realized by various types of A2X applications, i.e. BRID or DAA.

Access occasion: a time-frequency resource for A-IoT device(s) to transmit A-IoT MSG1 (i.e., the Random ID message) during an A-IoT CBRA procedure.

Activated AI/ML functionality: AI/ML functionality that is already enabled for performing inference.

Aerial UE communication: functionality enabling Aerial UE function, as defined in 16.18.

AI/ML functionality: inference configuration or a set of inference related parameters.

AI/ML Model: a data driven algorithm that applies AI/ML techniques to generate a set of outputs based on a set of inputs.

A-IoT CN node: The core network node which the gNB connects to 5GC for A-IoT operation. More specifically, it is the AIOTF in case the gNB directly connects with the AIOTF, and it includes both the AMF and AIOTF in case the gNB connects with the AIOTF via AMF.

A-IoT device: a device that supports A-IoT radio interface towards A-IoT reader, as defined in 16.23.

A-IoT MSG1: first D2R message transmission in the A-IoT CBRA procedure, as defined in 16.23.

A-IoT MSG2: R2D message in response to A-IoT MSG1 in the A-IoT CBRA procedure, as defined in 16.23.

A-IoT reader: reader providing A-IoT protocol terminations towards the A-IoT device, as defined in 16.23.

Air to Ground network: An NG-RAN consisting of ground-based gNBs, which provide cell towers that send signals up to an aircraft's antenna(s) of onboard ATG terminal, with typical vertical altitude of around 10,000m and take-off/landing altitudes down to 3000m.

Applicable AI/ML functionality: AI/ML functionality for which the UE is ready to perform inference.

AS ID: the AS layer identifier to address the specific A-IoT device for R2D reception and D2R scheduling.

BH RLC channel: an RLC channel between two nodes, which is used to transport backhaul packets**.**

Boundary IAB-node: as defined in TS 38.401 [4].

Broadcast MRB: A radio bearer configured for MBS broadcast delivery.

CAG Cell: a PLMN cell broadcasting at least one Closed Access Group identity.

CAG Member Cell: for a UE, a CAG cell broadcasting the identity of the selected PLMN, registered PLMN or equivalent PLMN, and for that PLMN, a CAG identifier belonging to the Allowed CAG list of the UE for that PLMN.

CAG-only cell: a CAG cell that is only available for normal service for CAG UEs.

Cell-Defining SSB: an SSB with an RMSI associated.

Child node: IAB-DU's and IAB-donor-DU's next hop neighbour node; the child node is also an IAB-node.

Child UE: a U2N Relay UE's next hop in downstream direction for serving a U2N Remote UE in U2N Relay communication. Child UE can be the U2N Remote UE or a U2N Relay UE.

Conditional Handover (CHO): a handover procedure that is executed only when execution condition(s) are met.

Conditional L1/L2 Triggered Mobility (CLTM): an LTM cell switch procedure that is executed only when execution condition(s) are met.

CORESET#0: the control resource set for at least SIB1 scheduling, can be configured either via MIB or via dedicated RRC signalling.

DAPS Handover: a handover procedure that maintains the source gNB connection after reception of RRC message for handover and until releasing the source cell after successful random access to the target gNB.

Data Burst: A set of multiple PDUs generated and sent by the application in a short period of time, as defined in TS 23.501 [3].

Direct Path: a type of UE-to-Network transmission path, where data is transmitted between a UE and the network without sidelink relaying.

Downstream: direction toward child node or UE in IAB-topology or U2N Remote UE in U2N Relay communication.

Early Data Forwarding: data forwarding that is initiated before the UE executes the handover.

Earth-centered, earth-fixed: a global geodetic reference system for the Earth intended for practical applications of mapping, charting, geopositioning and navigation, as specified in NIMA TR 8350.2 [51].

eRedCap UE: a UE with enhanced reduced capabilities as specified in clause 4.2.22.1 in TS 38.306 [11].

Feeder link: wireless transport link between the NTN Gateway and the NTN payload.

First U2N Relay UE: an Intermediate U2N Relay UE having both PC5 connection to a parent UE and PC5 connection to a U2N Remote UE for serving the U2N Remote UE in case of multi-hop L2 U2N Relay communication. In this release, a first U2N Relay UE first establishes a connection to the network before beginning to relay traffic for connected U2N Remote UEs.

Geosynchronous Orbit: earth-centered orbit at approximately 35786 kilometres above Earth's surface and synchronised with Earth's rotation. A geostationary orbit is a non-inclined geosynchronous orbit, i.e. in the Earth's equator plane.

Group ID for Network Selection: an identifier used during SNPN selection to enhance the likelihood of selecting a preferred SNPN that supports a Default Credentials Server or a Credentials Holder, as specified in TS 23.501 [3].

gNB: node providing NR user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.

gNB-reader: an A-IoT reader that is deployed within the gNB, as defined in 16.23.

High Altitude Platform Station: airborne vehicle embarking the NTN payload placed at an altitude between 8 and 50 km.

IAB-donor: gNB that provides network access to UEs via a network of backhaul and access links.

IAB-donor-CU: as defined in TS 38.401 [4].

IAB-donor-DU: as defined in TS 38.401 [4].

IAB-DU: gNB-DU functionality supported by the IAB-node to terminate the NR access interface to UEs and next-hop IAB-nodes, and to terminate the F1 protocol to the gNB-CU functionality, as defined in TS 38.401 [4], on the IAB-donor.

IAB-MT: IAB-node function that terminates the Uu interface to the parent node using the procedures and behaviours specified for UEs unless stated otherwise. IAB-MT function used in 38-series of 3GPP Specifications corresponds to IAB-UE function defined in TS 23.501 [3].

IAB-node: RAN node that supports NR access links to UEs and NR backhaul links to parent nodes and child nodes. The IAB-node does not support backhauling via LTE.

IAB topology: the unison of all IAB-nodes and IAB-donor-DUs whose F1 and/or RRC connections are terminated at the same IAB-donor-CU.

Indirect Path: a type of UE-to-Network transmission path, where data is forwarded via a U2N Relay UE between a U2N Remote UE and the network.

Inter-donor partial migration: migration of an IAB-MT to a parent node underneath a different IAB-donor-CU while the collocated IAB-DU and its descendant IAB-node(s), if any, are terminated at the initial IAB-donor-CU. The procedure renders the said IAB-node as a boundary IAB-node.

Intermediate U2N Relay UE: a U2N Relay UE having both PC5 connection to a parent UE and PC5 connection to a child UE or a U2N Remote UE for serving the U2N Remote UE in case of multi-hop L2 U2N Relay communication. In this release, an intermediate U2N Relay UE first establishes a connection to the network as a U2N Remote UE before beginning to relay traffic for connected U2N Remote UEs.

Inter-satellite link: wireless transport link between two regenerative NTN payloads.

Intra-system Handover: handover that does not involve a CN change (EPC or 5GC).

Inter-system Handover: handover that involves a CN change (EPC or 5GC).

Last U2N Relay UE: a U2N Relay UE having both Uu connection to the network and PC5 connection to a child UE for serving a U2N Remote UE in case of L2 U2N Relay communication. The child UE is the U2N Remote UE in case of single-hop L2 U2N Relay communication.

Late Data Forwarding: data forwarding that is initiated after the source NG-RAN node knows that the UE has successfully accessed a target NG-RAN node.

L1/L2 Triggered Mobility: a cell switch procedure that the network triggers via MAC CE based on L1 or L3 measurement report.

Mapped Cell ID: in NTN, it corresponds to a fixed geographical area.

MBS Radio Bearer: A radio bearer configured for MBS delivery.

Mobile-IAB cell: a cell of a mobile IAB-DU.

Mobile IAB-DU: gNB-DU functionality supported by the mobile IAB-node to terminate the NR access interface to UEs, and to terminate the F1 protocol to the gNB-CU functionality on the IAB-donor, as defined in TS 38.401 [4].

Mobile IAB-DU migration: procedure for a mobile IAB-node as defined in TS 38.401 [4].

Mobile IAB-MT: mobile IAB-node function that terminates the Uu interface to the parent node using the procedures and behaviours specified for UEs unless stated otherwise.

Mobile IAB-MT migration: procedure for a mobile IAB-MT as defined in TS 38.401 [4].

Mobile IAB-node: RAN node that supports NR access links to UEs and an NR backhaul link to a parent node, and that can conduct physical mobility across the RAN area. The mobile IAB-node function used in 38-series of 3GPP Specifications corresponds to the MBSR function defined in TS 23.501 [3].

MP Relay UE: a UE that provides functionality to support connectivity to the network for MP Remote UE(s).

MP Remote UE: a UE that communicates with the network via a direct Uu link and a MP Relay UE.

MSG1: preamble transmission of the random access procedure for 4-step random access (RA) type.

MSG3: first scheduled transmission of the random access procedure.

MSGA: preamble and payload transmissions of the random access procedure for 2-step RA type.

MSGB: response to MSGA in the 2-step random access procedure. MSGB may consist of response(s) for contention resolution, fallback indication(s), and backoff indication.

Multicast/Broadcast Service: A point-to-multipoint service as defined in TS 23.247 [45].

Multicast MRB: A radio bearer configured for MBS multicast delivery.

Multi-hop backhauling: using a chain of NR backhaul links between an IAB-node and an IAB-donor.

NCR-Fwd: Network-Controlled Repeater node function, which performs amplifying-and-forwarding of UL/DL RF signals between gNB and UE. The behaviour of the NCR-Fwd is controlled according to the side control information received by the NCR-MT from a gNB.

NCR-Fwd access link: link used for transmissions between the NCR-Fwd and UEs.

NCR-Fwd backhaul link: link used for backhauling between the NCR-Fwd and gNB.

NCR-MT: NCR-node entity which communicates with a gNB via a control link to receive side control information. The control link is based on NR Uu interface.

NCR-node: RAN node comprising NCR-MT and NCR-Fwd.

Network-side (AI/ML) model: an AI/ML model whose inference is performed at the network.

ng-eNB: node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.

NG-C: control plane interface between NG-RAN and 5GC.

NG-U: user plane interface between NG-RAN and 5GC.

NG-RAN node: either a gNB or an ng-eNB.

Non-CAG Cell: a PLMN cell which does not broadcast any Closed Access Group identity.

Non-Cell Defining SSB: an SSB without an RMSI associated.

Non-Geosynchronous orbit: earth-centered orbit with an orbital period that does not match Earth's rotation on its axis. This includes Low and Medium Earth Orbit (LEO and MEO). LEO operates at altitudes between 300 km and 1500 km and MEO at altitudes between 7000 km and 25000 km, approximately.

Non-terrestrial network: an NG-RAN consisting of gNBs, which provide non-terrestrial NR access to UEs by means of an NTN payload embarked on an airborne or space-borne NTN vehicle and an NTN Gateway.

NR backhaul link: NR link used for backhauling between an IAB-node and an IAB-donor, and between IAB-nodes in case of a multi-hop backhauling.

NR sidelink communication: AS functionality enabling at least V2X communication as defined in TS 23.287 [40] and/or A2X communication as defined in TS 23.256 [60] and/or the ProSe communication (including ProSe non-Relay and UE-to-Network Relay communication) as defined in TS 23.304 [48], between two or more nearby UEs, using NR technology but not traversing any network node.

NR sidelink discovery: AS functionality enabling ProSe non-Relay Discovery and ProSe UE-to-Network Relay discovery for Proximity based Services as defined in TS 23.304 [48] between two or more nearby UEs, using NR technology but not traversing any network node.

NTN Gateway: an earth station located at the surface of the earth, providing connectivity to the NTN payload using the feeder link. An NTN Gateway is a TNL node.

NTN payload: a network node, embarked on board a satellite or high altitude platform station, providing connectivity functions, between the service link and the feeder link. The NTN payload may be a TNL node (transparent payload) or a gNB (regenerative payload).

Numerology: corresponds to one subcarrier spacing in the frequency domain. By scaling a reference subcarrier spacing by an integer *N*, different numerologies can be defined.

Offline model training: an AI/ML training process where the model is trained based on collected dataset, and where the trained model is later used or delivered for inference.

Parent node: IAB-MT's or mobile IAB-MT's next hop neighbour node; the parent node can be an IAB-node or IAB-donor-DU

Parent UE: a U2N Remote UE or U2N Relay UE's next hop U2N Relay UE in upstream direction for serving the U2N Remote UE in U2N Relay communication.

PC5 Relay RLC channel: an RLC channel between L2 U2N Remote UE and L2 U2N Relay UE, between L2 U2N Relay UEs (in case of multi-hop L2 U2N relay communication), or between L2 U2U Remote UE and L2 U2U Relay UE, which is used to transport packets over PC5 for L2 UE-to-Network/UE-to-UE Relay**.**

PDU Set: one or more PDUs carrying the payload of one unit of information generated at the application level (e.g. frame(s) or video slice(s) for XR Services), as defined in TS 23.501 [3].

PLMN Cell: a cell of the PLMN.

RACH-less LTM: an LTM cell switch procedure where UE skips the random access procedure.

RedCap UE: a UE with reduced capabilities as specified in clause 4.2.21.1 in TS 38.306 [11].

Relay discovery: AS functionality enabling 5G ProSe UE-to-Network Relay Discovery as defined in TS 23.304 [48], using NR technology but not traversing any network node.

Satellite: a space-borne vehicle orbiting the Earth embarking the NTN payload.

Service link: wireless link between the NTN payload and UE.

Sidelink Discovery RSRP: RSRP measurements on PC5 link related to NR sidelink discovery.

Sidelink RSRP: RSRP measurements on PC5 link related to NR sidelink communication.

SNPN Access Mode: mode of operation whereby a UE only accesses SNPNs.

SNPN-only cell: a cell that is only available for normal service for SNPN subscribers.

SNPN Identity: the identity of Stand-alone NPN defined by the pair (PLMN ID, NID).

Special Cell: For Dual Connectivity operation the term Special Cell refers to the PCell of the MCG or the PSCell of the SCG, otherwise, in case of NR Standalone, the term Special Cell refers to the PCell.

Supported (AI/ML) functionality: AI/ML functionality which can be indicated by using UE capability information.

Transmit/Receive Point: part of the gNB transmitting and receiving radio signals to/from UE according to physical layer properties and parameters inherent to that element.

U2N Relay UE: a UE that provides functionality to support connectivity to the network for U2N Remote UE(s). Up to three L2 U2N Relay UEs (i.e. one Last U2N Relay and up to two Intermediate U2N Relays including one First U2N Relay) can be configured for serving a L2 U2N Remote UE in multi-hop L2 U2N Relay communication in this release.

U2N Remote UE: a UE that communicates with the network via one or more U2N Relay UEs on an indirect path.

U2U Relay UE: a UE that provides functionality to support connectivity between two U2U Remote UEs.

U2U Remote UE: a UE that communicates with other UE(s) via a U2U Relay UE.

UE-side (AI/ML) model: an AI/ML model whose inference is performed at the UE.

UE-to-Network Relay communication: A mode of communication in which a UE communicates with the network through an indirect path involving only one U2N Relay UE for single-hop L2 U2N Relay communication or multiple L2 U2N Relay UEs for multi-hop L2 U2N Relay communication.

UE-to-Network Relay discovery: A mode of NR sidelink discovery in which a UE discovers other UEs for U2N Relay communication.

Upstream: direction toward parent node in IAB-topology or gNB in U2N Relay communication.

Uu Relay RLC channel: an RLC channel between L2 U2N Relay UE or MP Relay UE and gNB, which is used to transport packets over Uu for L2 UE-to-Network Relay or for indirect path in case of MP.

V2X sidelink communication: AS functionality enabling V2X communication as defined in TS 23.285 [41], between nearby UEs, using E-UTRA technology but not traversing any network node.

WAB-gNB: as defined in TS 38.401 [4].

WAB-MT: as defined in TS 38.401 [4].

WAB-node: as defined in TS 38.401 [4].

Xn: network interface between NG-RAN nodes.

4 Overall Architecture and Functional Split

4.1 Overall Architecture

An NG-RAN node is either:

- a gNB, providing NR user plane and control plane protocol terminations towards the UE; or
- an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE.

The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]).

NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4].

The NG-RAN architecture is illustrated in Figure 4.1-1 below.

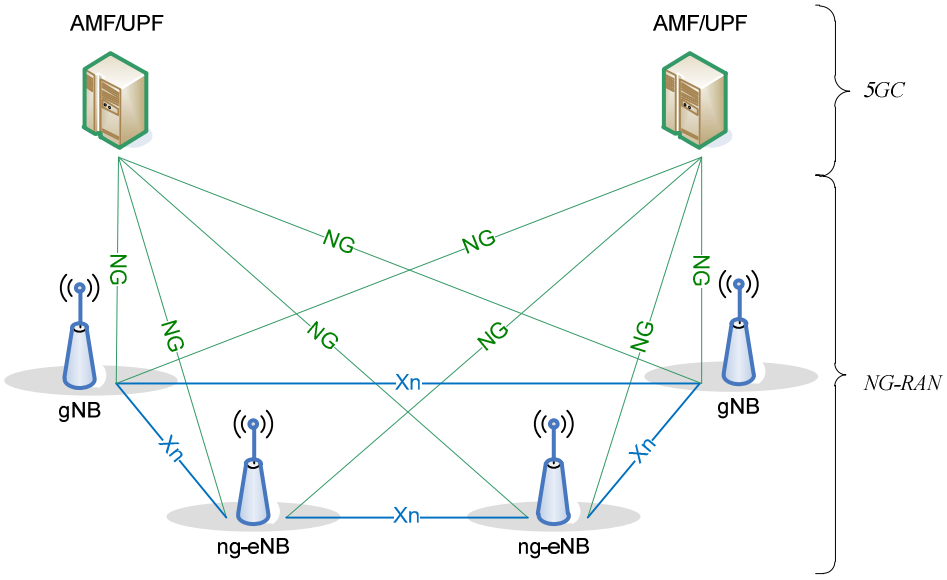


Figure 4.1-1: Overall Architecture

4.2 Functional Split

The **gNB** and **ng-eNB** host the following functions:

- Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in uplink, downlink and sidelink (scheduling);
- IP and Ethernet header compression, uplink data decompression, encryption and integrity protection of data;
- Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information provided by the UE;
- Routing of User Plane data towards UPF(s);
- Routing of Control Plane information towards AMF;
- Connection setup and release;
- Scheduling and transmission of paging messages;
- Scheduling and transmission of system broadcast information (originated from the AMF or OAM);
- Measurement and measurement reporting configuration for mobility and scheduling;
- Transport level packet marking in the uplink;
- Session Management;
- Support of Network Slicing;
- QoS Flow management and mapping to data radio bearers;
- Support of UEs in RRC_INACTIVE state;
- Distribution function for NAS messages;
- Radio access network sharing;
- Dual Connectivity;
- Tight interworking between NR and E-UTRA;

- Maintain security and radio configuration for User Plane CIoT 5GS Optimisation, as defined in TS 23.501 [3] (ng-eNB only).

NOTE 1: BL UE or UE in enhanced coverage is only supported by ng-eNB, see TS 36.300 [2].

NOTE 2: NB-IoT UE is only supported by ng-eNB, see TS 36.300 [2].

The **AMF** hosts the following main functions (see TS 23.501 [3]):

- NAS signalling termination;
- NAS signalling security;
- AS Security control;
- Inter CN node signalling for mobility between 3GPP access networks;
- Idle mode UE Reachability (including control and execution of paging retransmission);
- Registration Area management;
- Support of intra-system and inter-system mobility;
- Access Authentication;
- Access Authorization including check of roaming rights;
- Mobility management control (subscription and policies);
- Support of Network Slicing;
- SMF selection.
- Selection of CIoT 5GS optimisations;

The **UPF** hosts the following main functions (see TS 23.501 [3]):

- Anchor point for Intra-/Inter-RAT mobility (when applicable);
- External PDU session point of interconnect to Data Network;
- Packet routing & forwarding;
- Packet inspection and User plane part of Policy rule enforcement;
- Traffic usage reporting;
- Uplink classifier to support routing traffic flows to a data network;
- Branching point to support multi-homed PDU session;
- QoS handling for user plane, e.g. packet filtering, gating, UL/DL rate enforcement;
- Uplink Traffic verification (SDF to QoS flow mapping);
- Downlink packet buffering and downlink data notification triggering.

The Session Management function (**SMF**) hosts the following main functions (see TS 23.501 [3]):

- Session Management;
- UE IP address allocation and management;
- Selection and control of UP function;
- Configures traffic steering at UPF to route traffic to proper destination;
- Control part of policy enforcement and QoS;

- Downlink Data Notification.

This is summarized on the figure below where yellow boxes depict the logical nodes and white boxes depict the main functions.

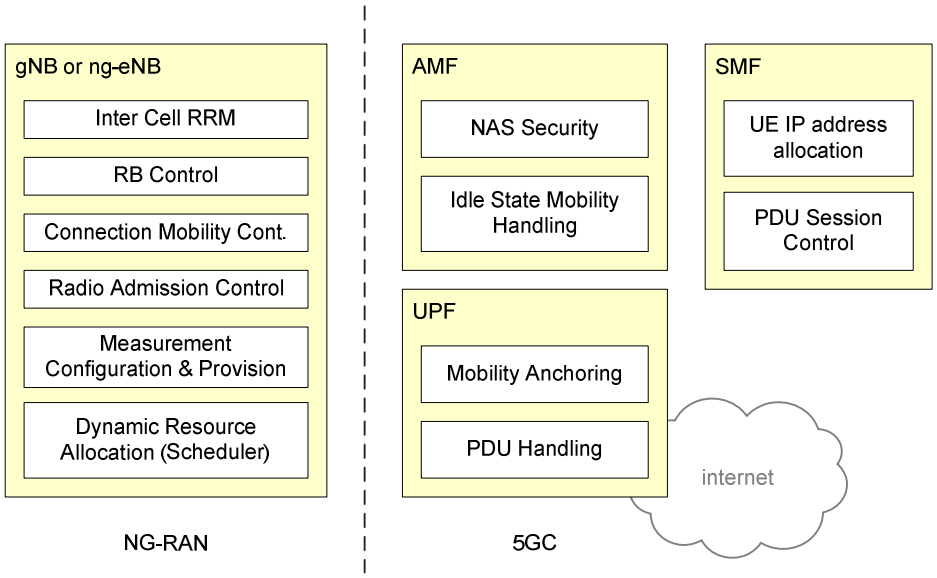


Figure 4.2-1: Functional Split between NG-RAN and 5GC

4.3 Network Interfaces

4.3.1 NG Interface

4.3.1.1 NG User Plane

The NG user plane interface (NG-U) is defined between the NG-RAN node and the UPF. The user plane protocol stack of the NG interface is shown on Figure 4.3.1.1-1. The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs between the NG-RAN node and the UPF.

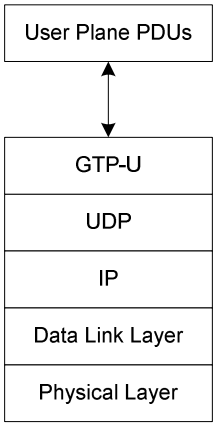


Figure 4.3.1.1-1: NG-U Protocol Stack

NG-U provides non-guaranteed delivery of user plane PDUs between the NG-RAN node and the UPF.

Further details of NG-U can be found in TS 38.410 [16].

4.3.1.2 NG Control Plane

The NG control plane interface (NG-C) is defined between the NG-RAN node and the AMF, or between the NG-RAN node and the AIOTF. The control plane protocol stack of the NG interface is shown on Figure 4.3.1.2-1. The transport network layer is built on IP transport. For the reliable transport of signalling messages, SCTP is added on top of IP. The application layer signalling protocol is referred to as NGAP (NG Application Protocol). The SCTP layer provides guaranteed delivery of application layer messages. In the transport, IP layer point-to-point transmission is used to deliver the signalling PDUs.

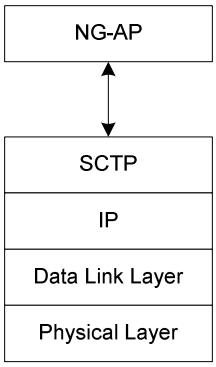


Figure 4.3.1.2-1: NG-C Protocol Stack

NG-C provides the following functions:

- NG interface management;
- UE context management;
- UE mobility management;
- Transport of NAS messages;
- Paging;
- PDU Session Management;
- Configuration Transfer;
- Warning Message Transmission.

Further details of NG-C can be found in TS 38.410 [16].

4.3.2 Xn Interface

4.3.2.1 Xn User Plane

The Xn User plane (Xn-U) interface is defined between two NG-RAN nodes. The user plane protocol stack on the Xn interface is shown in Figure 4.3.2.1-1. The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs.

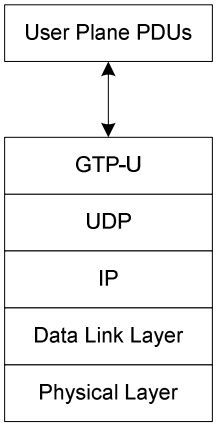


Figure 4.3.2.1-1: Xn-U Protocol Stack

Xn-U provides non-guaranteed delivery of user plane PDUs and supports the following functions:

- Data forwarding;
- Flow control.

Further details of Xn-U can be found in TS 38.420 [17].

4.3.2.2 Xn Control Plane

The Xn control plane interface (Xn-C) is defined between two NG-RAN nodes. The control plane protocol stack of the Xn interface is shown on Figure 4.3.2.2-1. The transport network layer is built on SCTP on top of IP. The application layer signalling protocol is referred to as XnAP (Xn Application Protocol). The SCTP layer provides the guaranteed delivery of application layer messages. In the transport IP layer point-to-point transmission is used to deliver the signalling PDUs.

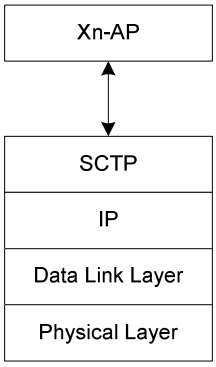


Figure 4.3.2.2-1: Xn-C Protocol Stack

The Xn-C interface supports the following functions:

- Xn interface management;
- UE mobility management, including context transfer and RAN paging;
- Dual connectivity.

Further details of Xn-C can be found in TS 38.420 [17].

4.4 Radio Protocol Architecture

4.4.1 User Plane

The figure below shows the protocol stack for the user plane, where SDAP, PDCP, RLC and MAC sublayers (terminated in gNB on the network side) perform the functions listed in clause 6.

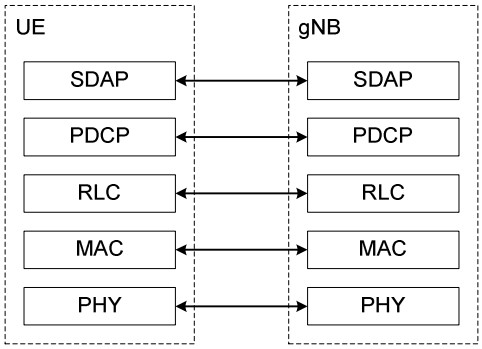


Figure 4.4.1-1: User Plane Protocol Stack

4.4.2 Control Plane

The figure below shows the protocol stack for the control plane, where:

- PDCP, RLC and MAC sublayers (terminated in gNB on the network side) perform the functions listed in clause 6;
- RRC (terminated in gNB on the network side) performs the functions listed in clause 7;
- NAS control protocol (terminated in AMF on the network side) performs the functions listed in TS 23.501 [3]), for instance: authentication, mobility management, security control…

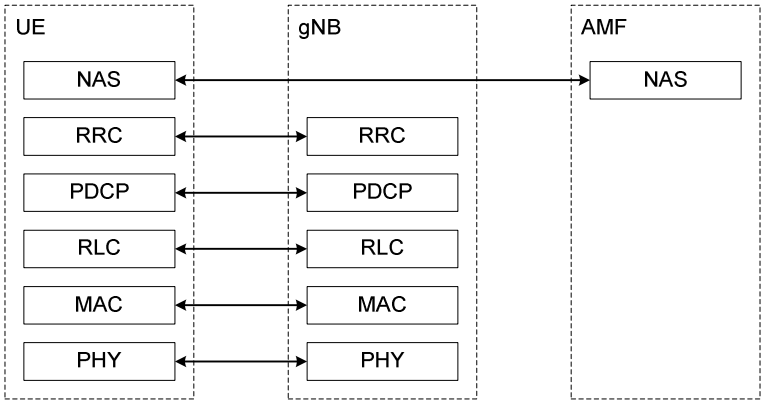


Figure 4.4.2-1: Control Plane Protocol Stack

4.5 Multi-Radio Dual Connectivity

NG-RAN supports Multi-Radio Dual Connectivity (MR-DC) operation whereby a UE in RRC_CONNECTED is configured to utilise radio resources provided by two distinct schedulers, located in two different NG-RAN nodes connected via a non-ideal backhaul, one providing NR access and the other one providing either E-UTRA or NR access. Further details of MR-DC operation, including Conditional PSCell Addition (CPA) and Conditional PSCell Change (CPC), can be found in TS 37.340 [21].

4.6 Radio Access Network Sharing

NG-RAN supports radio access network sharing as defined in TS 23.501 [3].

If NR access is shared, system information broadcast in a shared cell indicates a TAC and a Cell Identity for each subset of PLMNs, PNI-NPNs and SNPNs. NR access provides only one TAC and one Cell Identity per cell per PLMN, SNPN or PNI-NPN. In this version of the specification, a Cell Identity can only belong to one network type among PLMN, PNI-NPN or SNPN as defined in TS 23.501 [3].

Each Cell Identity associated with a subset of PLMNs, SNPNs or PNI-NPNs identifies its serving NG-RAN node.

4.7 Integrated Access and Backhaul

4.7.1 Architecture

Integrated access and backhaul (IAB) enables wireless relaying in NG-RAN. The relaying node, referred to as *IAB-node*, supports access and backhauling via NR. The terminating node of NR backhauling on network side is referred to as the *IAB-donor*, which represents a gNB with additional functionality to support IAB. Backhauling can occur via a single or via multiple hops. The IAB architecture is shown in Figure 4.7.1-1.

The IAB-node supports the gNB-DU functionality, as defined in TS 38.401 [4], to terminate the NR access interface to UEs and next-hop IAB-nodes, and to terminate the F1 protocol to the gNB-CU functionality, as defined in TS 38.401 [4], on the IAB-donor. The gNB-DU functionality on the IAB-node is also referred to as *IAB-DU*.

In addition to the gNB-DU functionality, the IAB-node also supports a subset of the UE functionality referred to as *IAB-MT*, which includes, e.g., physical layer, layer-2, RRC and NAS functionality to connect to the gNB-DU of another IAB-node or the IAB-donor, to connect to the gNB-CU on the IAB-donor, and to the core network.

The IAB-node can access the network using either SA mode or EN-DC. In EN-DC, the IAB-node connects via E-UTRA to a MeNB, and the IAB-donor terminates X2-C as SgNB (TS 37.340 [21]).

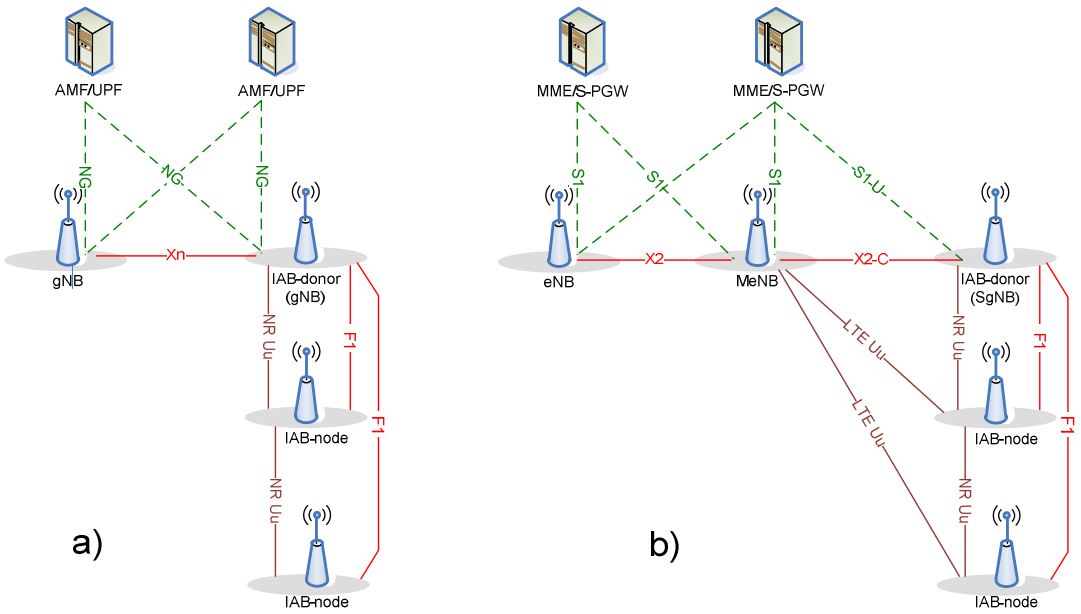


Figure 4.7.1-1: IAB architecture; a) IAB-node using SA mode with 5GC; b) IAB-node using EN-DC

All IAB-nodes that are connected to an IAB-donor via one or multiple backhaul hops and controlled by this IAB-donor via F1AP and/or RRC form an IAB topology with the IAB-donor as its root (Fig. 4.7.1-2). In this IAB topology, the neighbour node of the IAB-DU or the IAB-donor-DU is referred to as the *child* node and the neighbour node of the IAB-MT is referred to as the *parent* node. The direction toward the child node is referred to as *downstream* while the

direction toward the parent node is referred to as *upstream*. The IAB-donor performs centralized resource, topology and route management for its IAB topology.

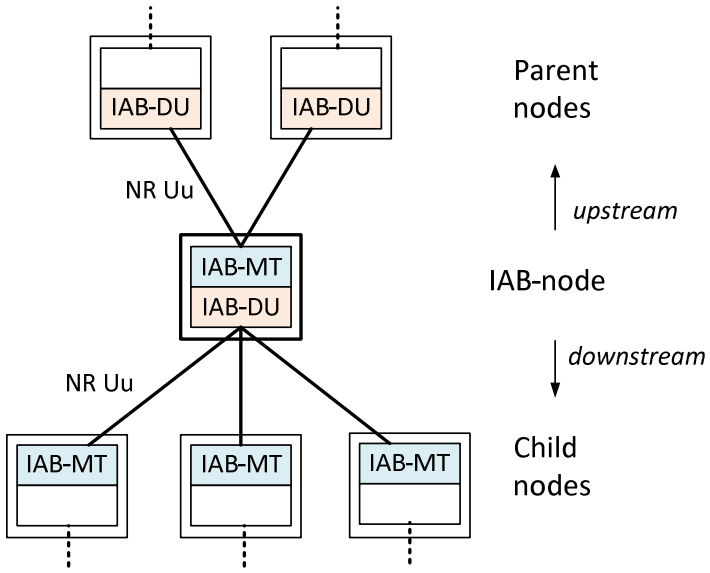


Figure 4.7.1-2: Parent- and child-node relationship for IAB-node

4.7.2 Protocol Stacks

Fig. 4.7.2-1 shows the protocol stack for F1-U and Fig. 4.7.2-2 shows the protocol stack for F1-C between IAB-DU and IAB-donor-CU. In these figures, F1-U and F1-C are carried over two backhaul hops.

F1-U and F1-C use an IP transport layer between IAB-DU and IAB-donor-CU as defined in TS 38.470 [32]. F1-U and F1-C need to be security-protected as described in TS 33.501 [5] (the security layer is not shown in the Figures 4.7.2-1/2).

On the wireless backhaul, the IP layer is carried over the Backhaul Adaptation Protocol (BAP) sublayer, which enables routing over multiple hops. The IP layer can also be used for *non*-F1 traffic, such as OAM traffic as defined in TS 38.401 [4].

On each backhaul link, the BAP PDUs are carried by BH RLC channels. Multiple BH RLC channels can be configured on each BH link to allow traffic prioritization and QoS enforcement. The BH-RLC-channel mapping for BAP PDUs is performed by the BAP entities on each IAB-node and the IAB-donor-DU.

Protocol stacks for an IAB-donor with split gNB architecture are specified in TS 38.401 [4].

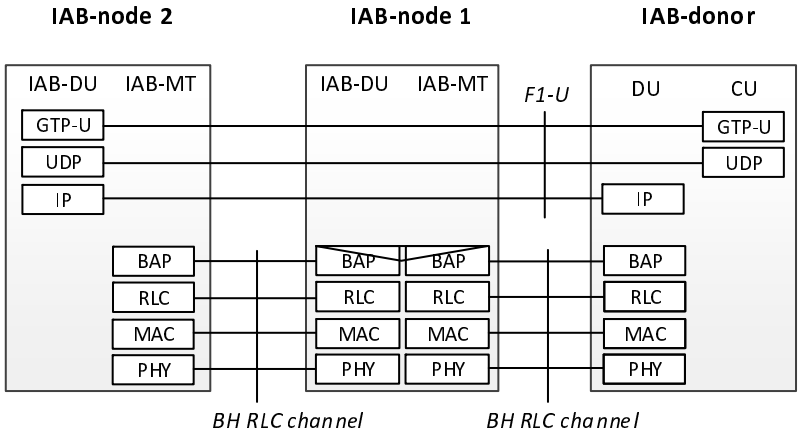


Fig. 4.7.2-1: Protocol stack for the support of F1-U protocol

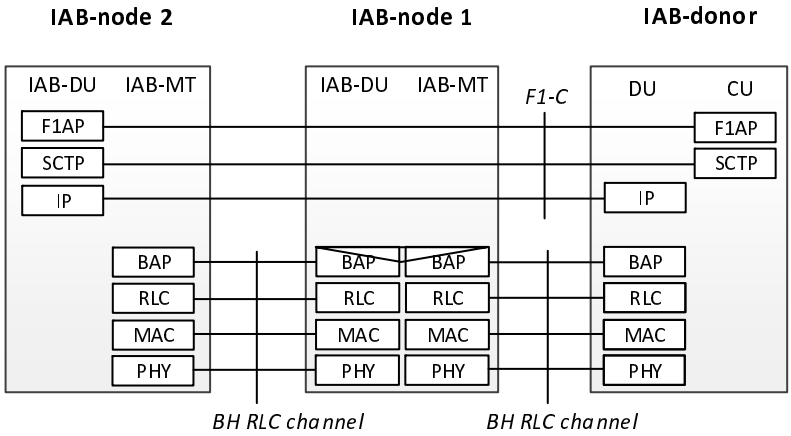


Fig. 4.7.2-2: Protocol stack for the support of F1-C protocol

The IAB-MT further establishes SRBs (carrying RRC and NAS) with the IAB-donor-CU. For IAB-nodes operating in EN-DC, the IAB-MT establishes one or more DRBs with the eNB and one or more DRBs with the IAB-donor-CU, which can be used, e.g., to carry OAM traffic. For SA mode, the establishment of DRBs is optional. These SRBs and DRBs are transported between the IAB-MT and its parent node over Uu access channel(s). The protocol stacks for the SRB is shown in Fig. 4.7.2-3.

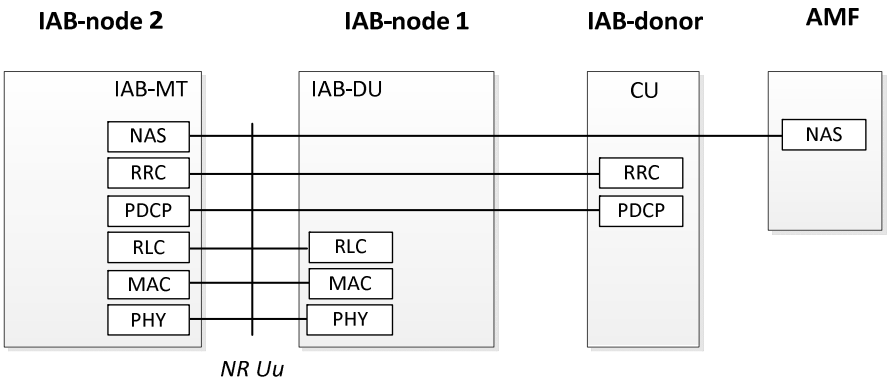


Figure 4.7.2-3: Protocol stack for the support of IAB-MT's RRC and NAS connections

4.7.3 User-plane Aspects

4.7.3.1 Backhaul transport

The IAB-DU's IP traffic is routed over the wireless backhaul via the BAP sublayer. The BAP sublayer is specified in TS 38.340 [31]. In downstream direction, upper layer packets are encapsulated by the BAP sublayer at the IAB-donor-DU and de-encapsulated at the destination IAB-node. In upstream direction, upper layer packets are encapsulated at the IAB-node and de-encapsulated at the IAB-donor-DU. IAB-specific transport between IAB-donor-CU and IAB-donor-DU is specified in TS 38.401 [4].

On the BAP sublayer, packets are routed based on the BAP routing ID, which is carried in the BAP header. The BAP header is added to the packet when it arrives from upper layers, and the BAP header is stripped off when the packet has reached its destination node. The selection of the packet's BAP routing ID is configured by the IAB-donor-CU. The BAP routing ID consists of BAP address and BAP path ID, where the BAP address indicates the destination node of the packet on the BAP sublayer, and the BAP path ID indicates the routing path the packet should follow to this destination. For the purpose of routing, each IAB-node and IAB-donor-DU is further configured with a designated BAP address.

On each hop of the packet's path, the IAB-node inspects the packet's BAP address in the BAP routing ID carried in the BAP header to determine if the packet has reached its destination, i.e., matches the IAB-node's BAP address. In case the packet has *not* reached the destination, the IAB-node determines the next hop backhaul link, referred to as *egress* link, based on the BAP routing ID carried in the BAP header and a routing configuration it received from the IAB-donor-CU.

For each packet, the IAB-node further determines the egress BH RLC channel on the designated egress link. For packets arriving from upper layers, the designated egress BH RLC channel is configured by the IAB-donor-CU, and it is based on upper layer traffic specifiers. Since each BH RLC channel is configured with QoS information or priority level, BH-RLC-channel selection facilitates traffic-specific prioritization and QoS enforcement on the BH. For F1-U traffic, it is possible to map each GTP-U tunnel to a dedicated BH RLC channel or to aggregate multiple GTP-U tunnels into one common BH RLC channel. For traffic other than F1-U traffic, it is possible to map UE-associated F1AP messages, non-UE-associated F1AP messages and non-F1 traffic onto the same or separate BH RLC channels.

When packets are routed from one BH link to another, the egress BH RLC channel on the egress BH link is determined based on the mapping configuration between ingress BH RLC channels and egress BH RLC channels provided by the IAB-donor-CU.

4.7.3.2 Flow and Congestion Control

Flow and congestion control can be supported in both upstream and downstream directions in order to avoid congestion-related packet drops on IAB-nodes and IAB-donor-DU:

- In upstream direction, UL scheduling on MAC layer can support flow control on each hop;
- In downstream direction, the NR user plane protocol (TS 38.425 [33]) supports flow and congestion control between the IAB-node and the IAB-donor-CU for UE bearers that terminate at this IAB-node. Further, flow control is supported on BAP sublayer, where the IAB-node can send feedback information on the available buffer size for an ingress BH RLC channel or BAP routing ID to its parent node. The feedback can be sent proactively, e.g., when the buffer load exceeds a certain threshold, or based on polling by the parent node.

4.7.3.3 Uplink Scheduling Latency

The IAB-node can reduce UL scheduling latency through signalling of a Pre-emptive BSR to its parent node. The IAB-node can send the Pre-emptive BSR based on UL grants it has provided to child nodes and/or UEs, or based on BSRs it has received from child nodes or UEs (Figure 4.7.3.3-1). The Pre-emptive BSR conveys the data expected rather than the data buffered.

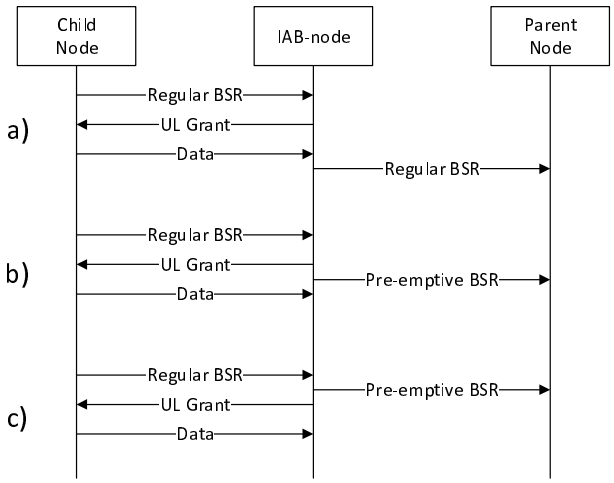


Figure 4.7.3.3-1: Scheduling of BSR in IAB:
a) regular BSR based on buffered data,
b) Pre-emptive BSR based on UL grant,
c) Pre-emptive BSR based on reception of regular BSR

4.7.4 Signalling procedures

4.7.4.1 IAB-node Integration

The IAB-node integration procedure is captured in TS 38.401 [4].

4.7.4.2 IAB-node Migration

The IAB-node can migrate to a different parent node underneath the same IAB-donor-CU. The IAB-node continues providing access and backhaul service when migrating to a different parent node.

The IAB-MT can also migrate to a different parent node underneath another IAB-donor-CU. In this case, the collocated IAB-DU and the IAB-DU(s) of its descendant node(s) retain F1 connectivity with the initial IAB-donor-CU. The IAB-MT of each descendant node and all the served UEs retain the RRC connectivity with the initial IAB-donor-CU. This migration is referred to as *inter-donor partial migration*. The IAB-node, whose IAB-MT migrates to the new IAB-donor-CU, is referred to as a *boundary IAB-node*. After inter-donor partial migration, the F1 traffic of the IAB-DU and its descendant nodes is routed via the BAP layer of the IAB topology to which the IAB-MT has migrated.

Inter-donor partial migration is only supported for SA-mode.

The intra-donor IAB-node migration procedure and inter-donor partial migration procedures are captured in TS 38.401 [4].

4.7.4.3 Topological Redundancy

The IAB-node may have redundant routes to the IAB-donor-CU(s).

For IAB-nodes operating in SA-mode, NR DC can be used to enable route redundancy in the BH by allowing the IAB-MT to have concurrent BH links with two parent nodes. The parent nodes may be connected to the same or to different IAB-donor-CUs, which control the establishment and release of redundant routes via these two parent nodes. Either parent node's gNB-DU functionality together with the respective IAB-donor-CU assumes the role of the IAB-MT's master node or secondary node. The NR DC framework (e.g., MCG/SCG-related procedures) is used to configure the dual radio links with the parent nodes (TS 37.340 [21]).

The procedure for establishment of topological redundancy for IAB-nodes operating in SA-mode is captured in TS 38.401 [4].

An IAB-node operating in NR-DC may also use one of its links for BH connectivity with an IAB-donor and the other link for access-only connectivity with a separate gNB that does not assume IAB-donor role. The IAB-donor can assume the MN or the SN role. The IAB-node may exchange F1-C traffic with the IAB-donor via the backhaul link and/or via the access link with the gNB. In the latter case, the F1-C messages are carried over NR RRC between the IAB-node and the gNB, and via XnAP between the gNB and the IAB-donor.

IAB-nodes operating in EN-DC can exchange F1-C traffic with the IAB-donor via the MeNB. The F1-C message is carried over LTE RRC using SRB2 between IAB-node and MeNB and via X2AP between the MeNB and the IAB-donor.

The procedures for establishment of redundant transport of F1-C for IAB-nodes using NR-DC and EN-DC are captured in TS 37.340 [21] and TS 38.401 [4].

4.7.4.4 Backhaul RLF Recovery

When the IAB-node using SA-mode declares RLF on the backhaul link, it can perform RLF recovery at another parent node underneath the same or underneath a different IAB-donor-CU. In the latter case, the collocated IAB-DU and the IAB-DU(s) of its descendant node(s) may retain the F1 connectivity with the initial IAB-donor-CU, while the IAB-MT(s) of the descendant node(s) and all the served UEs retain the RRC connectivity with the initial IAB-donor-CU, in the same manner as for *inter-donor partial migration*.

The BH RLF recovery procedure for the IAB-node is captured in TS 38.401 [4]. BH RLF declaration for IAB-node and the aspects of RLF recovery by the IAB-MT are handled in clause 9.2.7 of the present document.

4.7.4.5 OTA timing synchronization

An IAB-DU is subject to the same downlink timing alignment of a gNB. The IAB-DU may use the received downlink signal from a parent as a reference to control its downlink timing using TA in conjunction with an additional Tdelta parameter received by the collocated IAB-MT from the parent via MAC-CE.

4.7.4.6 Inter node discovery

Inter node discovery is supported via SSB-based and/or CSI-RS-based measurements. An IAB-node can be configured to transmit and receive off synchronization raster SSB signals to discover neighbouring IAB-nodes. The configuration is not expected to create a conflict between IAB-DU SSB transmission and IAB-MT SSB measurement windows.

4.7.5 Mobile IAB

4.7.5.1 General

Mobile IAB introduces the *mobile IAB-node*, which is a RAN node that provides NR access links to UEs and an NR backhaul link to a parent node, and that can conduct physical mobility across the RAN area. The mobile IAB-node includes a *mobile IAB-MT* and a *mobile IAB-DU*. Mobile IAB supports the same functionality as IAB unless explicitly specified. The following enhancements/restrictions *only* apply to mobile IAB:

- The mobile IAB-node uses the mobile IAB-node authorization procedure defined in TS 38.401 [4] and the MBSR authorization procedure defined in TS 23.501 [3].
- A RAN node operating as a mobile IAB-node shall not concurrently operate as an IAB-node. During network integration, the RAN node shall indicate whether it intends to operate as a mobile IAB-node or as an IAB-node via an indicator in the *RRCSetupComplete* message.
- The parent node indicates support for mobile IAB-nodes by broadcasting a mobile-IAB-specific indicator in SIB1.
- The mobile IAB-node shall not have descendent nodes. A mobile-IAB cell shall therefore not broadcast any indication that it is a suitable parent node for IAB-nodes or mobile IAB-nodes.
- The cell of a mobile IAB-DU may indicate to UEs via a SIB1 indicator that it is a mobile-IAB cell.
- The mobile IAB-node uses the mobile IAB-node network integration procedure as defined in TS 38.401 [4].
- The mobile IAB-MT can perform the mobile IAB-MT migration procedures via Xn handover and/or via NG handover as defined in TS 38.401 [4]. The mobile IAB-MT can also perform the mobile IAB-node recovery procedure as defined in TS 38.401 [4].
- The mobile IAB-node can perform the mobile IAB-DU migration procedure, where a new logical mobile IAB-DU is established on the mobile IAB-node and the initial logical mobile IAB-DU is released some time later. The UE identifies the cells of the two logical mobile IAB-DUs as different physical cells. During this procedure, the UEs connected via the mobile IAB-node are handed over from the initial logical mobile IAB-DU, referred to as the source logical mobile IAB-DU, to the new logical mobile IAB-DU, referred to as the target logical mobile IAB-DU. The details of this procedure are defined in TS 38.401 [4]. Enhancements related to BAP for mobile IAB-DU migration are defined in TS 38.340 [31].
- When a RAN node is operating as a mobile IAB node, dual connectivity for this node is not supported.

RACH-less handover as specified in 9.2.3.6, in TS 38.321 [6] and in TS 38.331 [12] is supported in mobile IAB. RACH-less handover can be used during the mobile IAB-DU migration procedure for a UE that is migrated from the source logical mobile IAB-DU to the target logical mobile IAB-DU.

4.7.5.2 Void

4.8 Non-Public Networks

A Non-Public Network (NPN) is a network for non-public use (see TS 22.261 [19]), which can be deployed as (see TS 23.501 [3]):

- a Stand-alone Non-Public Network (SNPN) when not relying on network functions provided by a PLMN; or
- a Public Network Integrated (PNI) NPN when relying on the support of a PLMN.

NOTE: As described in clause 5.30.3.1 of TS 23.501 [3], there are several approaches in which PNI-NPNs can be made available via PLMNs. The only approach visible to AS, and hence the only approach that is addressed in AS specifications is the approach of using CAGs.

4.9 Network-Controlled Repeaters

4.9.1 Architecture

A Network-Controlled Repeater node, referred to as NCR-node, is an RF repeater that enables wireless amplifying-and-forwarding functionality in NG-RAN. The NCR-node is capable of receiving and applying side control information from a gNB with additional functionality to support Network-Controlled Repeater.

The NCR-node comprises an NCR-MT and an NCR-Fwd. The NCR-MT is an entity supporting a subset of the UE functionality that communicates with the gNB to receive side control information via a control link based on the NR Uu interface. The NCR-Fwd is the function performing amplifying-and-forwarding of signals between gNB and UE via the NCR-Fwd backhaul link and NCR-Fwd access link, respectively. The NCR-Fwd can support multiple beams towards the UE. The NCR-Fwd can support multiple beams in the backhaul link, and those may be different from the beams in the control link. The behaviour of the NCR-Fwd is controlled according to the side control information received from the gNB. The NCR-node is modelled as depicted in Figure 4.9.1-1.

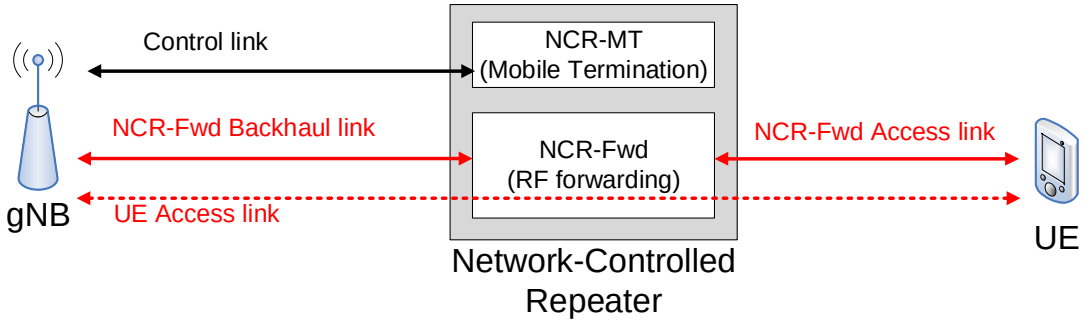


Figure 4.9.1-1: Conceptual model of network-controlled repeater.

An NCR-MT establishes SRBs and, optionally, DRB(s) with a gNB. The establishment of DRB(s) can be used to transport OAM traffic.

The signal that NCR-Fwd forwards is associated to the cell that the NCR-MT is connected to via the control link. Whether the NCR-Fwd can forward other signals is up to implementation.

4.9.2 Capabilities

Carrier Aggregation (CA), Multi-Radio Dual Connectivity (MR-DC), handover and its related features (e.g., CHO, DAPS, CPAC, etc.) are not supported by NCR-MT, as defined together with other limitations in TS 38.306 [11].

4.9.3 Signalling procedures

RRC signalling is utilized to configure the NCR-MT to receive side control information from a gNB, which is used to control the amplify-and-forward function of the NCR-Fwd. If the side control configuration is removed, the NCR-Fwd ceases its amplifying-and-forwarding function.

MAC CE indications can be used to configure the backhaul link and the access link of the NCR-Fwd as specified in TS 38.321 [6].

When the NCR-MT is in RRC_CONNECTED state, the NCR-Fwd may amplify-and-forward RF signals based on the side control information received from the gNB. The NCR-MT does not support RRM measurements in RRC_CONNECTED.

When the NCR-MT transitions from RRC_CONNECTED state to RRC_INACTIVE state, the NCR-Fwd may continue to amplify-and-forward RF signals in accordance with the last side control information received from the gNB. When

the NCR-MT is in RRC_INACTIVE state, the NCR-Fwd ceases to amplify-and-forward RF signals if no suitable cell is detected, or if the NCR-MT selects a different cell than the last serving cell on which side control configuration was received.

When an NCR-MT in RRC_INACTIVE state determines degradation of the NCR-Fwd backhaul link beam, then the NCR-Fwd should cease amplifying-and-forwarding RF signals, and the NCR-MT should attempt to resume its RRC connection (with cause value *mo-Signalling*). The criteria to evaluate backhaul beam degradation are left to the NCR-node implementation.

When the NCR-MT transitions from RRC_CONNECTED state to RRC_IDLE, the NCR-Fwd ceases any amplifying-and-forwarding of RF signals. How an NCR-MT transitions back from RRC_IDLE state to RRC_CONNECTED state is left to NCR-node or network implementation.

An NCR-MT can detect RLF on the control link as specified in TS 38.331 clause 5.3.10 [12]. When RLF is detected, the NCR-MT performs the RRC re-establishment procedure as specified in TS 38.331 [12]. During the RRC re-establishment procedure, the NCR-Fwd ceases to amplify-and-forward RF signals.

After successfully performing the RRC re-establishment procedure, the NCR-MT waits for the new side control configuration for the NCR-Fwd to resume the amplifying-and-forwarding of RF signals.

An NCR-MT can also perform Beam Failure Detection (BFD) and Beam Failure Recovery (BFR) as described in clause 9.2.8. Once the NCR-MT detects beam failure in the control link, the NCR-Fwd should cease amplifying-and-forwarding RF signals until BFR is completed.

4.9.4 OAM aspects

The transport connection between the NCR-node and its OAM may be provided by the NCR-MT's PDU session. A Network-Controlled Repeater may be configured with a list of allowed gNB cell(s) that the NCR-MT is allowed to connect with, and/or a list of forbidden gNB cell(s) that the NCR-MT is not allowed to connect with.

The information on the physical beam(s) used by NCR-Fwd for access link may be provided by OAM to the gNB and the Network-Controlled Repeater for operation. How to characterize and provide the physical beams of NCR-Fwd is up to implementation.

4.9.5 Network-controlled repeater management

Network-Controlled Repeater identification is performed in RAN, and Network-Control Repeater authorization is performed in 5GC. The general procedure of the Network-Controlled Repeater management is illustrated in Figure 4.9.5-1:

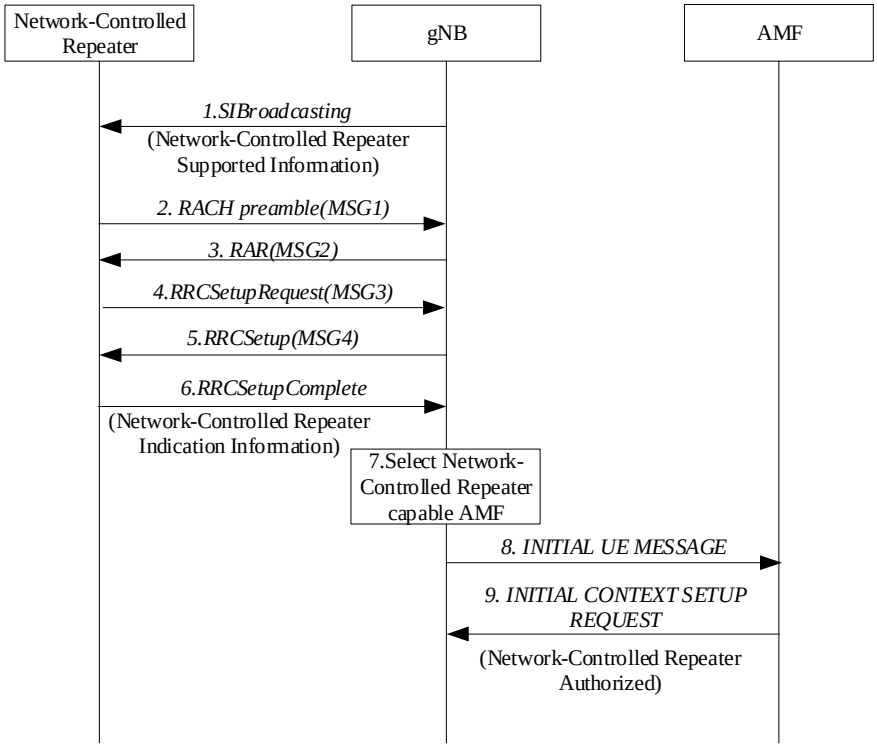


Figure 4.9.5-1: Network-Controlled Repeater management.

1. The gNB broadcasts the Network-Controlled Repeater supported information via system information.
6. When a Network-Controlled Repeater is trying to access the network as a Network-Controlled Repeater, the Network-Controlled Repeater indication is sent to the serving gNB.
7. The serving gNB selects an appropriate AMF for the Network-Controlled Repeater.
9. AMF provides Network-Controlled Repeater authorization information to the gNB.

Other steps refer to the signalling flow as defined in 9.2.1.3.

4.10 Support of NR Femto nodes

4.10.1 Architecture

Figure 4.10.1-1 shows a logical architecture for the NR Femto node to connect via the NG interface to the 5GC.

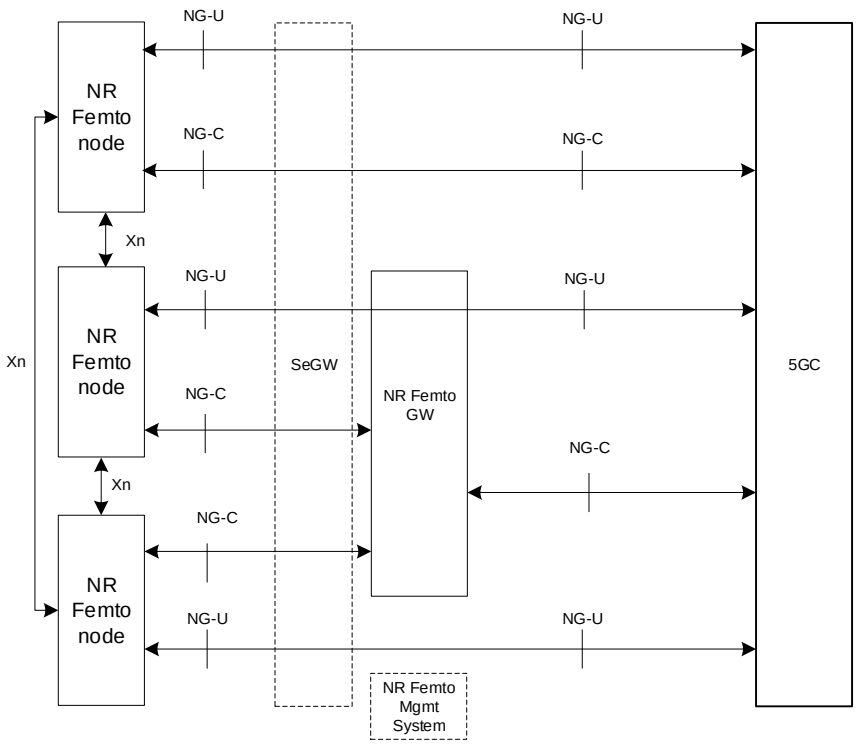


Figure 4.10.1-1: NR Femto Logical Architecture

NOTE: The SeGW and NR Femto Mgmt System are out of RAN scope.

The NR Femto node may directly connect to the 5GC. The NG-RAN architecture may also deploy an NR Femto Gateway (NR Femto GW) to allow the concentration of the NG-C interface between NR Femto nodes and the 5GC. Based on implementation, the transport of NG-U between NR Femto nodes and the 5GC may be optionally concentrated in the NR Femto GW.

For the NR Femto node, the NG-C interface is defined as the interface:

- Between the NR Femto GW and the Core Network;
- Between the NR Femto node and the NR Femto GW;
- Between the NR Femto node and the Core Network.

The NR Femto GW appears to the AMF as a gNB. The NR Femto GW appears to the NR Femto node as an AMF. The NG interface between the NR Femto node and the 5GC is the same regardless whether the NR Femto node is connected to the 5GC via an NR Femto GW or not.

The functions supported by the NR Femto node shall be the same as those supported by a gNB (with possible exceptions e.g. NAS Node Selection Function when the NR Femto node connects via the NR Femto GW) and the procedures run between an NR Femto node, the NR Femto GW and the 5GC shall be the same as those between a gNB and the 5GC with specific handling as specified in clause 4.10.2.

Xn-connectivity is supported between NR Femto nodes and between NR Femto nodes and gNBs, independent of whether any of the involved NR Femto nodes is connected to an NR Femto GW. One NR Femto node serves one or more cells.

4.10.2 Functional Split

4.10.2.1 NR Femto node

An NR Femto node hosts the same functions as a gNB as described in clause 4.1, with the following additional specifics in case of connecting to the NR Femto GW:

- Discovery of a suitable NR Femto GW;

NOTE 1: The NR Femto node may be configured with the identity and/or address of an appropriate NR Femto GW.

- An NR Femto node shall only connect to a single NR Femto GW at one time:
  - The NR Femto node will not simultaneously connect to another NR Femto GW, or another AMF;

NOTE 2: NR Femto nodes may be deployed without network planning. An NR Femto node may be moved from one geographical area to another and therefore it may need to connect to a different NR Femto GW depending on its location.

  - The TAC(s) and PLMN ID(s) used by the NR Femto node shall also be supported by the NR Femto GW;

- Selection of an AMF at UE attachment is performed by the NR Femto GW:
  - An NR Femto node shall provide any of the GUAMI, GUAMI Type or Requested NSSAI, if received from the UE, to the NR Femto GW in the INITIAL UE MESSAGE message.

- At Xn handover:
  - Allowing the NR Femto GW to identify the serving AMF at path switch:
    - Including the GUAMI of the serving AMF in the PATH SWITCH REQUEST message;
  - Allowing the AMF to identify the termination of the source UE associated signalling connection:
    - Including the *Source AMF UE NGAP ID* IE in the PATH SWITCH REQUEST message to the NR Femto GW.
  - Sending the UE CONTEXT RELEASE REQUEST message including a GW Context Release Indication to the NR Femto GW after the successful Xn handover initiated by the NR Femto node, in order to indicate that the NR Femto GW may release the UE context.

4.10.2.2 AMF

In addition to functions specified in clauses 4.1 and 16.7, the AMF hosts the following functions:

- In case of an NR Femto node connected to an NR Femto GW:
  - Routing of handover messages, DOWNLINK RAN CONFIGURATION TRANSFER message and DOWNLINK RIM INFORMATION TRANSFER message towards the appropriate NR Femto GW based on the received Selected TAI.
  - In NG handover towards the NR Femto node, including the Global RAN Node ID of the NR Femto node in the HANDOVER REQUEST message to the NR Femto GW.
- In case of an NR Femto node directly connected to an AMF:
  - At NG Setup, verifying, as defined in TS 33.545 [70], that the identity used by the NR Femto node is valid.
  - At Initial UE Message and NG Handover procedures, verifying, as defined in TS 33.545 [70], that the reported CAG ID list is valid for the indicated cell of the NR Femto node.
  - At NG PWS Restart Indication and PWS Failure Indication, verifying, as defined in TS 33.545 [70], that the indicated cell identity is valid.

4.10.2.3 NR Femto GW

The NR Femto GW hosts the following functions:

- Relaying UE-associated NGAP messages between the AMF and the NR Femto node serving the UE, applying the following additional functions:

- Terminating the UE Context Release Request procedure if an explicit GW Context Release Indication is included. In this case, the NR Femto GW releases the UE context if it determines that the UE identified by the received UE NGAP IDs is no longer served by another NR Femto node attached to it.
- At UE context establishment (Initial Context Setup or NG Handover) the NR Femto GW sends to the NR Femto node the serving AMF's GUAMI as well as the AMF UE NGAP ID assigned by the AMF and the AMF UE NGAP ID assigned by the NR Femto GW for the UE.
- At Path Switch, the NR Femto GW sends to the NR Femto node the AMF UE NGAP ID assigned by the AMF and the AMF UE NGAP ID assigned by the NR Femto GW for the UE.
- At Initial UE Message and NG Handover procedures, the NR Femto GW verifies, as defined in TS 33.545 [70], that the reported CAG ID list is valid for the indicated cell of the NR Femto node.

- Terminating non-UE associated NGAP procedures towards the NR Femto node and towards the AMF, applying the following additional functions:
  - At NG Setup, the NR Femto GW verifies, as defined in TS 33.545 [70], that the identity used by the NR Femto node is valid.
  - In case of NG PWS Restart Indication and PWS Failure Indication, the NR Femto GW verifies, as defined in TS 33.545 [70], that the indicated cell identity is valid and replaces the Global gNB ID of the NR Femto node with the NR Femto GW ID before sending the respective message to the AMF.
  - At Overload Start/Stop, the NR Femto GW should provide the NR Femto node with the identities of the affected AMF node(s). The NR Femto node uses the received information to identify the traffic and the AMF to which the overload indication applies. The NR Femto node shall apply the defined rejections until reception of an OVERLOAD STOP message applicable to this traffic, or until the NR Femto node receives a further OVERLOAD START message applicable to the same traffic, in which case it shall replace the ongoing overload action with the newly requested one.
- Supporting TAC(s) and PLMN ID(s) used by the NR Femto node.
- Relaying the PATH SWITCH REQUEST message towards the AMF indicated by the GUAMI of the serving AMF received from the NR Femto node.
- Selecting AMF at UE attachment based on the GUAMI, GUAMI type or Requested NSSAI provided by the NR Femto node in the INITIAL UE MESSAGE message.

A TAI used in a NR Femto GW shall not be reused in another NR Femto GW.

4.10.3 Interfaces

4.10.3.1 Protocol Stack for NG User Plane

NG-U is defined as specified in clause 4.3.1.1 regardless of whether its transport is concentrated in the NR Femto GW. The figure below shows the NG-U protocol stack between NR Femto node and UPF.

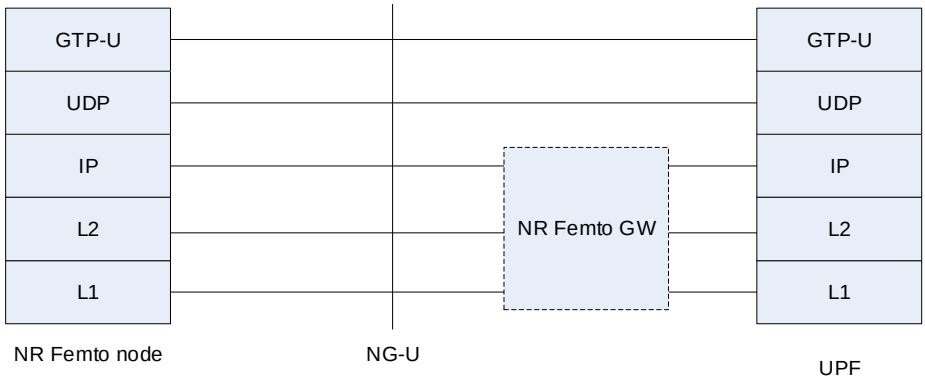


Figure 4.10.3.1-1: User plane for NG Interface between NR Femto node and UPF

4.10.3.2 Protocol Stacks for NG Control Plane

The figure below shows the NG-C protocol stack with the NR Femto GW.

When the NR Femto GW is not present, NG-C is defined as specified in clause 4.3.1.2, and all the NGAP procedures are terminated at the NR Femto node and the AMF.

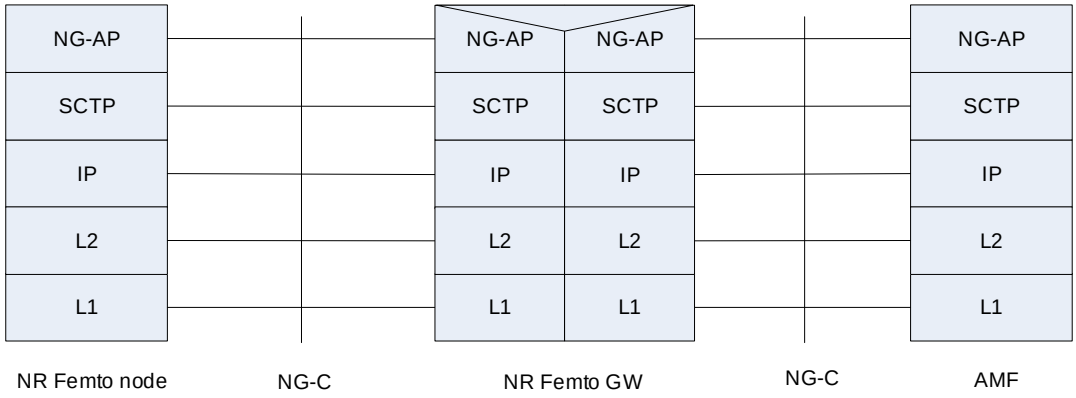


Figure 4.10.3.2-1: Control plane for NG Interface between NR Femto node and AMF with the NR Femto GW

4.10.4 Access Control

Cells served by an NR Femto node may be deployed as part of a PNI-NPN (see clause 4.8) in order to restrict access to UEs according to the respective subscription.

NOTE: The NR Femto node may use the CAG mechanism for PNI-NPN (see clause 16.7.4) as follows:

- The NR Femto node may activate a PLMN cell, which can be accessed by legacy UE without access control of CAG;
- The NR Femto physical node may activate a physical cell shared by both PLMN and PNI-NPN, as specified in clause 4.6, through broadcasting both the *plmn-IdentityInfoList* and the *npn-IdentityInfoList-r16* in the SIB1, but without the *cellReservedForOtherUse*;
- The NR Femto node may activate an NPN-only cell by broadcasting the *cellReservedForOtherUse* with value "*true*", then this cell can only be accessed by the UEs whose allowed CAG list includes a CAG-ID broadcasted by the cell.

4.11 Wireless Access Backhaul

Wireless Access Backhaul (WAB) is supported by means of the WAB-node, which provides NR access links to UEs via a gNB functionality, referred to as the WAB-gNB. The WAB-node further supports a WAB-MT function, which terminates an NR Uu interface to a gNB that is used for the backhauling of the WAB-gNB's traffic. The WAB-node may be stationary or mobile.

Further details of WAB are defined in TS 23.501 [3] and TS 38.401 [4].

5 Physical Layer

5.1 Waveform, numerology and frame structure

The downlink transmission waveform is conventional OFDM using a Cyclic Prefix. The uplink transmission waveform is conventional OFDM using a CP with a transform precoding function performing DFT spreading that can be disabled

or enabled. For operation with shared spectrum channel access in FR1, the uplink transmission waveform subcarrier mapping can map to subcarriers in one or more PRB interlaces.

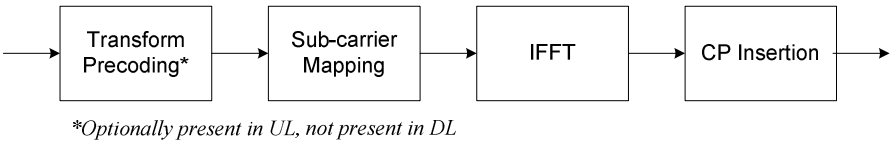


Figure 5.1-1: Transmitter block diagram for CP-OFDM with optional DFT-spreading

The numerology is based on exponentially scalable sub-carrier spacing $\Delta f = 2^{\mu} \times 15$ kHz with μ={0,1,3,4,5,6} for PSS, SSS and PBCH and μ={0,1,2,3,5,6} for other channels. Normal CP is supported for all sub-carrier spacings, Extended CP is supported for μ=2. 12 consecutive sub-carriers form a Physical Resource Block (PRB). Up to 275 PRBs are supported on a carrier.

Table 5.1-1: Supported transmission numerologies.

μ	$\Delta f = 2^{\mu} \cdot 15$[kHz]	CP	Supported for data	Supported for synch
0	15	Normal	Yes	Yes
1	30	Normal	Yes	Yes
2	60	Normal, Extended	Yes	No
3	120	Normal	Yes	Yes
4	240	Normal	No	Yes
5	480	Normal	Yes	Yes
6	960	Normal	Yes	Yes

The UE may be configured with one or more bandwidth parts on a given component carrier, of which only one can be active at a time, as described in clauses 7.8 and 6.10 respectively. The active bandwidth part defines the UE's operating bandwidth within the cell's operating bandwidth. For initial access, and until the UE's configuration in a cell is received, initial bandwidth part detected from system information is used.

Downlink and uplink transmissions are organized into frames with 10 ms duration, consisting of ten 1 ms subframes. Each frame is divided into two equally-sized half-frames of five subframes each. The slot duration is 14 symbols with Normal CP and 12 symbols with Extended CP, and scales in time as a function of the used sub-carrier spacing so that there is always an integer number of slots in a subframe.

Timing Advance *TA* is used to adjust the uplink frame timing relative to the downlink frame timing.

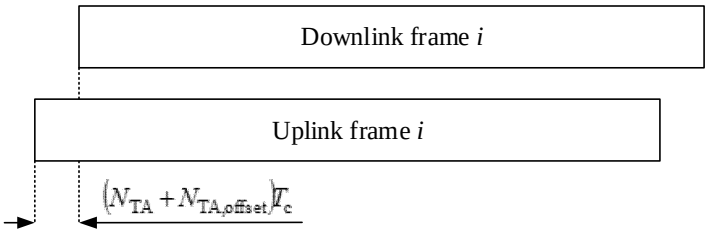


Figure 5.1-2: Uplink-downlink timing relation

Operation on both paired and unpaired spectrum is supported.

5.2 Downlink

5.2.1 Downlink transmission scheme

Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8, 12, 16 and 24 orthogonal DL DMRS ports are supported for type 1, type 2, enhanced type 1, and enhanced type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO

and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions.

The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG).

Transmission durations from 2 to 14 symbols in a slot is supported.

Aggregation of multiple slots with Transport Block (TB) repetition is supported.

5.2.2 Physical-layer processing for physical downlink shared channel

The downlink physical-layer processing of transport channels consists of the following steps:

- Transport block CRC attachment;
- Code block segmentation and code block CRC attachment;
- Channel coding: LDPC coding;
- Physical-layer hybrid-ARQ processing;
- Rate matching;
- Scrambling;
- Modulation: QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM;
- Layer mapping;
- Mapping to assigned resources and antenna ports.

The UE may assume that at least one symbol with demodulation reference signal is present on each layer in which PDSCH is transmitted to a UE, and up to 3 additional DMRS can be configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

The DL-SCH physical layer model is described in TS 38.202 [20].

5.2.3 Physical downlink control channels

The Physical Downlink Control Channel (PDCCH) can be used to schedule DL transmissions on PDSCH and UL transmissions on PUSCH, where the Downlink Control Information (DCI) on PDCCH includes:

- Downlink assignments containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to DL-SCH;
- Uplink scheduling grants containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to UL-SCH.

In addition to scheduling, PDCCH can be used to for:

- Activation and deactivation of configured PUSCH transmission with configured grant;
- Activation and deactivation of PDSCH semi-persistent transmission;
- Notifying one or more UEs of the slot format;
- Notifying one or more UEs of the PRB(s) and OFDM symbol(s) where the UE may assume no transmission is intended for the UE;
- Transmission of TPC commands for PUCCH and PUSCH;

- Transmission of one or more TPC commands for SRS transmissions by one or more UEs;
- Switching a UE's active bandwidth part;
- Initiating a random access procedure;
- Indicating the UE(s) to monitor the PDCCH during the next occurrence of the DRX on-duration;
- In IAB context, indicating the availability for soft symbols of an IAB-DU;
- Triggering one shot HARQ-ACK codebook feedback;
- For operation with shared spectrum channel access:
  - Triggering search space set group switching;
  - Indicating one or more UEs about the available RB sets and channel occupancy time duration;
  - Indicating downlink feedback information for configured grant PUSCH (CG-DFI).

A UE monitors a set of PDCCH candidates in the configured monitoring occasions in one or more configured COntrol REsource SETs (CORESETs) according to the corresponding search space configurations.

A CORESET consists of a set of PRBs with a time duration of 1 to 3 OFDM symbols. The resource units Resource Element Groups (REGs) and Control Channel Elements (CCEs) are defined within a CORESET with each CCE consisting a set of REGs. Control channels are formed by aggregation of CCE. Different code rates for the control channels are realized by aggregating different number of CCE. Interleaved and non-interleaved CCE-to-REG mapping are supported in a CORESET.

The PDCCH repetition is operated by using two search spaces which are explicitly linked by configuration provided by the RRC layer, and are associated with corresponding CORESETs. For PDCCH repetition, two linked search spaces are configured with the same number of candidates, and two PDCCH candidates in two search spaces are linked with the same candidate index. When PDCCH repetition is scheduled to a UE, an intra-slot repetition is allowed and each repetition has the same number of CCEs and coded bits, and corresponds to the same DCI payload.

Polar coding is used for PDCCH.

Each resource element group carrying PDCCH carries its own DMRS.

QPSK modulation is used for PDCCH.

5.2.4 Synchronization signal and PBCH block

The Synchronization Signal and PBCH block (SSB) consists of primary and secondary synchronization signals (PSS, SSS), each occupying 1 symbol and 127 subcarriers, and PBCH spanning across 3 OFDM symbols and 240 subcarriers, but on one symbol leaving an unused part in the middle for SSS as show in Figure 5.2.4-1. For the 3 MHz channel bandwidth, the PBCH is further equally punctured from both edges to span 144 subcarriers. The possible time locations of SSBs within a half-frame are determined by sub-carrier spacing and the periodicity of the half-frames where SSBs are transmitted is configured by the network. During a half-frame, different SSBs may be transmitted in different spatial directions (i.e. using different beams, spanning the coverage area of a cell).

Within the frequency span of a carrier, multiple SSBs can be transmitted. The PCIs of SSBs transmitted in different frequency locations do not have to be unique, i.e. different SSBs in the frequency domain can have different PCIs. However, when an SSB is associated with an RMSI, the SSB is referred to as a Cell-Defining SSB (CD-SSB). A PCell is always associated to a CD-SSB located on the synchronization raster.

When an SSB is not associated with an RMSI, the SSB is referred to as a non-Cell Defining SSB (NCD-SSB), which can be used to perform RLM, BFD, and RRM measurements and measurements for RA resource selection inside the active DL BWP when the active BWP does not contain the CD-SSB. A UE may be configured with multiple SSBs provided that each BWP is configured with at most one SSB (CD-SSB or NCD-SSB).

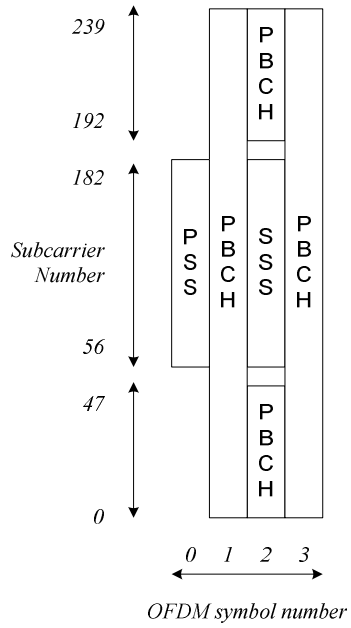


Figure 5.2.4-1: Time-frequency structure of SSB

Polar coding is used for PBCH.

The UE may assume a band-specific sub-carrier spacing for the SSB unless a network has configured the UE to assume a different sub-carrier spacing.

PBCH symbols carry its own frequency-multiplexed DMRS.

QPSK modulation is used for PBCH.

The PBCH physical layer model is described in TS 38.202 [20].

5.2.5 Physical layer procedures

5.2.5.1 Link adaptation

Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one transmission duration and within a MIMO codeword.

For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation.

5.2.5.2 Power Control

Downlink power control can be used.

5.2.5.3 Cell search

Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the Cell ID of that cell. NR cell search is based on the primary and secondary synchronization signals, and PBCH DMRS, located on the synchronization raster.

5.2.5.4 HARQ

Asynchronous Incremental Redundancy Hybrid ARQ is supported. The gNB provides the UE with the HARQ-ACK feedback timing either dynamically in the DCI or semi-statically in an RRC configuration. Retransmission of HARQ-ACK feedback is supported by using enhanced dynamic codebook and/or one-shot triggering of HARQ-ACK transmission for (i) all configured CCs and HARQ processes in the PUCCH group, (ii) a configured subset of CCs and/or HARQ processes in the PUCCH group, or (iii) a dynamically indicated HARQ-ACK feedback instance. For HARQ-ACK of SPS PDSCH without associated PDCCH, in case of HARQ-ACK dropping due to TDD specific collisions, the HARQ-ACK feedback can be deferred to a next available PUCCH transmission occasion.

The UE may be configured to receive code block group based transmissions where retransmissions may be scheduled to carry a sub-set of all the code blocks of a TB.

5.2.5.5 Reception of SIB1

The Master Information Block (MIB) on PBCH provides the UE with parameters (e.g. CORESET#0 configuration) for monitoring of PDCCH for scheduling PDSCH that carries the System Information Block 1 (SIB1). PBCH may also indicate that there is no associated SIB1, in which case the UE may be pointed to another frequency from where to search for an SSB that is associated with a SIB1 as well as a frequency range where the UE may assume no SSB associated with SIB1 is present. The indicated frequency range is confined within a contiguous spectrum allocation of the same operator in which SSB is detected. MIB on PBCH may also indicate that SIB1 is not being broadcast, in which case the UE may transmit OD-SIB1 request if it has a valid OD-SIB1 request configuration for this cell as described in 15.4.2.9.

5.2.6 Downlink Reference Signals and Measurements for Positioning

The DL Positioning Reference Signals (DL PRS) are defined to facilitate support of different positioning methods such as DL-TDOA, DL-AoD, multi-RTT through the following set of UE measurements DL RSTD, DL PRS-RSRP/DL PRS-RSRPP, and UE Rx-Tx time difference respectively as described in TS 38.305 [42]. The DL PRS also facilitates Carrier Phase Positioning measurements such as DL-RSCP and DL-RSCPD as described in TS 38.305 [42].

Besides DL PRS signals, UE can use SSB and CSI-RS for RRM (RSRP and RSRQ) measurements for E-CID type of positioning.

5.3 Uplink

5.3.1 Uplink transmission scheme

Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission.

For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI.

DMRS based spatial multiplexing is supported for PUSCH. Up to 8, 12, 16, and 24 orthogonal UL DMRS ports are supported for type 1, type 2, enhanced type 1, and enhanced type 2 DMRS respectively. For a given UE, up to 4 or up to 8 layer transmissions are supported. The number of code words is one for 1 to 4 layer transmission and two for 5 to 8 layer transmission. When transform precoding is used, only a single MIMO layer transmission is supported.

Transmission durations from 1 to 14 symbols in a slot is supported.

Aggregation of multiple slots with TB repetition is supported.

Two types of frequency hopping are supported, intra-slot frequency hopping, and in case of slot aggregation, inter-slot frequency hopping. Intra-slot and inter-slot frequency hopping are not supported when PRB interlace uplink transmission waveform is used.

PUSCH may be scheduled with DCI on PDCCH, or a semi-static configured grant may be provided over RRC, where two types of operation are supported:

- The first PUSCH is triggered with a DCI, with subsequent PUSCH transmissions following the RRC configuration and scheduling received on the DCI, or
- The PUSCH is triggered by data arrival to the UE's transmit buffer and the PUSCH transmissions follow the RRC configuration.

5.3.2 Physical-layer processing for physical uplink shared channel

The uplink physical-layer processing of transport channels consists of the following steps:

- Transport Block CRC attachment;
- Code block segmentation and Code Block CRC attachment;
- Channel coding: LDPC coding;
- Physical-layer hybrid-ARQ processing;
- Rate matching;
- Scrambling;
- Modulation: $\pi/2$ BPSK (with transform precoding only), QPSK, 16QAM, 64QAM and 256QAM;
- Layer mapping, transform precoding (enabled/disabled by configuration), and pre-coding;
- Mapping to assigned resources and antenna ports.

The UE transmits at least one symbol with demodulation reference signal on each layer on each frequency hop in which the PUSCH is transmitted, and up to 3 additional DMRS can be configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

The UL-SCH physical layer model is described in TS 38.202 [20].

For configured grants operation with shared spectrum channel access, described in clause 10.3, a CG-UCI (Configured Grant Uplink Control Information) can be transmitted in PUSCH scheduled by configured uplink grant.

5.3.3 Physical uplink control channel

Physical uplink control channel (PUCCH) carries the Uplink Control Information (UCI) from the UE to the gNB. Five formats of PUCCH exist, depending on the duration of PUCCH and the UCI payload size:

- Format #0: Short PUCCH of 1 or 2 symbols with small UCI payloads of up to two bits with UE multiplexing capacity of up to 6 UEs with 1-bit payload in the same PRB;
- Format #1: Long PUCCH of 4-14 symbols with small UCI payloads of up to two bits with UE multiplexing capacity of up to 84 UEs without frequency hopping and 36 UEs with frequency hopping in the same PRB;
- Format #2: Short PUCCH of 1 or 2 symbols with large UCI payloads of more than two bits with no UE multiplexing capability in the same PRBs;
- Format #3: Long PUCCH of 4-14 symbols with large UCI payloads with no UE multiplexing capability in the same PRBs;
- Format #4: Long PUCCH of 4-14 symbols with moderate UCI payloads with multiplexing capacity of up to 4 UEs in the same PRBs.

The short PUCCH format of up to two UCI bits is based on sequence selection, while the short PUCCH format of more than two UCI bits frequency multiplexes UCI and DMRS. The long PUCCH formats time-multiplex the UCI and DMRS. Frequency hopping is supported for long PUCCH formats and for short PUCCH formats of duration of 2 symbols. Short and long PUCCH formats can be repeated over multiple slots or sub-slots, where the repetition factor is either indicated dynamically in the DCI or semi-statically in an RRC configuration.

For operation with shared spectrum channel access in FR1, PUCCH Format #0, #1, #2, #3 are extended to use resource in one PRB interlace (up to two interlaces for Format #2 and Format #3) in one RB Set. PUCCH Format #2 and #3 are enhanced to support multiplexing capacity of up to 4 UEs in the same PRB interlace when one interlace is used.

For operation in FR2-2, PUCCH Format #0, #1, #4 are extended to use resource in configurable number of continuous PRBs, up to 16 PRBs.

Up to two PUCCH configurations can be configured for a UE per PUCCH group (see TS 38.331 [12]), where the first PUCCH configuration is associated with a PUCCH of priority index 0 (low) and the second PUCCH configuration is associated with a PUCCH of priority index 1 (high).

UCI multiplexing in PUCCH is supported when PUCCH transmissions of UCIs coincide in time, and are associated with the same priority (high/low). In addition, multiplexing of HARQ-ACK of priority index 0 (low) and UCI of priority index 1 (high) in PUCCH of priority index 1 (high) is supported when PUCCH transmissions of HARQ-ACK of priority index 0 and UCI of priority index 1 (high) coincide in time.

UCI multiplexing in PUSCH is supported when UCI and PUSCH transmissions coincide in time, either due to transmission of a UL-SCH transport block or due to triggering of A-CSI transmission without UL-SCH transport block, and are associated with the same priority (high/low). In addition, HARQ-ACK multiplexing of a certain priority in PUSCH of a different priority is supported when HARQ-ACK and PUSCH transmissions coincide in time, either due to transmission of a UL-SCH transport block or due to triggering of A-CSI transmission without UL-SCH transport block:

- UCI carrying HARQ-ACK feedback with 1 or 2 bits is multiplexed by puncturing PUSCH;
- In all other cases UCI is multiplexed by rate matching PUSCH.

UCI consists of the following information:

- CSI;
- ACK/NAK;
- Scheduling request.

Simultaneous transmission of PUCCH and PUSCH associated with different priorities on cells of different bands in a PUCCH group is supported, where UCI multiplexing in the PUCCH associated with a priority in combination of UCI multiplexing in a PUSCH associated with a different priority is supported if the UCI multiplexed on PUSCH is of same priority as the PUSCH.

Simultaneous transmission of PUCCH and PUSCH associated with same priority on cells of different bands in a PUCCH group is supported (see clause 9 of TS 38.213 [38]).

For operation with shared spectrum channel access, multiplexing of CG-UCI and PUCCH carrying HARQ-ACK feedback can be configured by the gNB. If not configured, when PUCCH overlaps with PUSCH scheduled by a configured grant within a PUCCH group and PUCCH carries HARQ ACK feedback, PUSCH scheduled by configured grant is skipped.

QPSK and $\pi/2$ BPSK modulation can be used for long PUCCH with more than 2 bits of information, QPSK is used for short PUCCH with more than 2 bits of information and BPSK and QPSK modulation can be used for long PUCCH with up to 2 information bits.

Transform precoding is applied to PUCCH Format #3 and Format #4.

Channel coding used for uplink control information is described in table 5.3.3-1.

Table 5.3.3-1: Channel coding for uplink control information

Uplink Control Information size including CRC, if present	Channel code
1	Repetition code
2	Simplex code
3-11	Reed Muller code
>11	Polar code

5.3.4 Random access

Random access preamble sequences, of four different lengths are supported. Sequence length 839 is applied with subcarrier spacings of 1.25 and 5 kHz, sequence length 139 is applied with subcarrier spacings of 15, 30, 60, 120, 480, and 960 kHz, sequence length of 571 is applied with subcarrier spacings of 30, 120, and 480 kHz, and sequence length 1151 is applied with subcarrier spacings of 15 and 120 kHz. Sequence length 839 supports unrestricted sets and restricted sets of Type A and Type B, while sequence lengths 139, 571, and 1151 support unrestricted sets only. Sequence length 839 is only used for operation with licensed channel access while sequence length 139 can be used for operation with either licensed or shared spectrum channel access. For FR1, sequence lengths of 571 and 1151 can be used only for operation with shared spectrum channel access. For FR2-2, sequence lengths of 571 can be used for operation with either licensed or shared spectrum channel access only with subcarrier spacings of 120 kHz and 480 kHz and sequence lengths of 1151 can be used for operation with either licensed or shared spectrum channel access only with subcarrier spacings of 120 kHz.

Multiple PRACH preamble formats are defined with one or more PRACH OFDM symbols, and different CP and guard time. The PRACH preamble configuration to use is provided to the UE in the system information.

For IAB additional random access configurations are defined. These configurations are obtained by extending the random access configurations defined for UEs via scaling the periodicity and/or offsetting the time domain position of the RACH occasions.

IAB-MTs can be provided with random access configurations (as defined for UEs or after applying the aforementioned scaling/offsetting) different from random access configurations provided to UEs.

The UE calculates the PRACH transmit power for the retransmission of the preamble based on the most recent estimate pathloss and power ramping counter.

The system information provides information for the UE to determine the association between the SSB and the RACH resources. The RSRP threshold for SSB selection for RACH resource association is configurable by network.

5.3.5 Physical layer procedures

5.3.5.1 Link adaptation

Four types of link adaptation are supported as follows:

- Adaptive transmission bandwidth;
- Adaptive transmission duration;
- Transmission power control;
- Adaptive modulation and channel coding rate.

For channel state estimation purposes, the UE may be configured to transmit SRS that the gNB may use to estimate the uplink channel state and use the estimate in link adaptation.

5.3.5.2 Uplink Power control

The gNB determines the desired uplink transmit power and provides uplink transmit power control commands to the UE. The UE uses the provided uplink transmit power control commands to adjust its transmit power.

5.3.5.3 Uplink timing control

The gNB (including IAB-DU and IAB-donor-DU) determines the desired Timing Advance setting and provides that to the UE (or IAB-MT). The UE/IAB-MT uses the provided TA to determine its uplink transmit timing relative to the UE's/IAB-MTs observed downlink receive timing.

An IAB-node may support additional modes for uplink timing:

- The IAB-MT uses the provided TA plus a provided additional offset to determine its uplink transmission timing, to facilitate parent node's IAB-MT Rx / IAB-DU Rx multiplexing;

- The IAB-MT aligns its uplink transmission timing to that of the collocated IAB-DU downlink transmission timing, to facilitate IAB-MT Tx / IAB-DU Tx multiplexing of this IAB-node.

The IAB-node uplink timing mode is indicated by the parent node via MAC-CE.

5.3.5.4 HARQ

Asynchronous Incremental Redundancy Hybrid ARQ is supported. The gNB schedules each uplink transmission and retransmission using the uplink grant on DCI. For operation with shared spectrum channel access, UE can also retransmit on configured grants if configured.

The UE may be configured to transmit code block group based transmissions where retransmissions may be scheduled to carry a sub-set of all the code blocks of a transport block.

Up to two HARQ-ACK codebooks corresponding to a priority (high/low) can be constructed simultaneously. For each HARQ-ACK codebook, more than one PUCCH for HARQ-ACK transmission within a slot is supported. Each PUCCH is limited within one sub-slot, and the sub-slot pattern is configured per HARQ-ACK codebook.

5.3.5.5 Prioritization of overlapping transmissions

PUSCH and PUCCH can be associated with a priority (high/low) by RRC or L1 signalling. If a PUCCH transmission overlaps in time with a transmission of a PUSCH or another PUCCH, only the PUCCH or PUSCH associated with a high priority can be transmitted.

5.3.6 Uplink Reference Signals and Measurements for Positioning

The periodic, semipersistent and aperiodic transmission of Rel-15 SRS is defined for gNB UL RTOA, UL SRS-RSRP, UL-AoA measurements to facilitate support of UL TDOA and UL AoA positioning methods as described in TS 38.305 [42].

The periodic, semipersistent and aperiodic transmission of SRS for positioning is defined for gNB UL RTOA, UL SRS-RSRP/UL-SRS-RSRPP, UL-AoA, gNB Rx-Tx time difference measurements to facilitate support of UL TDOA, UL AoA and multi-RTT positioning methods as described in TS 38.305 [42]. Carrier phase positioning measurement UL-RSCP can be used by UL TDOA or multi-RTT positioning methods as described in TS 38.305 [42].

5.4 Carrier aggregation

5.4.1 Carrier aggregation

In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities:

- A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG);

- A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell;

- A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG).

CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the SpCell and an SCell is configured to the UE.

5.4.2 Supplementary Uplink

In conjunction with a UL/DL carrier pair (FDD band) or a bidirectional carrier (TDD band), a UE may be configured with additional, Supplementary Uplink (SUL). SUL differs from the aggregated uplink in that the UE may be scheduled to transmit either on the supplementary uplink or on the uplink of the carrier being supplemented, but not on both at the same time.

5.4.3 Uplink Tx switching

In uplink CA or SUL, a UE configured with uplink Tx switching can have Tx chain(s) dynamically switched from one uplink band or two uplink bands to another uplink band or two uplink bands for enabling up to 2Tx UL transmission in one uplink band or simultaneous UL transmissions in two uplink bands at a time.

5.4.4 Low band carrier aggregation via switching

In CA with low band spectrums of FDD carrier and supplementary DL (SDL) carrier, a UE may be configured with switching pattern between transmitter and receiver on FDD carrier used for PCell and receiver on SDL carrier used for an SCell.

5.5 Transport Channels

The physical layer offers information transfer services to MAC and higher layers. The physical layer transport services are described by *how* and with what characteristics data are transferred over the radio interface. An adequate term for this is "Transport Channel". This should be clearly separated from the classification of *what* is transported, which relates to the concept of logical channels at MAC sublayer.

Downlink transport channel types are:

1. **Broadcast Channel (BCH)** characterised by:
   - fixed, pre-defined transport format;
   - requirement to be broadcast in the entire coverage area of the cell, either as a single message or by beamforming different BCH instances.
2. **Downlink Shared Channel (DL-SCH)** characterised by:
   - support for HARQ;
   - support for dynamic link adaptation by varying the modulation, coding and transmit power;
   - possibility to be broadcast in the entire cell;
   - possibility to use beamforming;
   - support for both dynamic and semi-static resource allocation;
   - support for UE discontinuous reception (DRX) to enable UE power saving.
3. **Paging Channel (PCH)** characterised by:
   - support for UE discontinuous reception (DRX) to enable UE power saving (DRX cycle is indicated by the network to the UE);
   - requirement to be broadcast in the entire coverage area of the cell, either as a single message or by beamforming different PCH instances;
   - mapped to physical resources which can be used dynamically also for traffic/other control channels.

Uplink transport channel types are:

1. **Uplink Shared Channel (UL-SCH)** characterised by:

- possibility to use beamforming;
- support for dynamic link adaptation by varying the transmit power and potentially modulation and coding;
- support for HARQ;
- support for both dynamic and semi-static resource allocation.

2. **Random Access Channel(s) (RACH)** characterised by:
   - limited control information;
   - collision risk.

Sidelink transport channel types are:

1. **Sidelink broadcast channel (SL-BCH)** characterised by:
   - pre-defined transport format.
2. **Sidelink shared channel (SL-SCH)** characterised by:
   - support for unicast transmission, groupcast transmission and broadcast transmission;
   - support for both UE autonomous resource selection and scheduled resource allocation by NG-RAN;
   - support for both dynamic and semi-static resource allocation when UE is allocated resources by the NG-RAN;
   - support for HARQ;
   - support for dynamic link adaptation by varying the transmit power, modulation and coding;
   - support for SL discontinuous reception (SL DRX) to enable UE power saving.

Association of transport channels to physical channels is described in TS 38.202 [20].

5.6 Access to Shared Spectrum

5.6.1 Overview

NR Radio Access operating with shared spectrum channel access can operate in different modes where either PCell, PSCell, or SCells can be in shared spectrum and an SCell may or may not be configured with uplink. The applicable deployment scenarios are described in Annex B.3.

The gNB performs channel access mode procedures as described in TS 37.213 [37]. The gNB and the UE may apply Listen-Before-Talk (LBT) before performing a transmission on a cell configured with shared spectrum channel access. When LBT is applied, the transmitter listens to/senses the channel to determine whether the channel is free or busy and performs transmission only if the channel is sensed free.

When the UE detects consistent uplink LBT failures, it takes actions as specified in TS 38.321 [6]. The detection is per Bandwidth Part (BWP) and based on all uplink transmissions within this BWP. When consistent uplink LBT failures are detected on SCell(s), the UE reports this to the corresponding gNB (MN for MCG, SN for SCG) via MAC CE on a different serving cell than the SCell(s) where the failures were detected. If no resources are available to transmit the MAC CE, a Scheduling Request (SR) can be transmitted by the UE. When consistent uplink LBT failures are detected on SpCell, the UE switches to another UL BWP with configured RACH resources on that cell, initiates RACH, and reports the failure via MAC CE. When multiple UL BWPs are available for switching, it is up to the UE implementation which one to select. For PSCell, if consistent uplink LBT failures are detected on all the UL BWPs with configured RACH resources, the UE declares SCG RLF and reports the failure to the MN via *SCGFailureInformation.* For PCell, if the uplink LBT failures are detected on all the UL BWP(s) with configured RACH resources, the UE declares RLF.

5.6.2 Channel Access Priority Classes

The Channel Access Priority Classes (CAPC) of radio bearers and MAC CEs are either fixed or configurable for operation in FR1:

- Fixed to the lowest priority for the padding BSR and recommended bit rate MAC CEs;
- Fixed to the highest priority for SRB0, SRB1, SRB3 and other MAC CEs;
- Configured by the gNB for SRB2 and DRB.

When choosing the CAPC of a DRB, the gNB takes into account the 5QIs of all the QoS flows multiplexed in that DRB while considering fairness between different traffic types and transmissions. Table 5.6.2-1 below shows which CAPC should be used for which standardized 5QIs i.e. which CAPC to use for a given QoS flow.

NOTE: A QoS flow corresponding to a non-standardized 5QI (i.e. operator specific 5QI) should use the CAPC of the standardized 5QI which best matches the QoS characteristics of the non-standardized 5QI.

Table 5.6.2-1: Mapping between Channel Access Priority Classes and 5QI

CAPC	5QI
1	1, 3, 5, 65, 66, 67, 69, 70, 79, 80, 82, 83, 84, 85
2	2, 7, 71
3	4, 6, 8, 9, 72, 73, 74, 76
4	-
NOTE: lower CAPC value means higher priority	

When performing Type 1 LBT for the transmission of an uplink TB (see TS 37.213 [37], clause 4.2.1.1) and when the CAPC is not indicated in the DCI, the UE shall select the CAPC as follows:

- If only MAC CE(s) are included in the TB, the highest priority CAPC of those MAC CE(s) is used; or
- If CCCH SDU(s) are included in the TB, the highest priority CAPC is used; or
- If DCCH SDU(s) are included in the TB, the highest priority CAPC of the DCCH(s) is used; or
- The lowest priority CAPC of the logical channel(s) with MAC SDU multiplexed in the TB is used otherwise.

5.7 Sidelink

5.7.1 General

Sidelink supports UE-to-UE direct communication using the sidelink resource allocation modes, physical-layer signals/channels, and physical layer procedures below.

5.7.2 Sidelink resource allocation modes/schemes

Two sidelink resource allocation modes are supported for sidelink communication: mode 1 and mode 2. Two sidelink resource allocation schemes are supported for SL-PRS transmission: scheme 1 and scheme 2. In mode 1/scheme 1, the sidelink resource allocation is provided by the network. In mode 2/scheme 2, UE decides the SL transmission resources in the resource pool(s).

5.7.3 Physical sidelink channels and signals

Physical Sidelink Control Channel (PSCCH) indicates resource and other transmission parameters used by a UE for PSSCH. PSCCH transmission is associated with a DM-RS.

Physical Sidelink Shared Channel (PSSCH) transmits the TBs of data themselves, and control information for HARQ procedures and CSI feedback triggers, etc. At least 6 OFDM symbols within a slot are used for PSSCH transmission. PSSCH transmission is associated with a DM-RS and may be associated with a PT-RS.

Physical Sidelink Feedback Channel (PSFCH) carries HARQ feedback over the sidelink from a UE which is an intended recipient of a PSSCH transmission to the UE which performed the transmission. PSFCH sequence is transmitted in one PRB repeated over two OFDM symbols near the end of the sidelink resource in a slot.

The Sidelink synchronization signal consists of sidelink primary and sidelink secondary synchronization signals (S-PSS, S-SSS), each occupying 2 symbols and 127 subcarriers. Physical Sidelink Broadcast Channel (PSBCH) occupies 9 and 7 symbols for normal and extended CP cases respectively, including the associated DM-RS.

5.7.4 Physical layer procedures for sidelink

5.7.4.1 HARQ feedback

Sidelink HARQ feedback uses PSFCH and can be operated in one of two options. In one option, which can be configured for unicast and groupcast, PSFCH transmits either ACK or NACK using a resource dedicated to a single PSFCH transmitting UE. In another option, which can be configured for groupcast, PSFCH transmits NACK, or no PSFCH signal is transmitted, on a resource that can be shared by multiple PSFCH transmitting UEs. The latter option is not supported for sidelink in shared spectrum.

In sidelink resource allocation mode 1, a UE which received PSFCH can report sidelink HARQ feedback to gNB via PUCCH or PUSCH.

5.7.4.2 Power Control

For in-coverage operation, the power spectral density of the sidelink transmissions can be adjusted based on the pathloss from the gNB.

For unicast, the power spectral density of some sidelink transmissions can be adjusted based on the pathloss between the two communicating UEs.

5.7.4.3 CSI report

For unicast, channel state information reference signal (CSI-RS) is supported for CSI measurement and reporting in sidelink. A CSI report is carried in a sidelink MAC CE.

5.7.5 Physical layer measurement definition

For measurement on the sidelink, the following UE measurement quantities are supported:

- PSBCH reference signal received power (PSBCH RSRP);
- PSSCH reference signal received power (PSSCH-RSRP);
- PSCCH reference signal received power (PSCCH-RSRP);
- Sidelink received signal strength indicator (SL RSSI);
- Sidelink channel occupancy ratio (SL CR);
- Sidelink channel busy ratio (SL CBR).

5.7.6 Sidelink Reference Signal and Measurements for Positioning

The Sidelink Positioning Reference Signal (SL-PRS) is defined to facilitate Ranging/Sidelink positioning methods, such as SL-TOA, SL-TDOA, SL-RTT, SL-AoA, through the following set of measurements SL-PRS RSRP, RSRPP, RTOA, RSTD, Rx-Tx timing difference and AoA as described in TS 38.305 [42].

6 Layer 2

6.1 Overview

The layer 2 of NR is split into the following sublayers: Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and Service Data Adaptation Protocol (SDAP). The two figures below depict the Layer 2 architecture for downlink and uplink, where:

- The physical layer offers to the MAC sublayer transport channels;
- The MAC sublayer offers to the RLC sublayer logical channels;
- The RLC sublayer offers to the PDCP sublayer RLC channels;
- The PDCP sublayer offers to the SDAP sublayer radio bearers;
- The SDAP sublayer offers to 5GC QoS flows;
- *Comp.* refers to header compression or uplink data compression;
- *Segm.* refers to segmentation;
- Control channels (BCCH, PCCH are not depicted for clarity).

NOTE: The gNB may not be able to guarantee that a L2 buffer overflow will never occur. If such overflow occurs, the UE may discard packets in the L2 buffer.

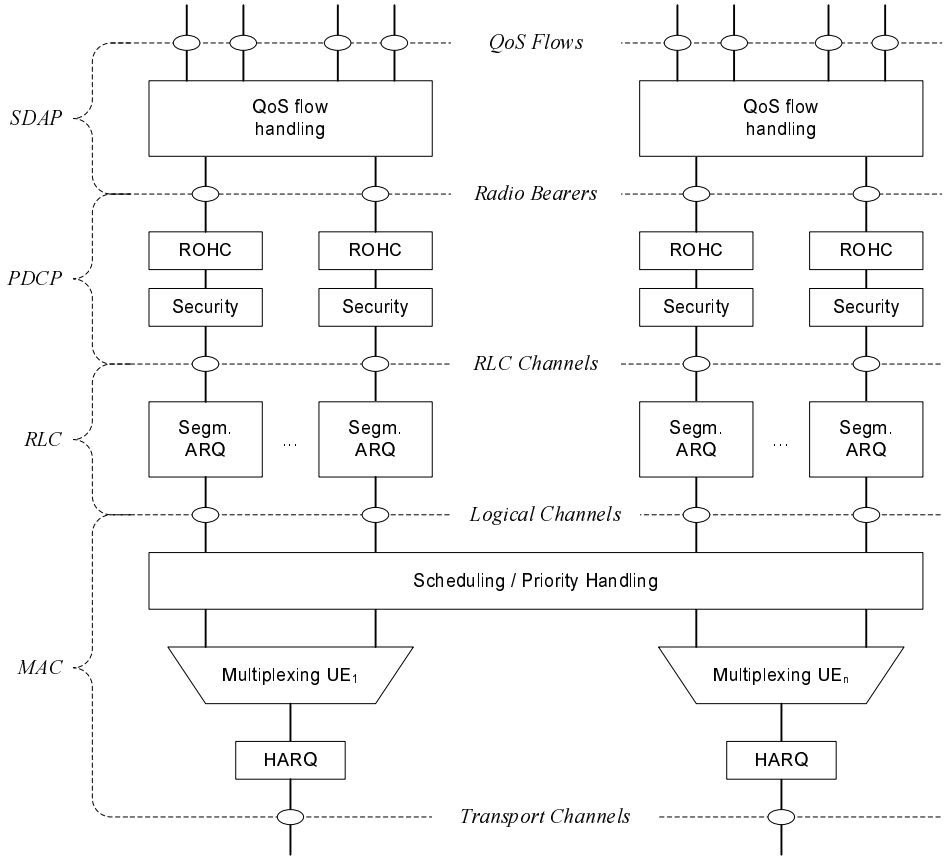


Figure 6.1-1: Downlink Layer 2 Structure

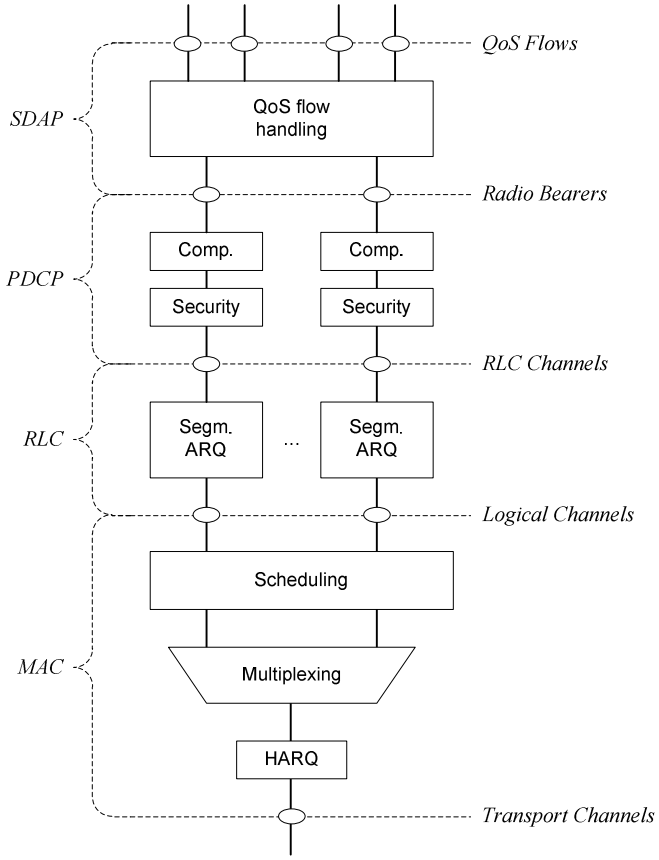


Figure 6.1-2: Uplink Layer 2 Structure

Radio bearers are categorized into two groups: data radio bearers (DRB) for user plane data and signalling radio bearers (SRB) for control plane data.

For IAB, the Layer 2 of NR includes: MAC, RLC, Backhaul Adaptation Protocol (BAP), PDCP and optionally SDAP. The BAP sublayer supports routing across the IAB topology and traffic mapping to BH RLC channels for enforcement of traffic prioritization and QoS.

Figures 6.1-3 below depicts the Layer-2 architecture for downlink on the IAB-donor. Figures 6.1-4 and 6.1-5 depict the Layer-2 architecture for downlink and uplink on the IAB-node, where the BAP sublayer offers routing functionality and mapping to BH RLC channels.

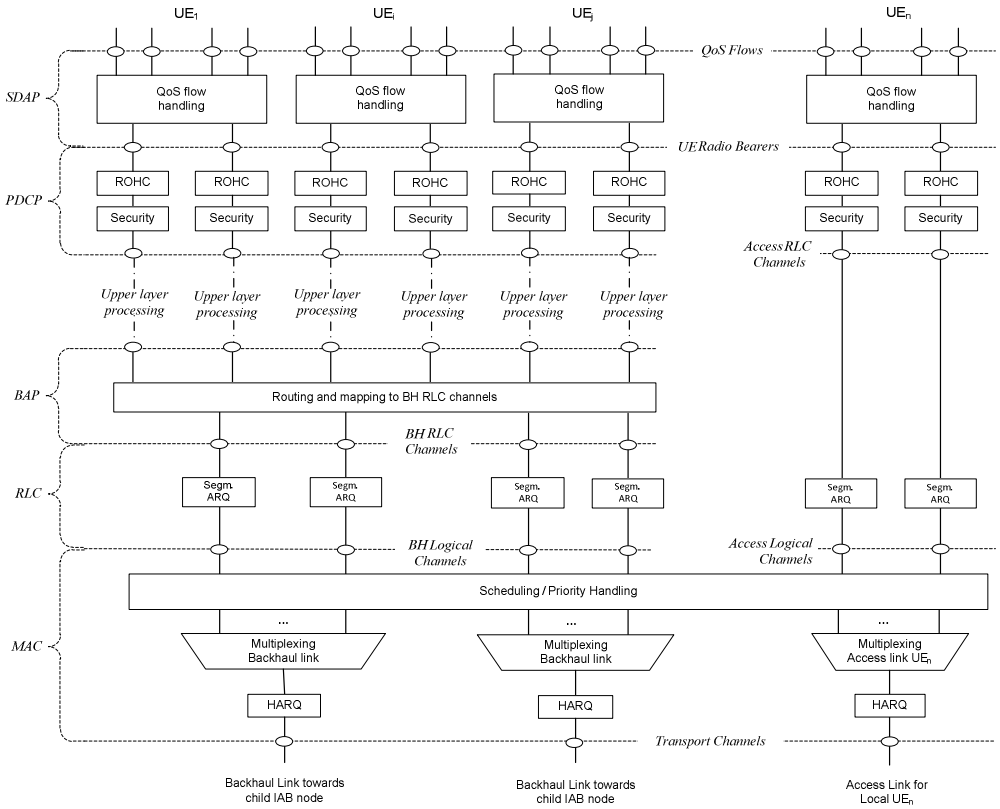


Figure 6.1-3: DL L2-structure for user plane at IAB-donor

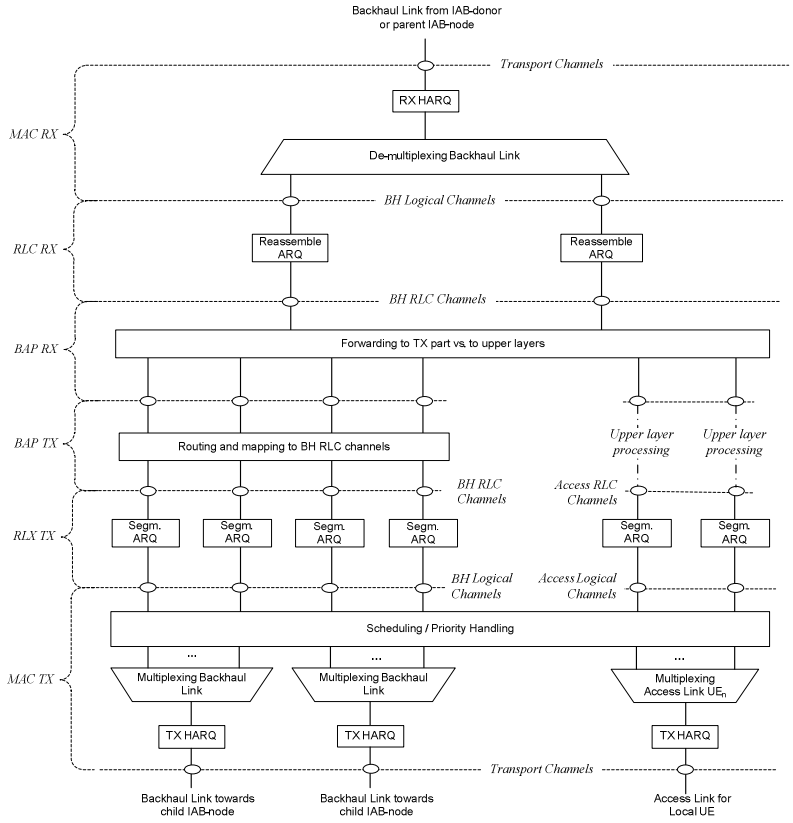


Figure 6.1-4: DL L2-structure at IAB-node

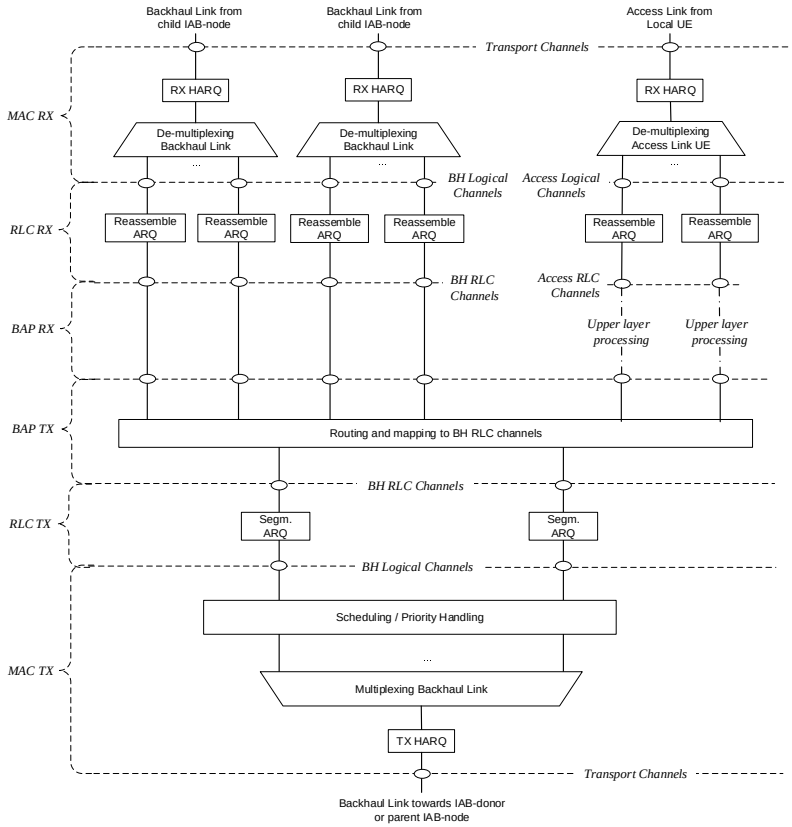


Figure 6.1-5: UL L2-structure at IAB-node

6.2 MAC Sublayer

6.2.1 Services and Functions

The main services and functions of the MAC sublayer include:

- Mapping between logical channels and transport channels;
- Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels;
- Scheduling information reporting;
- Error correction through HARQ (one HARQ entity per cell in case of CA);
- Priority handling between UEs by means of dynamic scheduling;
- Priority handling between logical channels of one UE by means of logical channel prioritisation;
- Priority handling between overlapping resources of one UE;
- Padding.

A single MAC entity can support multiple numerologies, transmission timings and cells. Mapping restrictions in logical channel prioritisation control which numerology(ies), cell(s), and transmission timing(s) a logical channel can use (see clause 16.1.2).

6.2.2 Logical Channels

Different kinds of data transfer services as offered by MAC. Each logical channel type is defined by what type of information is transferred. Logical channels are classified into two groups: Control Channels and Traffic Channels. Control channels are used for the transfer of control plane information only:

- Broadcast Control Channel (BCCH): a downlink channel for broadcasting system control information.
- Paging Control Channel (PCCH): a downlink channel that carries paging messages.
- Common Control Channel (CCCH): channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network.
- Dedicated Control Channel (DCCH): a point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.

Traffic channels are used for the transfer of user plane information only:

- Dedicated Traffic Channel (DTCH): point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

6.2.3 Mapping to Transport Channels

In Downlink, the following connections between logical channels and transport channels exist:

- BCCH can be mapped to BCH;
- BCCH can be mapped to DL-SCH;
- PCCH can be mapped to PCH;
- CCCH can be mapped to DL-SCH;
- DCCH can be mapped to DL-SCH;
- DTCH can be mapped to DL-SCH.

In Uplink, the following connections between logical channels and transport channels exist:

- CCCH can be mapped to UL-SCH;
- DCCH can be mapped to UL- SCH;
- DTCH can be mapped to UL-SCH.

6.2.4 HARQ

The HARQ functionality ensures delivery between peer entities at Layer 1. A single HARQ process supports one TB when the physical layer is not configured for downlink/uplink spatial multiplexing, and when the physical layer is configured for downlink/uplink spatial multiplexing, a single HARQ process supports one or multiple TBs.

6.3 RLC Sublayer

6.3.1 Transmission Modes

The RLC sublayer supports three transmission modes:

- Transparent Mode (TM);
- Unacknowledged Mode (UM);
- Acknowledged Mode (AM).

The RLC configuration is per logical channel with no dependency on numerologies and/or transmission durations, and ARQ can operate on any of the numerologies and/or transmission durations the logical channel is configured with.

For SRB0, paging and broadcast system information, TM mode is used. For other SRBs AM mode used. For DRBs, either UM or AM mode are used.

6.3.2 Services and Functions

The main services and functions of the RLC sublayer depend on the transmission mode and include:

- Transfer of upper layer PDUs;
- Sequence numbering independent of the one in PDCP (UM and AM);
- Error Correction through ARQ (AM only);
- Segmentation (AM and UM) and re-segmentation (AM only) of RLC SDUs;
- Reassembly of SDU (AM and UM);
- Duplicate Detection (AM only);
- RLC SDU discard (AM and UM);
- RLC re-establishment;
- Protocol error detection (AM only).

6.3.3 ARQ

The ARQ within the RLC sublayer has the following characteristics:

- ARQ retransmits RLC SDUs or RLC SDU segments based on RLC status reports;
- Polling for RLC status report is used when needed by RLC;
- RLC receiver can also trigger RLC status report after detecting a missing RLC SDU or RLC SDU segment.

6.4 PDCP Sublayer

6.4.1 Services and Functions

The main services and functions of the PDCP sublayer include:

- Transfer of data (user plane or control plane);
- Maintenance of PDCP SNs;
- Header compression and decompression using the ROHC protocol;
- Header compression and decompression using EHC protocol;
- Compression and decompression of uplink PDCP SDUs: DEFLATE based UDC only;
- Ciphering and deciphering;
- Integrity protection and integrity verification;
- Timer based SDU discard;
- For split bearers, routing;
- Duplication;

- Reordering and in-order delivery;
- Out-of-order delivery;
- Duplicate discarding.

Since PDCP does not allow COUNT to wrap around in DL and UL, it is up to the network to prevent it from happening (e.g. by using a release and add of the corresponding radio bearer or a full configuration).

6.5 SDAP Sublayer

The main services and functions of SDAP include:

- Mapping between a QoS flow and a data radio bearer;

NOTE: When remapping an XR QoS flow carrying PDU sets (see clause 16.15) from one DRB to another (as exemplified in Annex A), all SDAP SDUs belonging to a PDU Set should be mapped to the same DRB.

- Marking QoS flow ID (QFI) in both DL and UL packets.

A single protocol entity of SDAP is configured for each individual PDU session.

6.6 L2 Data Flow

An example of the Layer 2 Data Flow is depicted on Figure 6.6-1, where a transport block is generated by MAC by concatenating two RLC PDUs from RB_x and one RLC PDU from RB_y. The two RLC PDUs from RB_x each corresponds to one IP packet (*n* and *n+1*) while the RLC PDU from RB_y is a segment of an IP packet (*m*).

NOTE: H depicts the headers and subheaders.

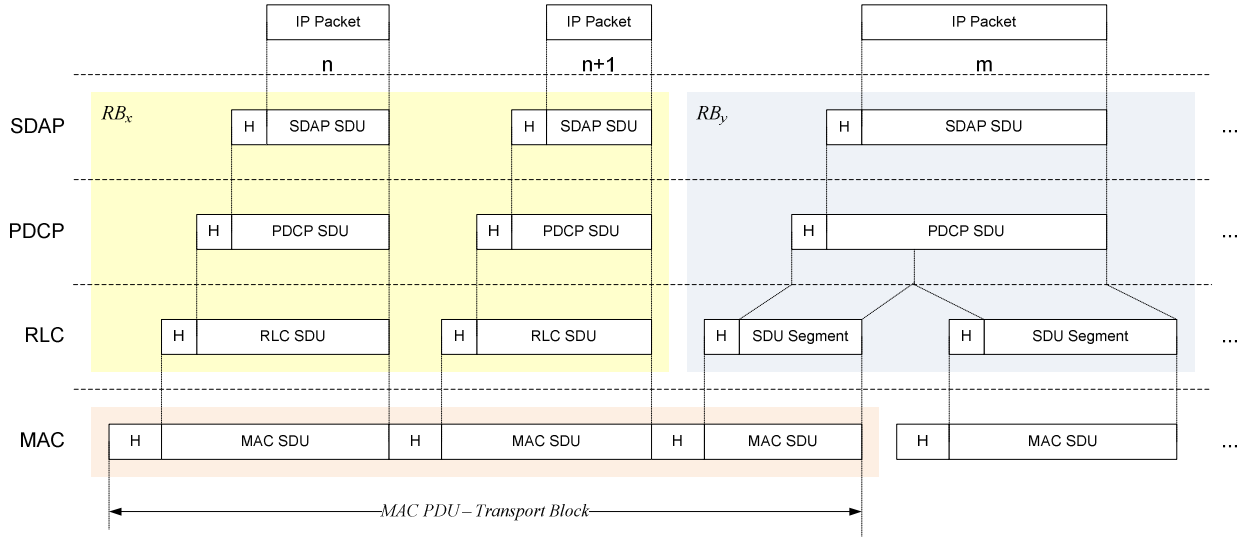


Figure 6.6-1: Data Flow Example

6.7 Carrier Aggregation

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

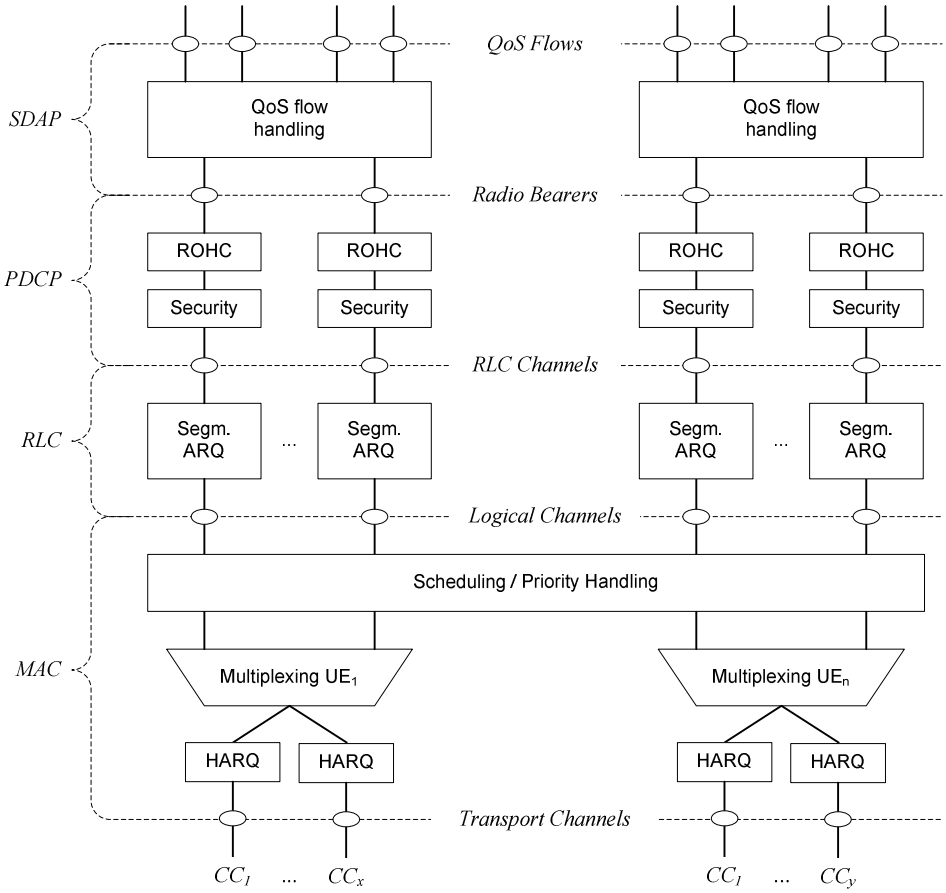


Figure 6.7-1: Layer 2 Structure for DL with CA configured

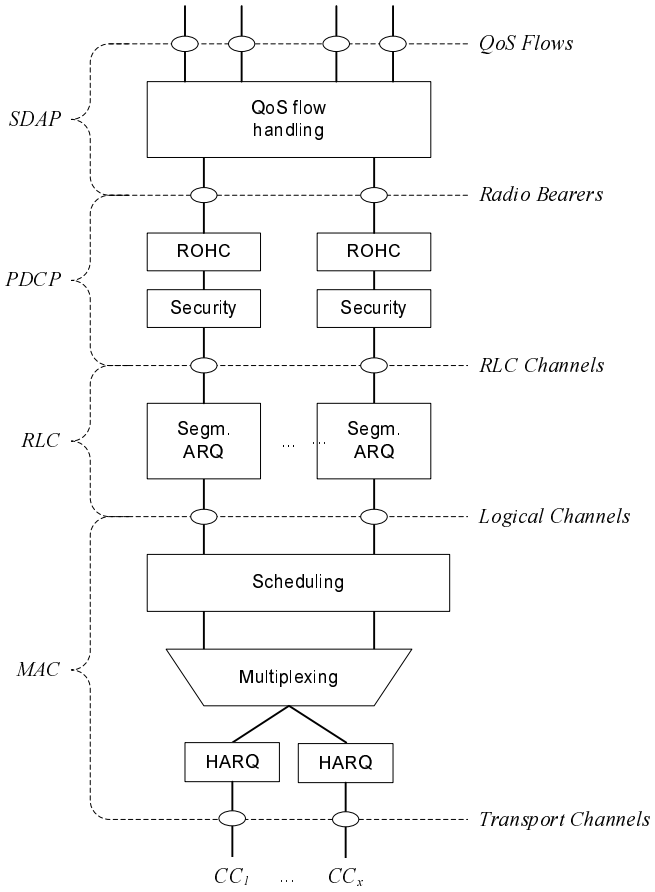


Figure 6.7-2: Layer 2 Structure for UL with CA configured

6.8 Dual Connectivity

When the UE is configured with SCG, the UE is configured with two MAC entities: one MAC entity for the MCG and one MAC entity for the SCG. Further details of DC operation can be found in TS 37.340 [21].

6.9 Supplementary Uplink

In case of Supplementary Uplink (SUL, see TS 38.101-1 [18]), the UE is configured with 2 ULs for one DL of the same cell, and uplink transmissions on those two ULs are controlled by the network to avoid overlapping PUSCH/PUCCH transmissions in time. Overlapping transmissions on PUSCH are avoided through scheduling while overlapping transmissions on PUCCH are avoided through configuration (PUCCH can only be configured for only one of the 2 ULs of the cell). In addition, initial access is supported in each of the uplink (see clause 9.2.6). An example of SUL is given in Annex B.

6.10 Bandwidth Adaptation

With Bandwidth Adaptation (BA), the receive and transmit bandwidth of a UE need not be as large as the bandwidth of the cell and can be adjusted: the width can be ordered to change (e.g. to shrink during period of low activity to save power); the location can move in the frequency domain (e.g. to increase scheduling flexibility); and the subcarrier spacing can be ordered to change (e.g. to allow different services). A subset of the total cell bandwidth of a cell is referred to as a Bandwidth Part (BWP) and BA is achieved by configuring the UE with BWP(s) and telling the UE which of the configured BWPs is currently the active one.

Figure 6.10-1 below describes a scenario where 3 different BWPs are configured:

- BWP_1 with a width of 40 MHz and subcarrier spacing of 15 kHz;

- BWP_2 with a width of 10 MHz and subcarrier spacing of 15 kHz;
- BWP_3 with a width of 20 MHz and subcarrier spacing of 60 kHz.

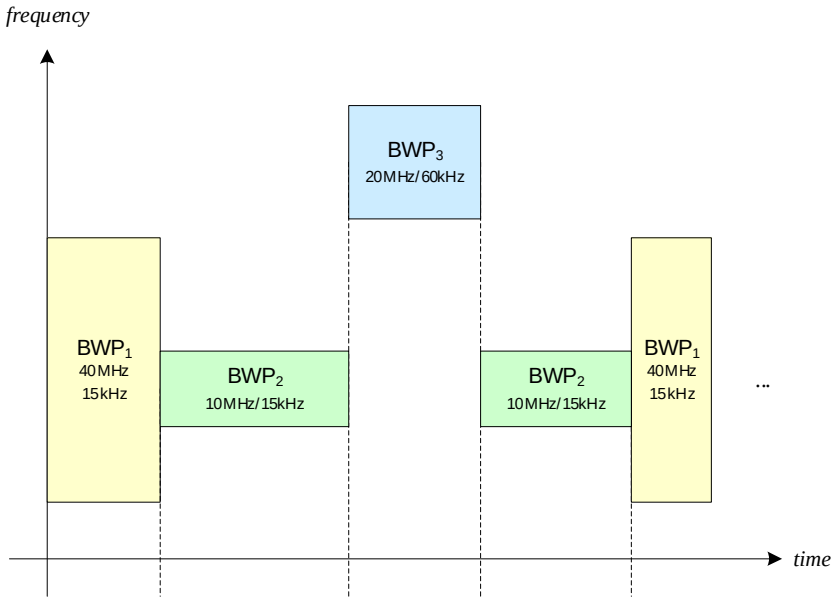


Figure 6.10-1: BA Example

6.11 Backhaul Adaptation Protocol Sublayer

6.11.1 Services and Functions

The main service and functions of the BAP sublayer include:

- Transfer of data;
- Routing of packets to next hop;
- Determination of BAP destination and BAP path for packets from upper layers;
- Determination of egress BH RLC channels for packets routed to next hop;
- Differentiating traffic to be delivered to upper layers from traffic to be delivered to egress link;
- Flow control feedback and polling signalling;
- BH RLF detection indication, BH RLF recovery indication, and BH RLF indication;
- BAP header rewriting.

6.11.2 Traffic Mapping from Upper Layers to Layer-2

In upstream direction, the IAB-donor-CU configures the IAB-node with mappings between upstream F1 and non-F1 traffic originated at the IAB-node, and the appropriate BAP routing ID, next-hop BAP address and BH RLC channel. A specific mapping is configured:

- for each F1-U GTP-U tunnel;
- for non-UE associated F1AP messages;
- for UE-associated F1AP messages;
- for non-F1 traffic.

Multiple mappings can contain the same BH RLC channel and/or next-hop BAP address and/or BAP routing ID. In case the IAB-MT is NR-dual-connected (SA mode only), the mapping may include two separate BH RLC channels, where the two BH RLC channels are established toward different parent nodes.

In case the IAB-node is configured with multiple IP addresses for F1-C on the NR leg, multiple mappings can be configured for non-UE-associated F1AP messages or UE-associated F1AP messages. The appropriate mapping is selected based on the IAB-node's implementation.

These traffic mapping configurations are performed via F1AP. For a boundary IAB-node, the traffic mapping configuration includes information that allows the boundary IAB-node to determine the IAB topology the mapping applies to.

During IAB-node integration, a default BH RLC channel and a default BAP routing ID may be configured via RRC, which can be used for non-F1-U traffic. These default configurations may be updated during topology adaptation scenarios as discussed in TS 38.401 [4].

In downstream direction, traffic mapping occurs internal to the IAB-donor. Transport for IAB-donors that use split-gNB architecture is handled in TS 38.401 [4].

6.11.3 Routing, BAP Header Rewriting and BH-RLC-channel Mapping on BAP sublayer

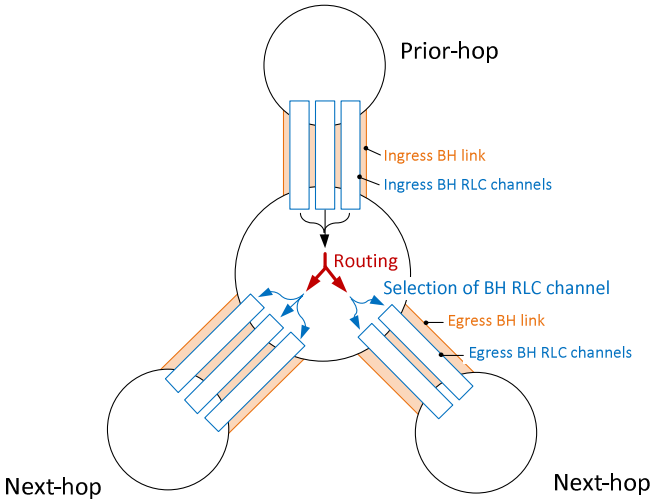


Figure 6.11.3-1: Routing and BH RLC channel selection on BAP sublayer

Routing on BAP sublayer uses the BAP routing ID, which is configured by the IAB-donor-CU. The BAP routing ID consists of BAP address and BAP path ID. The BAP address is used for the following purposes:

1. Determination if a packet has reached the destination node, i.e. IAB-node or IAB-donor-DU, on BAP sublayer. This is the case if the BAP address in the packet's BAP header matches the BAP address configured via RRC on the IAB-node, or via F1AP on the IAB-donor-DU. For a dual-connected boundary IAB-node that is configured with two BAP addresses, the BAP address in the packet's BAP header is matched with the BAP address configured by the CU of the IAB topology, where the packet has been received.

2. Determination of the next-hop node for packets that have not reached their destination. This applies to packets arriving from a prior hop on BAP sublayer or that have been received from IP layer.

For packets arriving from a prior hop or from upper layers, the determination of the next-hop node is based on a routing configuration provided by the IAB-donor-CU via F1AP signalling or a default configuration provided by the IAB-donor-CU via RRC signalling. This F1AP configuration contains the mapping between the BAP routing ID carried in the packet's BAP header and the next-hop node's BAP address.

Table 6.11.3-1: Routing configuration

BAP routing ID	Next-hop BAP address
Derived from BAP packet's BAP header	Egress BH link to forward packet

The IAB-node resolves the next-hop BAP address to a physical backhaul link. For this purpose, the IAB-donor-CU provides the IAB-node/IAB-donor-DU with its child-node's BAP address via F1AP, and it provides the IAB-node with its parent-node's BAP address via RRC. For a boundary IAB-node, the routing configuration also indicates the IAB topology it applies to. The BH link to the next-hop node and the next-hop BAP address belong to the IAB topology of the CU that provided the RRC configuration of the BH link to that next-hop node.

The IAB-node can receive multiple routing configurations with the same destination BAP address but different BAP path IDs. These routing configurations may resolve to the same or different egress BH links.

In case the BH link resolved from the routing entry is considered *unavailable* for this packet, the IAB-node may perform local rerouting as defined in TS 38.340 [31], i.e., select another BH link by considering only the packet's BAP address or, in some cases, by header rewriting. In this manner, the packet can be delivered via an alternative path as defined in TS 38.340 [31].

A BH link may be considered *unavailable* in case the BH link has RLF. A parent link may be considered *unavailable* after a BH RLF detection indication has been received on this parent link and before a subsequent BH RLF recovery indication has been received on the same parent link. For DL traffic, a BH link may be considered *unavailable* for BAP PDUs carrying a certain BAP routing ID due to congestion derived from flow-control feedback information related to this BAP routing ID, as defined in TS 38.340 [31].

For a boundary IAB-node, the routing configuration may carry information on the IAB topology the configuration applies to.

The IAB-node may rewrite the BAP routing ID in the packet's BAP header under the following circumstances:

- A packet is routed between two IAB topologies via a boundary IAB-node as defined in TS 38.401[31]. In this case, the BAP routing ID carried by the received BAP PDU is allocated by the IAB-donor-CU of the ingress IAB topology, while the BAP routing ID carried by the BAP PDU after header rewriting is allocated by the IAB-donor-CU of the egress IAB topology.

- An upstream packet is locally re-routed to a different IAB-donor-DU than indicated by the BAP address in the BAP header of the received packet. The rewritten BAP header carries the BAP address of the alternative IAB-donor-DU and the BAP path ID for a path to this alternative IAB-donor-DU. BAP header rewriting for upstream inter-IAB-donor-DU local rerouting is only applied if neither routing nor local re-routing without header rewriting resolve to an available egress BH link.

For packets that are routed between two IAB topologies via a boundary node, the BAP header rewriting configuration is provided via F1AP, and it includes the ingress BAP routing ID, the egress BAP routing ID, and it indicates the egress IAB topology:

Table 6.11.3-2a: BAP header rewriting configuration

Ingress BAP routing ID	Egress BAP routing ID	Egress topology indicator
BAP routing ID carried in the BAP header of the received BAP PDU	BAP routing ID carried in the BAP header of the transmitted BAP PDU	Indicates the egress IAB topology.

For upstream packets that are locally re-routed to a different IAB-donor-DU, the BAP header is rewritten with a BAP routing ID contained in the routing entry that was selected for re-routing.

Details of BAP header rewriting are defined in TS 38.340 [31].

When routing a packet from an ingress to an egress BH link, the IAB-node derives the egress BH RLC channel on the egress BH link through an F1AP-configured mapping from the BH RLC channel used on the ingress BH link. The BH RLC channel IDs used for ingress and egress BH RLC channels are generated by the IAB-donor-CU. Since the BH RLC channel ID only has link-local scope, the mapping configurations also include the BAP addresses of prior and next hop:

Table 6.11.3-2: BH RLC channel mapping configuration

Next-hop BAP address	Prior-hop BAP address	Ingress RLC channel ID	Egress RLC channel ID
Derived from routing configuration	Derived from packet's ingress BH link	Derived from packet's ingress BH RLC channel	BH RLC channel on egress BH link to forward packet

For a boundary IAB-node, the BH RLC channel mapping configuration may also include indicators for the IAB topology of the ingress and of the egress BH link.

The IAB-node resolves the BH RLC channel IDs from logical channel IDs based on the configuration by the IAB-donor-CU. The IAB-MT obtains the BH RLC channel ID in the RRC configuration of the corresponding logical channel. The IAB-DU obtains the BH RLC channel ID in the F1AP configuration of the BH RLC channel.

6.12 Multiple Transmit/Receive Point Operation

6.12.0 Overview

In Multiple Transmit/Receive Point (multi-TRP) operation, a serving cell can schedule the UE from two TRPs, providing better coverage, reliability and/or data rates for PDSCH, PDCCH, PUSCH, PUCCH, and SRS.

There are two different operation modes to schedule multi-TRP PDSCH transmissions: single-DCI and multi-DCI. For both modes, control of uplink and downlink operation can be done by physical layer and MAC layer, within the configuration provided by the RRC layer. In single-DCI mode, the UE is scheduled by the same DCI for both TRPs and in multi-DCI mode, the UE is scheduled by independent DCIs from each TRP.

There are two different operation modes for multi-TRP PDCCH: PDCCH repetition as in Clause 5.2.3 and Single Frequency Network (SFN) based PDCCH transmission. In both modes, the UE can receive two PDCCH transmissions, one from each TRP, carrying the same DCI. In PDCCH repetition mode, the UE can receive the two PDCCH transmissions carrying the same DCI from two linked search spaces each associated with a different CORESET. In SFN based PDCCH transmission mode, the UE can receive the two PDCCH transmissions carrying the same DCI from a single search space/CORESET using different TCI states.

For multi-TRP PUSCH repetition, according to indications in a single DCI or in a semi-static configured grant provided over RRC, the UE performs PUSCH transmission of the same contents toward two TRPs with corresponding beam directions associated with different spatial relations. For multi-TRP PUCCH repetition, the UE performs PUCCH transmission of the same contents toward two TRPs with corresponding beam directions associated with different spatial relations.

For inter-cell multi-TRP operation, for multi-DCI PDSCH transmission, one or more TCI states can be associated with SSB with a PCI different from the serving cell PCI. The activated TCI states can be associated with at most one PCI different from the serving cell PCI at a time.

For inter-cell and intra-cell multi-DCI multi-TRP operation, up to two TAGs with associated TAG IDs can be configured per serving cell. Each UL/Joint TCI state is associated with a TAG ID and the UE applies the timing advance of the TAG ID associated with the UL/joint TCI state utilized for UL transmission. For inter-cell without multi-DCI multi-TRP operation and intra-cell without multi-DCI multi-TRP operation, up to two TAGs can be configured in the serving cell, and each UL/Joint TCI state for PUSCH, PUCCH, and SRS transmission can be associated with any one of the two TAGs.

For single-DCI multi-TRP Simultaneous Transmission with Multi-Panel (STxMP) Spatial Domain Multiplexing (SDM) PUSCH transmission, different layers of one PUSCH are separately transmitted towards two TRPs. For single-DCI multi-TRP STxMP SFN PUSCH transmission, same layers of one PUSCH are transmitted towards two TRPs. For multi-DCI based multi-TRP STxMP PUSCH+PUSCH transmission, two PUSCHs are transmitted towards two TRPs. For single-DCI multi-TRP STxMP SFN PUCCH transmission, one PUCCH is transmitted towards two TRPs.

For inter-TRP delay, frequency, and phase calibration for coherent joint transmission (CJT), CSI-RS per TRP is transmitted and the UE measures the CSI-RS(s) and estimates the reporting quantity including inter-TRP delay offset(s), frequency offset(s), and phase offset(s). A CSI report associated with the reporting quantity is carried on a PUSCH.

6.12.1 Asymmetric DL single-TRP and UL multi-TRP

For asymmetric DL single-TRP and UL multi-TRP operation, the UL TRP may reduce or even disable DL transmission. Pathloss offsets between two TRPs can be configured by RRC and dynamically updated by Pathloss Offset Update MAC CE, which is defined in TS 38.321[6]. Each pathloss offset is explicitly indicated for the corresponding UL/Joint TCI state for PUSCH, PUCCH, and SRS transmission toward the UL TRP. The pathloss offset can also be indicated by a PDCCH order for a PDCCH order triggered PRACH toward the UL TRP, thereby facilitating pathloss calculation. In addition, up to two closed loop power control adjustment states, as specified in clause 7.3 of TS 38.213 [38], can be supported for SRS separated from those used for PUSCH.

7 RRC

7.1 Services and Functions

The main services and functions of the RRC sublayer over the Uu interface include:

- Broadcast of System Information related to AS and NAS;
- Paging initiated by 5GC or NG-RAN;
- Establishment, maintenance and release of an RRC connection between the UE and NG-RAN including:
  - Addition, modification and release of carrier aggregation;
  - Addition, modification and release of Dual Connectivity in NR or between E-UTRA and NR.
- Security functions including key management;
- Establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs);
- Mobility functions including:
  - Handover and context transfer;
  - UE cell selection and reselection and control of cell selection and reselection;
  - Inter-RAT mobility.
- QoS management functions;
- UE measurement reporting and control of the reporting;
- Detection of and recovery from radio link failure;
- NAS message transfer to/from NAS from/to UE.

The sidelink specific services and functions of the RRC sublayer over the Uu interface include:

- Configuration of sidelink resource allocation via system information or dedicated signalling;
- Reporting of UE sidelink information;
- Measurement configuration and reporting related to sidelink;
- Reporting of UE assistance information for SL traffic pattern(s).

7.2 Protocol States

RRC supports the following states which can be characterised as follows:

- **RRC_IDLE**:

- PLMN selection;
- Broadcast of system information;
- Cell re-selection mobility;
- Paging for mobile terminated data is initiated by 5GC;
- Transfer of MBS broadcast data to the UE over MRB(s);
- DRX for CN paging configured by NAS.

- **RRC_INACTIVE**:
  - PLMN selection;
  - Broadcast of system information;
  - Cell re-selection mobility;
  - Paging is initiated by NG-RAN (RAN paging);
  - RAN-based notification area (RNA) is managed by NG- RAN;
  - DRX for RAN paging configured by NG-RAN;
  - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
  - The UE Inactive AS context is stored in NG-RAN and the UE;
  - NG-RAN knows the RNA which the UE belongs to;
  - Transfer of MBS multicast/broadcast data to the UE over MRB(s);
  - Transfer of unicast data and/or signalling to/from the UE over radio bearers configured for SDT.
- **RRC_CONNECTED**:
  - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
  - The UE AS context is stored in NG-RAN and the UE;
  - NG-RAN knows the cell which the UE belongs to;
  - Transfer of unicast data to/from the UE;
  - Transfer of MBS multicast/broadcast data to the UE over MRB(s);
  - Network controlled mobility including measurements.

7.3 System Information Handling

7.3.1 Overview

System Information (SI) consists of a MIB and a number of SIBs, which are divided into Minimum SI and Other SI:

- **Minimum SI** comprises basic information required for initial access and information for acquiring any other SI. Minimum SI consists of:
  - *MIB* contains cell barred status information and essential physical layer information of the cell required to receive further system information, e.g. CORESET#0 configuration. *MIB* is periodically broadcast on BCH.
  - *SIB1* defines the scheduling of other system information blocks and contains information required for initial access. SIB1 is also referred to as Remaining Minimum SI (RMSI) and can either be periodically broadcast on DL-SCH, sent in a dedicated manner on DL-SCH to UEs in RRC_CONNECTED, or broadcast on-

demand upon OD-SIB1 request from UEs in RRC_IDLE, RRC_INACTIVE or RRC_CONNECTED state when T311 is running if a UE and cell support OD-SIB1 as described in 15.4.2.9.

- **Other SI** encompasses all SIBs not broadcast in the Minimum SI. Those SIBs can either be periodically broadcast on DL-SCH, broadcast on-demand on DL-SCH (i.e. upon request from UEs in RRC_IDLE, RRC_INACTIVE, or RRC_CONNECTED), or sent in a dedicated manner on DL-SCH to UEs in RRC_CONNECTED (i.e., upon request, if configured by the network, from UEs in RRC_CONNECTED or when the UE has an active BWP with no common search space configured or when the UE configured with inter cell beam management is receiving DL-SCH from a TRP with PCI different from serving cell's PCI). For on-demand SIB requests made in RRC_CONNECTED, the UE may also request the start or stop of posSIB deliveries in a dedicated manner on DL-SCH, if configured by the network. Other SI consists of:

  - *SIB2* contains cell re-selection information, mainly related to the serving cell;
  - *SIB3* contains information about the serving frequency and intra-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
  - *SIB4* contains information about other NR frequencies and inter-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters), which can also be used for NR idle/inactive measurements;
  - *SIB5* contains information about E-UTRA frequencies and E-UTRA neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);
  - *SIB6* contains an ETWS primary notification;
  - *SIB7* contains an ETWS secondary notification;
  - *SIB8* contains a CMAS warning notification;
  - *SIB9* contains information related to GPS time and Coordinated Universal Time (UTC);
  - *SIB10* contains the Human-Readable Network Names (HRNN) of the NPNs listed in SIB1;
  - *SIB11* contains information related to idle/inactive measurements;
  - *SIB15* contains information related to disaster roaming;
  - *SIB16* contains slice-based cell reselection information;
  - *SIB17* and *SIB17bis* contain information related to TRS configuration for UEs in RRC_IDLE/RRC_INACTIVE;
  - *SIBpos* contains positioning assistance data as defined in TS 37.355 [43] and TS 38.331 [12];
  - *SIB18* contains information related to the Group IDs for Network selection (GINs) associated with SNPNs listed in SIB1.
  - *SIB19* in TN contains NTN-specific parameters for NTN neighbour cells as defined in TS 38.331 [12].
  - *SIB26* contains OD-SIB1 request configurations of serving and neighbour cells which support OD-SIB1 as defined in TS 38.331 [12].

For sidelink, Other SI also includes:

  - *SIB12* contains information related to NR sidelink communication, ranging and sidelink positioning;
  - *SIB13* contains information related to *SystemInformationBlockType21* for V2X sidelink communication as specified in TS 36.331 clause 5.2.2.28 [29];
  - *SIB14* contains information related to *SystemInformationBlockType26* for V2X sidelink communication as specified in TS 36.331 clause 5.2.2.33 [29];
  - *SIB23* contains information related to ranging and sidelink positioning.

For non-terrestrial network, Other SI also includes:

- *SIB19* contains NTN-specific parameters for serving cell and optionally NTN-specific parameters for neighbour cells as defined in TS 38.331 [12].
- *SIB25* contains TN coverage information as defined in TS 38.331 [12].
- *SIB28* contains assistance information for cell selection to IoT NTN neighbour cells as defined in TS 38.331 [12].

For MBS broadcast, Other SI also includes:

- *SIB20* contains MCCH configuration;
- *SIB21* contains information related to service continuity for MBS broadcast reception;
- *SIB27* contains the information of the ISA(s) of MBS broadcast service(s) in an NTN cell.

For MBS multicast reception in RRC_INACTIVE state, Other SI also includes:

- *SIB24* contains the information required to acquire the multicast MCCH/MTCH configuration as defined in TS 38.331 [12].

For ATG network, Other SI also includes:

- *SIB22* contains ATG-specific parameters for serving cell and optionally ATG-specific parameters for neighbour cells as defined in TS 38.331 [12].

Figure 7.3.1-1 below summarises System Information provisioning.

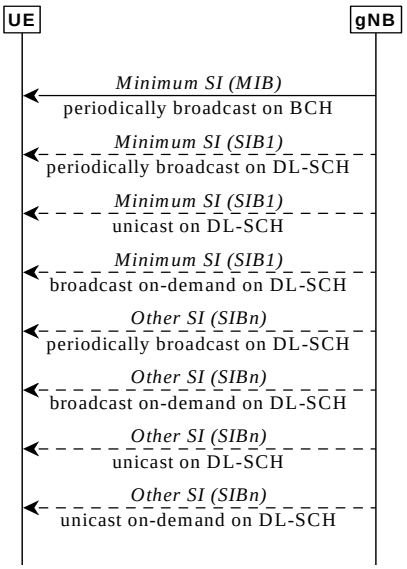


Figure 7.3.1-1: System Information Provisioning

For a cell/frequency that is considered for camping by the UE, the UE is not required to acquire the contents of the minimum SI of that cell/frequency from another cell/frequency layer. This does not preclude the case that the UE applies stored SI from previously visited cell(s).

If the UE cannot determine the full contents of the minimum SI of a cell by receiving from that cell, the UE shall consider that cell as barred.

In case of BA, the UE only acquires SI on the active BWP.

If the UE is configured with inter cell beam management:

- the UE is not required to acquire the SI from the serving cell while it is receiving DL-SCH from a TRP with PCI different from serving cell's PCI.

7.3.2 Scheduling

The MIB is mapped on the BCCH and carried on BCH while all other SI messages are mapped on the BCCH, where they are dynamically carried on DL-SCH. The scheduling of SI messages part of Other SI is indicated by *SIB1*.

For UEs in RRC_IDLE and RRC_INACTIVE while SDT procedure is not ongoing (see clause 18), a request for Other SI triggers a random access procedure (see clause 9.2.6) where MSG3 includes the SI request message unless the requested SI is associated to a subset of the PRACH resources, in which case MSG1 is used for indication of the requested Other SI. When MSG1 is used, the minimum granularity of the request is one SI message (i.e. a set of SIBs), one RACH preamble and/or PRACH resource can be used to request multiple SI messages and the gNB acknowledges the request in MSG2. When MSG 3 is used, the gNB acknowledges the request in MSG4. For UEs in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED when T311 is running, a request for OD-SIB1 triggers a random access procedure, in which case MSG1 is used for indicating OD-SIB1 request and the gNB acknowledges the request in MSG2.

For UEs in RRC_CONNECTED, a request for Other SI may be sent to the network, if configured by the network, in a dedicated manner (i.e., via UL-DCCH) and the granularity of the request is one SIB. The gNB may respond with an *RRCReconfiguration* including the requested SIB(s). It is a network choice to decide which requested SIBs are delivered in a dedicated or broadcasted manner.

The Other SI may be broadcast at a configurable periodicity and for a certain duration. The Other SI may also be broadcast when it is requested by UE in RRC_IDLE/RRC_INACTIVE/RRC_CONNECTED.

For a UE to be allowed to camp on a cell it must have acquired the contents of the Minimum SI from that cell. There may be cells in the system that do not broadcast the Minimum SI and where the UE therefore cannot camp.

7.3.3 SI Modification

Change of system information (other than for ETWS/CMAS, see clause 16.4) only occurs at specific radio frames, i.e. the concept of a modification period is used. System information may be transmitted a number of times with the same content within a modification period, as defined by its scheduling. The modification period is configured by system information.

When the network changes (some of the) system information, it first notifies the UEs about this change, i.e. this may be done throughout a modification period. In the next modification period, the network transmits the updated system information. Upon receiving a change notification, the UE acquires the new system information from the start of the next modification period. The UE applies the previously acquired system information until the UE acquires the new system information.

7.4 Access Control

NG-RAN supports overload and access control functionality such as RACH back off, RRC Connection Reject, RRC Connection Release and UE based access barring mechanisms.

One unified access control framework as specified in TS 22.261 [19] applies to all UE states (RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED) for NR. NG-RAN broadcasts barring control information associated with Access Categories and Access Identities (in case of network sharing, the barring control information can be set individually for each PLMN). The UE determines whether an access attempt is authorized based on the barring information broadcast for the selected PLMN, and the selected Access Category and Access Identity(ies) for the access attempt:

- For NAS triggered requests, NAS determines the Access Category and Access Identity(ies);
- For AS triggered requests, RRC determines the Access Category while NAS determines the Access Identity(ies).

The gNB handles access attempts with establishment or resume causes "emergency", "mps-PriorityAccess" and "mcs-PriorityAccess" (i.e. Emergency calls, MPS, MCS subscribers) with high priority and responds with RRC Reject to these access attempts only in extreme network load conditions that may threaten the gNB stability.

Unified access control does not apply to IAB-MTs or NCR-MTs.

7.5 UE Capability Retrieval framework

The UE reports its UE radio access capabilities which are static at least when the network requests. The gNB can request what capabilities for the UE to report based on band information. The UE capability can be represented by a capability ID, which may be exchanged in NAS signalling over the air and in network signalling instead of the UE capability structure.

In IAB, it is optional for an IAB-MT to support UE capability Retrieval framework and the related signalling. In case IAB-MT does not support UE capability Retrieval framework, IAB-MT capabilities are assumed to be known to the network by other means, e.g. OAM.

7.6 Transport of NAS Messages

NR provides reliable in-sequence delivery of NAS messages over SRBs in RRC, except at handover where losses or duplication can occur when PDCP is re-established. In RRC, NAS messages are sent in transparent containers. Piggybacking of NAS messages can occur in the following scenarios:

- At bearer establishment/modification/release in the DL;
- For transferring the initial NAS message during connection setup and connection resume in the UL.

NOTE: In addition to the integrity protection and ciphering performed by NAS, NAS messages can also be integrity protected and ciphered by PDCP.

Multiple NAS messages can be sent in a single downlink RRC message during PDU Session Resource establishment or modification. In this case, the order of the NAS messages contained in the RRC message shall be in the same order as that in the corresponding NG-AP message in order to ensure the in-sequence delivery of NAS messages.

NG-RAN node may trigger the NAS Non Delivery Indication procedure to report the non-delivery of the non PDU Session related NAS PDU received from the AMF as specified in TS 38.413 [26].

7.7 Carrier Aggregation

When CA is configured, the UE only has one RRC connection with the network. At RRC connection establishment/re-establishment/handover, one serving cell provides the NAS mobility information, and at RRC connection re-establishment/handover, one serving cell provides the security input. This cell is referred to as the Primary Cell (PCell). Depending on UE capabilities, Secondary Cells (SCells) can be configured to form together with the PCell a set of serving cells. The configured set of serving cells for a UE in a cell group always consists of one SpCell and one or more SCells.

The reconfiguration, addition and removal of SCells can be performed by RRC. At intra-NR handover and during connection resume from RRC_INACTIVE, the network can also add, remove, keep, or reconfigure SCells for usage with the target PCell. When adding a new SCell, dedicated RRC signalling is used for sending all required system information of the SCell i.e. while in connected mode, UEs need not acquire broadcast system information directly from the SCells.

7.8 Bandwidth Adaptation

To enable BA on the SpCell, the gNB configures the UE with UL and DL BWP(s). To enable BA on SCells in case of CA, the gNB configures the UE with DL BWP(s) at least (i.e. there may be none in the UL). For the PCell, the BWP used for initial access is configured via system information. For the SCell(s), the BWP used after initial activation is configured via dedicated RRC signalling.

In paired spectrum, DL and UL can switch BWP independently. In unpaired spectrum, DL and UL switch BWP simultaneously. Switching between configured BWPs happens by means of RRC signalling, DCI, inactivity timer or upon initiation of random access. When an inactivity timer is configured for a serving cell, the expiry of the inactivity timer associated to that cell switches the active BWP to a default BWP configured by the network. There can be at most one active BWP per cell, except when the serving cell is configured with SUL, in which case there can be at most one on each UL carrier.

7.9 UE Assistance Information

When configured to do so, the UE can signal the network through *UEAssistanceInformation*:

- If it prefers an adjustment in the connected mode DRX cycle length, for the purpose of delay budget reporting;
- If it is experiencing internal overheating;
- If it prefers certain DRX parameter values, and/or a reduced maximum number of secondary component carriers, and/or a reduced maximum aggregated bandwidth and/or a reduced maximum number of MIMO layers and/or minimum scheduling offsets K0 and K2 for power saving purpose;
- If it expects not to send or receive any more data in the near future, and in this case, it can provide its preference to transition out of RRC_CONNECTED where this indication may express its preferred RRC state, or alternately, it may cancel an earlier indicated preference to transition out of RRC_CONNECTED;
- If it prefers (not) to be provisioned with reference time information;
- If it prefers to transition out of RRC_CONNECTED state for MUSIM operation and its preferred RRC state after transition;
- If it wants to include assistance information for setup or release of MUSIM gaps, and/or for setup the priority of periodic MUSIM gaps, and/or for keeping the colliding MUSIM gaps;
- If it prefers to restrict UE capability temporarily or remove the restriction for MUSIM operation;
- When affected by IDC problems that it cannot solve by itself:
  - The list of frequencies affected by IDC problems (see clause 23.4 of TS 36.300 [2]);
  - The list of frequency ranges/frequency range combinations affected by the IDC problems;
  - DRX based TDM assistance information (see clause 23.4.2 of TS 36.300 [2]);
- Its RRM measurement relaxation status indicating whether RRM measurement relaxation criteria are met or not;
- Its RLM measurement relaxation status indicating whether the UE is applying RLM measurements relaxation;
- Its BFD measurement relaxation status indicating whether the UE is applying BFD measurements relaxation;
- If it prefers not operating on multi-Rx (i.e. not supporting simultaneous reception with different QCL-typeD) for FR2;
- If it is in low power state while performing data logging for Network-side data collection;
- If its AS layer memory to log data for Network -side data collection becomes full;
- If its AS layer memory to log data for Network-side data collection reaches a threshold configured by the network;
- If it prefers to start, or stop UE-side data collection for UE-side model;
- Its preference for UE-side data collection configuration(s) from a list of candidate configurations provided by the network for the training of UE-side model(s);
- Its AI/ML functionality applicability status;
- If it prefers to be configured with a specific time offset for LP-WUS monitoring in RRC_CONNECTED;
- Its preference for gap occasion cancellation ratio.

NOTE: The requirements on RRM/RLM/CSI measurements in different phases of IDC interference defined in TS 36.300 [2] are applicable except that for NR serving cell, the requirements in TS 38.133 [13] and TS 38.101-1 [18], TS 38.101-2 [35], TS 38.101-3 [36] apply.

In the second case, the UE can express a preference for temporarily reducing the number of maximum secondary component carriers, the maximum aggregated bandwidth and the number of maximum MIMO layers. In all cases, it is up to the gNB whether to accommodate the request.

For sidelink, the UE can report SL traffic pattern(s) to NG-RAN, for periodic traffic.

7.10 Segmentation of RRC messages

An RRC message may be segmented in case the size of the encoded RRC message PDU exceeds the maximum PDCP SDU size. Segmentation is performed in the RRC layer using a separate RRC PDU to carry each segment. The receiver reassembles the segments to form the complete RRC message. All segments of an RRC message are transmitted before sending another RRC message. Segmentation is supported in both uplink and downlink as specified in TS 38.331 [12].

8 NG Identities

8.1 UE Identities

In this clause, the identities used by NR connected to 5GC are listed. For scheduling at cell level, the following identities are used:

- C-RNTI: unique UE identification used as an identifier of the RRC Connection and for scheduling;
- CG-SDT-CS-RNTI: unique UE identification used for Configured Grant-based SDT in the uplink;
- CI-RNTI: identification of cancellation in the uplink;
- CS-RNTI: unique UE identification used for Semi-Persistent Scheduling in the downlink or configured grant in the uplink;
- INT-RNTI: identification of pre-emption in the downlink;
- MCS-C-RNTI: unique UE identification used for indicating an alternative MCS table for PDSCH and PUSCH;
- P-RNTI: identification of Paging and System Information change notification in the downlink;
- SI-RNTI: identification of Broadcast and System Information in the downlink;
- SP-CSI-RNTI: unique UE identification used for semi-persistent CSI reporting on PUSCH.

For power and slot format control, the following identities are used:

- SFI-RNTI: identification of slot format;
- TPC-PUCCH-RNTI: unique UE identification to control the power of PUCCH;
- TPC-PUSCH-RNTI: unique UE identification to control the power of PUSCH;
- TPC-SRS-RNTI: unique UE identification to control the power of SRS.

During the random access procedure, the following identities are also used:

- RA-RNTI: identification of the Random Access Response in the downlink;
- MSGB-RNTI: identification of the Random Access Response for 2-step RA type in the downlink;
- Temporary C-RNTI: UE identification temporarily used for scheduling during the random access procedure;
- Random value for contention resolution: UE identification temporarily used for contention resolution purposes during the random access procedure.

For NR connected to 5GC, the following UE identity is used at NG-RAN level:

- I-RNTI: used to identify the UE context in RRC_INACTIVE.

For UE power saving purpose, the following identities are used:

- PS-RNTI: used to determine if the UE needs to monitor PDCCH on the next occurrence of the connected mode DRX on-duration;

- PEI-RNTI: used to determine if the UE needs to monitor the associated PO.

For IAB the following identity is used:

- AI-RNTI: identification of the DCI carrying availability indication for soft symbols of an IAB-DU.

For Network-Controlled Repeater the following identity is used:

- NCR-RNTI: identification of the DCI carrying side control information.

For MBS, the following identities are used:

- G-RNTI: Identifies dynamically scheduled PTM transmissions of MTCH(s);

- G-CS-RNTI: Identifies configured scheduled PTM transmissions of MTCH(s) scheduled with configured grant;

- MCCH-RNTI: Identifies transmissions of MCCH and MCCH change notification for broadcast reception.

- Multicast MCCH-RNTI: Identifies transmissions of MCCH and MCCH change notification for multicast reception in RRC_INACTIVE state.

For sidelink, the following identities are used:

- SL-RNTI: unique UE identification used for NR sidelink communication scheduling;

- SL-CS-RNTI: unique UE identification used for configured sidelink grant for NR sidelink communication;

- SL Semi-Persistent Scheduling V-RNTI: unique UE identification used for semi-persistent scheduling for V2X sidelink communication;

- SL-PRS-RNTI: unique UE identification used for SL-PRS transmission scheduling on dedicated SL-PRS resource pool;

- SL-PRS-CS-RNTI: unique UE identification used for configured sidelink grant for SL-PRS transmission on dedicated SL-PRS resource pool.

For network energy saving purpose, the following identity is used:

- cellDTRX-RNTI: identification used for network energy saving indication.

8.2 Network Identities

The following identities are used in NG-RAN for identifying a specific network entity:

- AMF Name: used to identify an AMF.

- NR Cell Global Identifier (NCGI): used to identify NR cells globally. The NCGI is constructed from the PLMN identity the cell belongs to and the NR Cell Identity (NCI) of the cell. The PLMN ID included in the NCGI should be the first PLMN ID within the set of PLMN IDs associated to the NR Cell Identity in SIB1, following the order of broadcast.

NOTE 1: How to manage the scenario where a different PLMN ID has been allocated by the operator for an NCGI is left to OAM and/or implementation.

- gNB Identifier (gNB ID): used to identify gNBs within a PLMN. The gNB ID is contained within the NCI of its cells.

- Global gNB ID: used to identify gNBs globally. The Global gNB ID is constructed from the PLMN identity the gNB belongs to and the gNB ID. The MCC and MNC are the same as included in the NCGI.

NOTE 2: It is not precluded that a cell served by a gNB does not broadcast the PLMN ID included in the Global gNB ID.

- Tracking Area identity (TAI): used to identify tracking areas. The TAI is constructed from the PLMN identity the tracking area belongs to and the TAC (Tracking Area Code) of the Tracking Area.

- Single Network Slice Selection Assistance information (S-NSSAI): identifies a network slice.

- Network Slice AS Group (NSAG): identifies an association to a slice or a set of slices. An NSAG is defined within a TA, used for slice-based cell reselection and/or slice-based RACH configuration. Values of NSAG IDs associated with different slice or set of slices shall be unique within a TA, also when slice-based cell reselection and slice-based RACH configuration are both supported in the TA.

- Network Identifier (NID): identifies an SNPN in combination with a PLMN ID.

- Closed Access Group Identifier: identifies a CAG within a PLMN.

- Local NG-RAN Node Identifier: used as reference to the NG-RAN node in the I-RNTI.

8.3 User Data Transport on the CN-RAN Interface

The core network may provide two transport layer addresses of different versions to enable that a NG-RAN node can select either IPv4 or IPv6.

8.4 NR sidelink communication, V2X sidelink communication and Ranging/Sidelink positioning related identities

The following identities are used for NR sidelink communication and SL-PRS transmission on shared SL-PRS resource pool:

- Source Layer-2 ID: Identifies the sender of the data in NR sidelink communication and/or SL-PRS transmission. The Source Layer-2 ID is 24 bits long and is split in the MAC layer into two bit strings:

  - One bit string is the LSB part (8 bits) of Source Layer-2 ID and forwarded to physical layer of the sender. This identifies the source of the intended data and/or SL-PRS in sidelink control information and is used for filtering of packets at the physical layer of the receiver;

  - Second bit string is the MSB part (16 bits) of the Source Layer-2 ID and is carried within the MAC header. This is used for filtering of packets at the MAC layer of the receiver.

- Destination Layer-2 ID: Identifies the target of the data in NR sidelink communication and/or SL-PRS transmission. For NR sidelink communication and SL-PRS transmission on shared SL-PRS resource pool, the Destination Layer-2 ID is 24 bits long and is split in the MAC layer into two bit strings:

  - One bit string is the LSB part (16 bits) of Destination Layer-2 ID and forwarded to physical layer of the sender. This identifies the target of the intended data and/or SL-PRS in sidelink control information and is used for filtering of packets at the physical layer of the receiver;

  - Second bit string is the MSB part (8 bits) of the Destination Layer-2 ID and is carried within the MAC header. This is used for filtering of packets at the MAC layer of the receiver.

- PC5 Link Identifier: Uniquely identifies the PC5 unicast link in a UE for the lifetime of the PC5 unicast link as specified in TS 23.287 [40]. The PC5 Link Identifier is used to indicate to upper layers the PC5 unicast link in which sidelink RLF was declared and corresponding PC5-RRC connection was released.

V2X sidelink communication related identities are specified in clause 8.3 of TS 36.300 [2].

The following identities are used for SL-PRS transmission on dedicated SL-PRS resource pool:

- Source ID: Identifies the sender of the SL-PRS transmission. The length of the identifier is either 12 or 24 bits, which is indicated in the RRC configuration. The source ID identifies the source of the intended SL-PRS in sidelink control information and is used for filtering at the MAC layer of the receiver;

- Destination ID: Identifies the target of the SL-PRS transmission. The length of the identifier is 24 bits. The Destination ID identifies the target of the intended SL-PRS in sidelink control information and is used for filtering at the MAC layer of the receiver.

9 Mobility and State Transitions

9.1 Overview

Load balancing is achieved in NR with handover, redirection mechanisms upon RRC release and through the usage of inter-frequency and inter-RAT absolute priorities and inter-frequency Qoffset parameters.

Measurements to be performed by a UE for connected mode mobility are classified in at least four measurement types:

- Intra-frequency NR measurements;
- Inter-frequency NR measurements;
- Inter-RAT measurements for E-UTRA;
- Inter-RAT measurements for UTRA.

For each measurement type one or several measurement objects can be defined (a measurement object defines e.g. the carrier frequency to be monitored).

For each measurement object one or several reporting configurations can be defined (a reporting configuration defines the reporting criteria). Three reporting criteria are used: event triggered reporting, periodic reporting and event triggered periodic reporting.

The association between a measurement object and a reporting configuration is created by a measurement identity (a measurement identity links together one measurement object and one reporting configuration of the same RAT). By using several measurement identities (one for each measurement object, reporting configuration pair) it is then possible to:

- Associate several reporting configurations to one measurement object and;
- Associate one reporting configuration to several measurement objects.

The measurements identity is used as well when reporting results of the measurements.

Measurement quantities are considered separately for each RAT.

Measurement commands are used by NG-RAN to order the UE to start, modify or stop measurements.

Handover can be performed within the same RAT and/or CN, or it can involve a change of the RAT and/or CN.

Inter system fallback towards E-UTRAN is performed when 5GC does not support emergency services, voice services, for load balancing etc. Depending on factors such as CN interface availability, network configuration and radio conditions, the fallback procedure results in either RRC_CONNECTED state mobility (handover procedure) or RRC_IDLE state mobility (redirection), see TS 23.501 [3] and TS 38.331 [12].

SRVCC from 5G to UTRAN, if supported by both the UE and the network, may be performed to handover a UE with an ongoing voice call from NR to UTRAN. The overall procedure is described in TS 23.216 [34]. See also TS 38.331 [12] and TS 38.413 [26].

In the NG-C signalling procedure, the AMF based on support for emergency services, voice service, any other services or for load balancing etc, may indicate the target CN type as EPC or 5GC to the gNB node. When the target CN type is received by gNB, the target CN type is also conveyed to the UE in *RRCRelease* Message.

Inter-gNB CSI-RS based mobility, i.e. handover, is supported between two neighbour gNBs by enabling that neighbour gNBs can exchange and forward their own CSI-RS configurations and on/off status.

9.2 Intra-NR

9.2.1 Mobility in RRC_IDLE

9.2.1.1 Cell Selection

The principles of PLMN selection in NR are based on the 3GPP PLMN selection principles. Cell selection is required on transition from RM-DEREGISTERED to RM-REGISTERED, from CM-IDLE to CM-CONNECTED and from CM-CONNECTED to CM-IDLE and is based on the following principles:

- The UE NAS layer identifies a selected PLMN and equivalent PLMNs;
- Cell selection is always based on CD-SSBs located on the synchronization raster (see clause 5.2.4):
  - The UE searches the NR frequency bands and for each carrier frequency identifies the strongest cell as per the CD-SSB. It then reads cell system information broadcast to identify its PLMN(s):
    - The UE may search each carrier in turn ("initial cell selection") or make use of stored information to shorten the search ("stored information cell selection").
- The UE seeks to identify a suitable cell; if it is not able to identify a suitable cell it seeks to identify an acceptable cell. When a suitable cell is found or if only an acceptable cell is found it camps on that cell and commence the cell reselection procedure:
  - A suitable cell is one for which the measured cell attributes satisfy the cell selection criteria; the cell PLMN is the selected PLMN, registered or an equivalent PLMN; the cell is not barred or reserved, the cell is not part of a tracking area which is in the list of "forbidden tracking areas for roaming", and the access technology (as defined in TS 23.122 [47]) of the cell is not marked as restricted by the UE NAS layer;
  - An acceptable cell is one for which the measured cell attributes satisfy the cell selection criteria and the cell is not barred.
- The IAB-MT and NCR-MT apply the cell selection procedure as described for the UE with the following differences:
  - The IAB-MT and NCR-MT ignore cell-barring or cell-reservation indications contained in cell system information broadcast;
  - The IAB-MT only considers a cell as a candidate for cell selection if the cell system information broadcast indicates IAB support for the selected PLMN or the selected SNPN, and the NCR-MT only considers a cell as a candidate for cell selection if the cell system information broadcast indicates Network-Controlled Repeater support.
- The mobile IAB-MT applies the cell selection procedure as described for the IAB-MT with the following differences:
  - The mobile IAB-MT only considers a cell as a candidate cell for cell selection if the cell system information broadcast indicates mobile IAB support.

Transition to RRC_IDLE:

On transition from RRC_CONNECTED or RRC_INACTIVE to RRC_IDLE, a UE should camp on a cell as result of cell selection according to the frequency be assigned by RRC in the state transition message if any.

Recovery from out of coverage:

The UE should attempt to find a suitable cell in the manner described for stored information or initial cell selection above. If no suitable cell is found on any frequency or RAT, the UE should attempt to find an acceptable cell.

In multi-beam operations, the cell quality is derived amongst the beams corresponding to the same cell (see clause 9.2.4).

9.2.1.2 Cell Reselection

A UE in RRC_IDLE performs cell reselection. The principles of the procedure are the following:

- Cell reselection is always based on CD-SSBs located on the synchronization raster (see clause 5.2.4).
- The UE makes measurements of attributes of the serving and neighbour cells to enable the reselection process:
  - For the search and measurement of inter-frequency neighbouring cells, only the carrier frequencies need to be indicated.
- Cell reselection identifies the cell that the UE should camp on. It is based on cell reselection criteria which involves measurements of the serving and neighbour cells:
  - Intra-frequency reselection is based on ranking of cells;
  - Inter-frequency reselection is based on absolute priorities where a UE tries to camp on the highest priority frequency available;
  - A Neighbour Cell List (NCL) can be provided by the serving cell to handle specific cases for intra- and inter-frequency neighbouring cells;
  - Exclude-lists can be provided to prevent the UE from reselecting to specific intra- and inter-frequency neighbouring cells;
  - Allow-lists can be provided to request the UE to reselect to only specific intra- and inter-frequency neighbouring cells;
  - Cell reselection can be speed dependent;
  - Service specific prioritisation;
  - Cell-type-specific prioritisation, e.g., HSDN cell and mobile IAB cell;
  - Slice-based cell reselection information can be provided to facilitate the UE to reselect a cell that supports specific slices.

In multi-beam operations, the cell quality is derived amongst the beams corresponding to the same cell (see clause 9.2.4).

9.2.1.3 State Transitions

The following figure describes the UE triggered transition from RRC_IDLE to RRC_CONNECTED (for the NAS part, see TS 23.502 [22]):

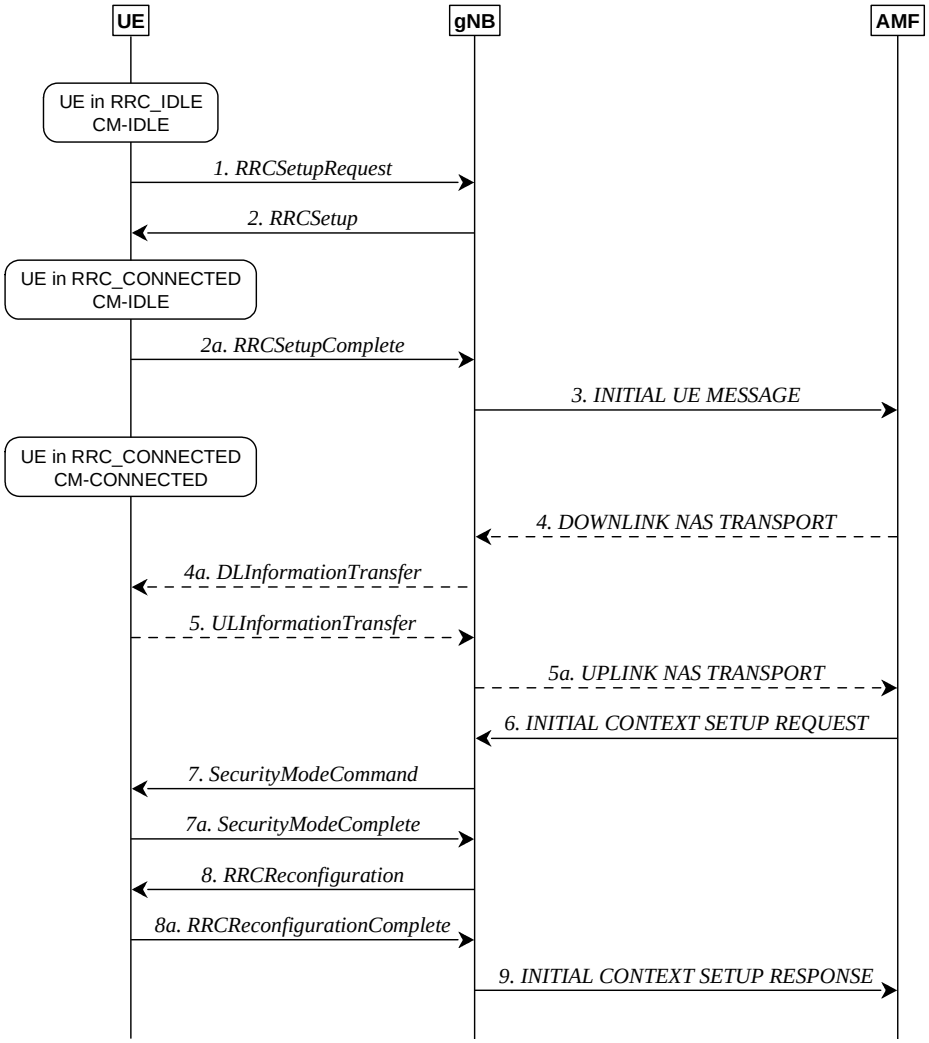


Figure 9.2.1.3-1: UE triggered transition from RRC_IDLE to RRC_CONNECTED

1. The UE requests to setup a new connection from RRC_IDLE.

2/2a. The gNB completes the RRC setup procedure.

NOTE 0: The scenario where the gNB rejects the request is described below.

3. The first NAS message from the UE, piggybacked in *RRCSetupComplete*, is sent to AMF.

4/4a/5/5a. Additional NAS messages may be exchanged between UE and AMF, see TS 23.502 [22].

6. The AMF prepares the UE context data (including PDU session context, the Security Key, UE Radio Capability and UE Security Capabilities, etc.) and sends it to the gNB.

7/7a. The gNB activates the AS security with the UE.

8/8a. The gNB performs the reconfiguration to setup SRB2 and DRBs for UE, or SRB2 and optionally DRBs for IAB-MT.

9. The gNB informs the AMF that the setup procedure is completed.

NOTE 1: RRC messages in step 1 and 2 use SRB0, all the subsequent messages use SRB1. Messages in steps 7/7a are integrity protected. From step 8 on, all the messages are integrity protected and ciphered.

NOTE 2: For signalling only connection, step 8 is skipped since SRB2 and DRBs are not setup.

The following figure describes the rejection from the network when the UE attempts to setup a connection from RRC_IDLE:

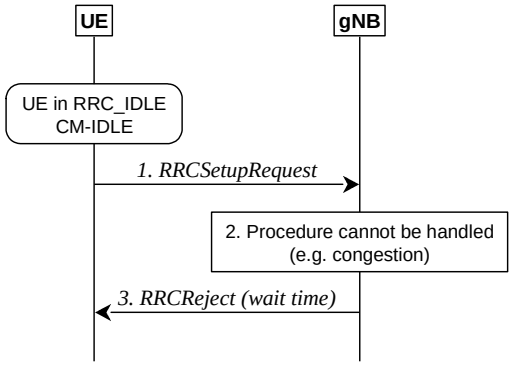


Figure 9.2.1.3-2: Rejection of UE triggered transition from RRC_IDLE

1. UE attempts to setup a new connection from RRC_IDLE.
2. The gNB is not able to handle the procedure, for instance due to congestion.
3. The gNB sends *RRCReject* (with a wait time) to keep the UE in RRC_IDLE.

9.2.2 Mobility in RRC_INACTIVE

9.2.2.1 Overview

RRC_INACTIVE is a state where a UE remains in CM-CONNECTED and can move within an area configured by NG-RAN (the RNA) without notifying NG-RAN. In RRC_INACTIVE, the last serving gNB node keeps the UE context and the UE-associated NG connection with the serving AMF and UPF.

For a UE in RRC_INACTIVE with eDRX cycle longer than 10.24 seconds, the NG-RAN node may, based on implementation, send a request to the AMF to perform MT Communication Handling as described in TS 23.501 [3]. If the UE accesses a gNB other than the last serving gNB and upon successful UE context retrieval, the AMF considers that the UE is reachable (i.e., the MT Communicating Handling is deactivated) and triggers the MT DL data/signalling delivery upon receiving the NGAP Path Switch Request message.

If the last serving gNB receives DL data from the UPF or DL UE-associated signalling from the AMF (except the UE Context Release Command message) while the UE is in RRC_INACTIVE, it pages in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s).

Upon receiving the RAN Paging Request message from the AMF while the UE is in RRC_INACTIVE with eDRX beyond 10.24 seconds, the last serving gNB may page in its cells comprised in the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s), in order to trigger the UE to resume connection in RRC_CONNECTED state, or in RRC_INACTIVE state for DL SDT, based on the DL data size if included in the NGAP RAN Paging Request message.

Upon receiving the UE Context Release Command message while the UE is in RRC_INACTIVE, the last serving gNB may page in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s), in order to release UE explicitly.

Upon receiving the NG RESET message while the UE is in RRC_INACTIVE, the last serving gNB may page involved UEs in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s) in order to explicitly release involved UEs.

Upon RAN paging failure, the gNB behaves according to TS 23.501 [3].

The AMF provides to the NG-RAN node the Core Network Assistance Information to assist the NG-RAN node's decision whether the UE can be sent to RRC_INACTIVE, and to assist UE configuration and paging in RRC_INACTIVE. The Core Network Assistance Information includes:

- The UE registration area, which is taken into account by the NG-RAN node when configuring the RNA.
- The UE specific DRX and UE Identity Index value, which are used by the NG-RAN node for RAN paging.

- The Periodic Registration Update timer, which is taken into account by the NG-RAN node to configure Periodic RNA Update timer.
- An indication if the UE is configured with Mobile Initiated Connection Only (MICO) mode by the AMF.
- The Expected UE Behaviour, which is taken into account by the NG-RAN node to assist the UE RRC state transition decision.
- The UE Radio Capability for Paging, which may be used by the NG-RAN node during RAN Paging.
- The PEI with Paging Subgrouping assistance information, which may be taken into account by the NG-RAN node for subgroup paging in RRC_INACTIVE, except when the UE context contains an emergency PDU session in which case the PEI with Paging Subgrouping assistance information shall not be used according to TS 24.501 [28].
- The LP-WUS with Paging Subgrouping assistance information, which is taken into account by the NG-RAN node for subgroup paging in RRC_INACTIVE.
- The LP-WUS disable indication, which is taken into account by the NG-RAN node to disable LP-WUS to UE, including both CN based subgrouping and UE ID based subgrouping.
- The Further Extended UE Identity Index value, if LP-WUS is not disabled, which is taken into account by the NG-RAN node for LP-WUS subgroup paging in RRC_INACTIVE.
- The NR Paging eDRX Information, which is taken into account by the NG-RAN node to configure the RAN Paging when the NR UE is in RRC_INACTIVE.
- The Paging Cause Indication for Voice Service, which is taken into account by the NG-RAN node to include the Paging Cause in RAN Paging for a UE in RRC_INACTIVE state.
- The Hashed UE Identity Index Value, which is used by the NG-RAN node to determine the start point of PTW.
- The CN support indication for MT Communication Handling, which is taken into account by the NG-RAN node when deciding to request the AMF for MT Communication Handling for a UE in RRC_INACTIVE state with long eDRX beyond 10.24 seconds as described in TS 23.501 [3].

When sending the XnAP RAN Paging to neighbour NG-RAN node(s), the PEI with Paging Subgrouping assistance information, the LP-WUS with Paging Subgrouping assistance information, the LP-WUS disable indication, the NR Paging eDRX Information for RRC_IDLE and for RRC_INACTIVE, the Paging Cause, the Hashed UE Identity Index Value and the Further Extended UE Identity Index Value may be included.

At transition to RRC_INACTIVE the NG-RAN node may configure the UE with a periodic RNA Update timer value. At periodic RNA Update timer expiry without notification from the UE, the gNB behaves as specified in TS 23.501 [3].

If the UE accesses a gNB other than the last serving gNB, the receiving gNB triggers the XnAP Retrieve UE Context procedure to get the UE context from the last serving gNB and may also trigger an Xn-U Address Indication procedure including tunnel information for potential recovery of data from the last serving gNB. Upon successful UE context retrieval, the receiving gNB shall perform the slice-aware admission control in case of receiving slice information and becomes the serving gNB and it further triggers the NGAP Path Switch Request and applicable RRC procedures. After the path switch procedure, the serving gNB triggers release of the UE context at the last serving gNB by means of the XnAP UE Context Release procedure.

In case the UE is not reachable at the last serving gNB, the gNB shall fail any AMF initiated UE-associated class 1 procedure which allows the signalling of unsuccessful operation in the respective response message. It may trigger the NAS Non Delivery Indication procedure to report the non-delivery of any non PDU Session related NAS PDU received from the AMF as specified in TS 38.413 [26].

If the UE accesses a gNB other than the last serving gNB and the receiving gNB does not find a valid UE Context, the receiving gNB can perform establishment of a new RRC connection instead of resumption of the previous RRC connection. UE context retrieval will also fail and hence a new RRC connection needs to be established if the serving AMF changes.

A UE in the RRC_INACTIVE state is required to initiate RNA update procedure when it moves out of the configured RNA. When receiving RNA update request from the UE, the receiving gNB triggers the XnAP Retrieve UE Context procedure to get the UE context from the last serving gNB and may decide to send the UE back to RRC_INACTIVE

state, move the UE into RRC_CONNECTED state, or send the UE to RRC_IDLE. In case of periodic RNA update, if the last serving gNB decides not to relocate the UE context, it fails the Retrieve UE Context procedure and sends the UE back to RRC_INACTIVE, or to RRC_IDLE directly by an encapsulated *RRCRelease* message.

9.2.2.2 Cell Reselection

A UE in RRC_INACTIVE performs cell reselection. The principles of the procedure are as for the RRC_IDLE state (see clause 9.2.1.2).

9.2.2.3 RAN-Based Notification Area

A UE in the RRC_INACTIVE state can be configured by the last serving NG-RAN node with an RNA, where:

- the RNA can cover a single or multiple cells, and shall be contained within the CN registration area; in this release Xn connectivity should be available within the RNA;
- a RAN-based notification area update (RNAU) is periodically sent by the UE and is also sent when the cell reselection procedure of the UE selects a cell that does not belong to the configured RNA.

There are several different alternatives on how the RNA can be configured:

- List of cells:
  - A UE is provided an explicit list of cells (one or more) that constitute the RNA.
- List of RAN areas:
  - A UE is provided (at least one) RAN area ID, where a RAN area is a subset of a CN Tracking Area or equal to a CN Tracking Area. A RAN area is specified by one RAN area ID, which consists of a TAC and optionally a RAN area Code;
  - A cell broadcasts one or, in case of network sharing with multiple cell ID broadcast, more RAN area IDs in the system information.

NG-RAN may provide different RNA definitions to different UEs but not mix different definitions to the same UE at the same time. UE shall support all RNA configuration options listed above.

9.2.2.4 State Transitions

9.2.2.4.1 UE triggered transition from RRC_INACTIVE to RRC_CONNECTED

The following figure describes the UE triggered transition from RRC_INACTIVE to RRC_CONNECTED in case of UE context retrieval success:

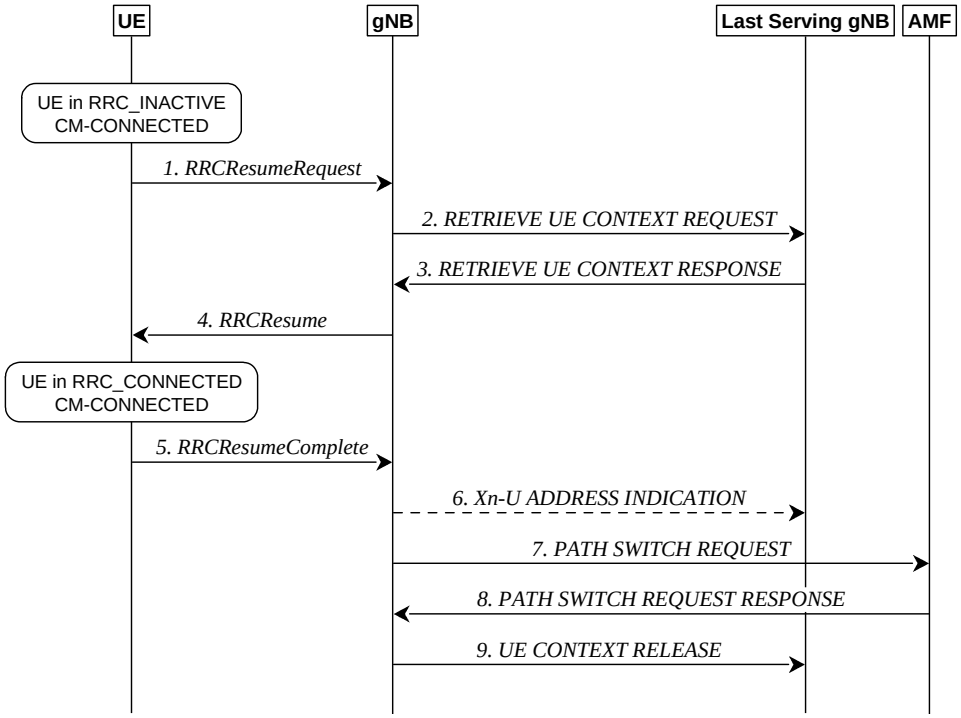


Figure 9.2.2.4.1-1: UE triggered transition from RRC_INACTIVE to RRC_CONNECTED (UE context retrieval success)

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI, allocated by the last serving gNB.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.
3. The last serving gNB provides UE context data.

4/5. The gNB and UE completes the resumption of the RRC connection.

NOTE 1: User Data can also be sent in step 5 if the grant allows.

6. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

7/8. The gNB performs path switch.

9. The gNB triggers the release of the UE resources at the last serving gNB.

After step 1 above, when the gNB decides to use a single RRC message to reject the Resume Request right away and keep the UE in RRC_INACTIVE without any reconfiguration (e.g. as described in the two examples below), or when the gNB decides to setup a new RRC connection, SRB0 (without security) is used. Conversely, when the gNB decides to reconfigure the UE (e.g. with a new DRX cycle or RNA) or when the gNB decides to push the UE to RRC_IDLE, SRB1 (with integrity protection and ciphering as previously configured for that SRB) shall be used.

NOTE 2: SRB1 can only be used once the UE Context is retrieved i.e. after step 3.

The following figure describes the UE triggered transition from RRC_INACTIVE to RRC_CONNECTED in case of UE context retrieval failure:

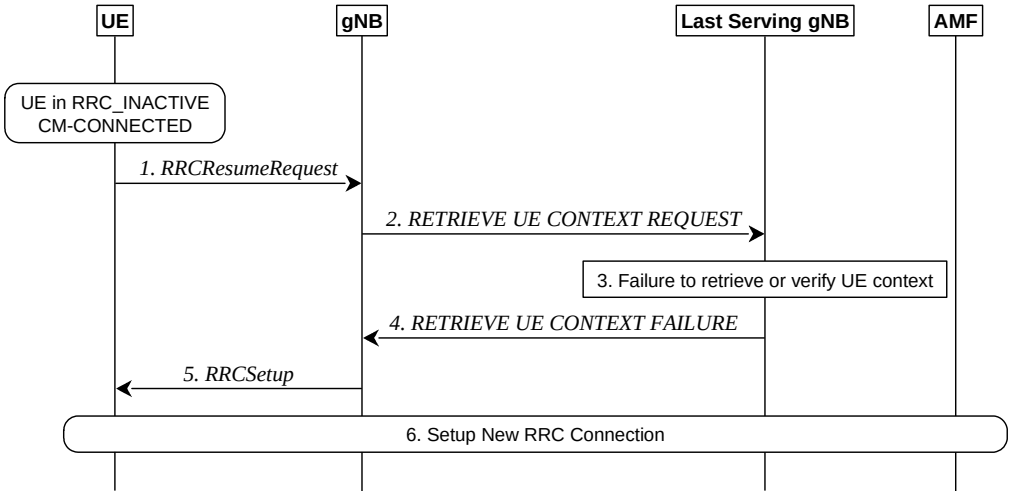


Figure 9.2.2.4.1-2: UE triggered transition from RRC_INACTIVE to RRC_CONNECTED (UE context retrieval failure)

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI, allocated by the last serving gNB.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.
3. The last serving gNB cannot retrieve or verify the UE context data.
4. The last serving gNB indicates the failure to the gNB.
5. The gNB performs a fallback to establish a new RRC connection by sending *RRCSetup*.
6. A new connection is setup as described in clause 9.2.1.3.

The following figure describes the rejection form the network when the UE attempts to resume a connection from RRC_INACTIVE:

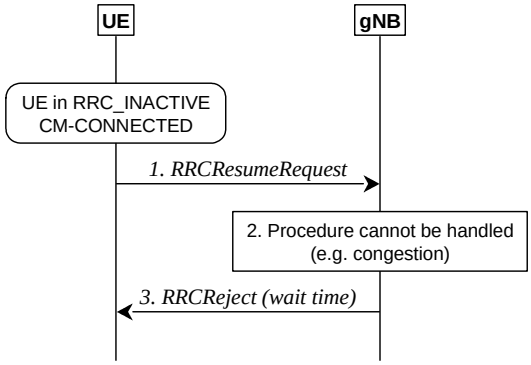


Figure 9.2.2.4.1-3: Reject from the network, UE attempts to resume a connection

1. UE attempts to resume the connection from RRC_INACTIVE.
2. The gNB is not able to handle the procedure, for instance due to congestion.
3. The gNB sends *RRCReject* (with a wait time) to keep the UE in RRC_INACTIVE.

9.2.2.4.2 Network triggered transition from RRC_INACTIVE to RRC_CONNECTED

The following figure describes the network triggered transition from RRC_INACTIVE to RRC_CONNECTED:

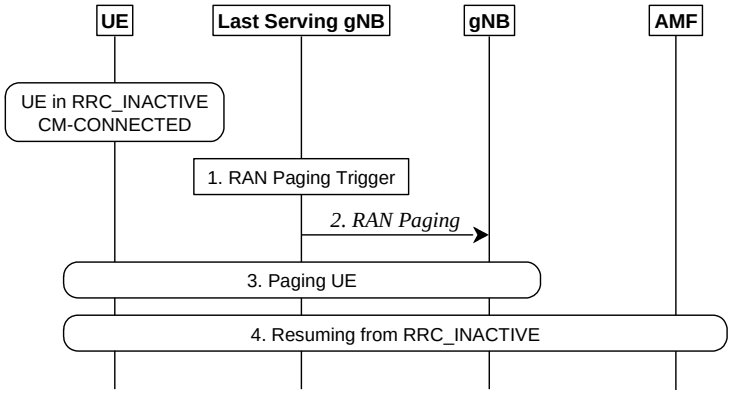


Figure 9.2.2.4.2-1: Network triggered transition from RRC_INACTIVE to RRC_CONNECTED

1. A RAN paging trigger event occurs (incoming DL user plane, DL signalling from 5GC, etc.).
2. RAN paging is triggered; either only in the cells controlled by the last serving gNB or also by means of Xn RAN Paging in cells controlled by other gNBs, configured to the UE in the RAN-based Notification Area (RNA).
3. The UE is paged with the I-RNTI.
4. If the UE has been successfully reached, it attempts to resume from RRC_INACTIVE, as described in clause 9.2.2.4.1.

9.2.2.5 RNA update

The following figure describes the UE triggered RNA update procedure involving context retrieval over Xn. The procedure may be triggered when the UE moves out of the configured RNA, or periodically.

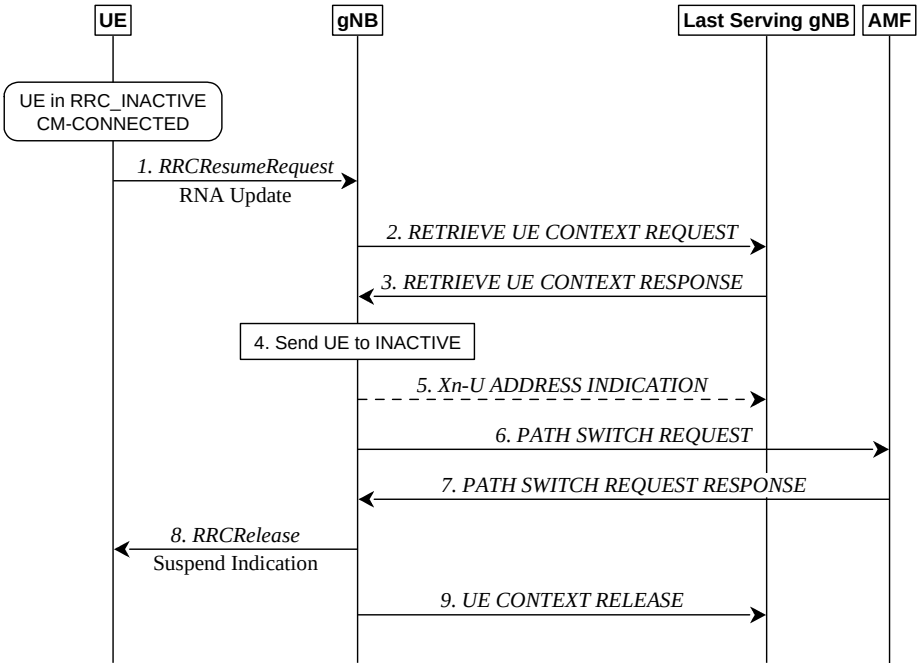


Figure 9.2.2.5-1: RNA update procedure with UE context relocation

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.

3. The last serving gNB may provide the UE context (as assumed in the following). Alternatively, the last serving gNB may decide to move the UE to RRC_IDLE (and the procedure follows steps 3 and later of figure 9.2.2.5-3) or, if the UE is still within the previously configured RNA, to keep the UE context in the last serving gNB and to keep the UE in RRC_INACTIVE (and the procedure follows steps 3 and later of figure 9.2.2.5-2).

4. The gNB may move the UE to RRC_CONNECTED (and the procedure follows step 4 of Figure 9.2.2.4.1-1), or send the UE back to RRC_IDLE (in which case an *RRCRelease* message is sent by the gNB), or send the UE back to RRC_INACTIVE as assumed in the following.

5. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

6./7. The gNB performs path switch.

8. The gNB keeps the UE in RRC_INACTIVE state by sending *RRCRelease* with suspend indication.

9. The gNB triggers the release of the UE resources at the last serving gNB.

The following figure describes the RNA update procedure for the case when the UE is still within the configured RNA and the last serving gNB decides not to relocate the UE context and to keep the UE in RRC_INACTIVE:

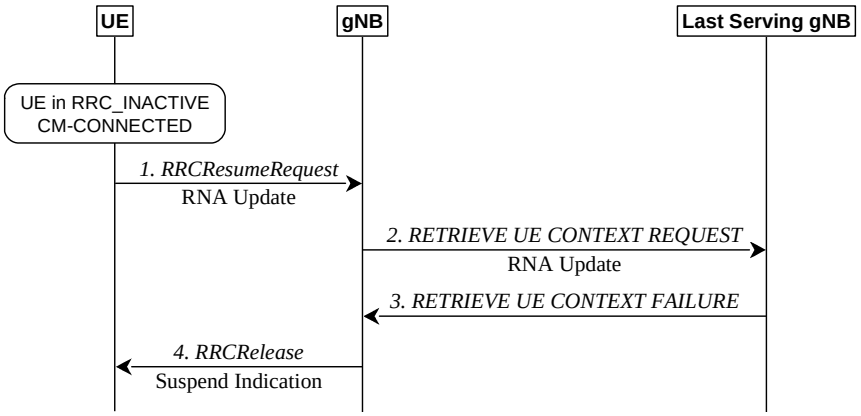


Figure 9.2.2.5-2: Periodic RNA update procedure without UE context relocation

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.

3. The last serving gNB stores received information to be used in the next resume attempt (e.g. C-RNTI and PCI related to the resumption cell), and responds to the gNB with the RETRIEVE UE CONTEXT FAILURE message including an encapsulated *RRCRelease* message. The *RRCRelease* message includes Suspend Indication.

4. The gNB forwards the *RRCRelease* message to the UE.

The following figure describes the RNA update procedure for the case when the last serving gNB decides to move the UE to RRC_IDLE:

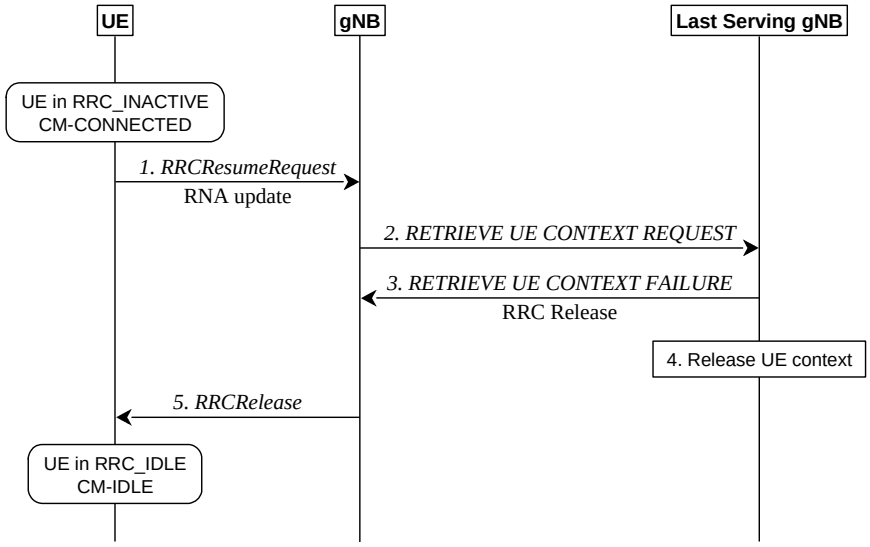


Figure 9.2.2.5-3: RNA update procedure with transition to RRC_IDLE

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.
3. Instead of providing the UE context, the last serving gNB provides an *RRCRelease* message to move the UE to RRC_IDLE.
4. The last serving gNB deletes the UE context.
5. The gNB sends the *RRCRelease* which triggers the UE to move to RRC_IDLE.

9.2.2.6 Resume request responded with Release with Redirect, with UE context relocation

The following figure describes a UE triggered NAS procedure responded by the network with a release with redirect, with UE context relocation.

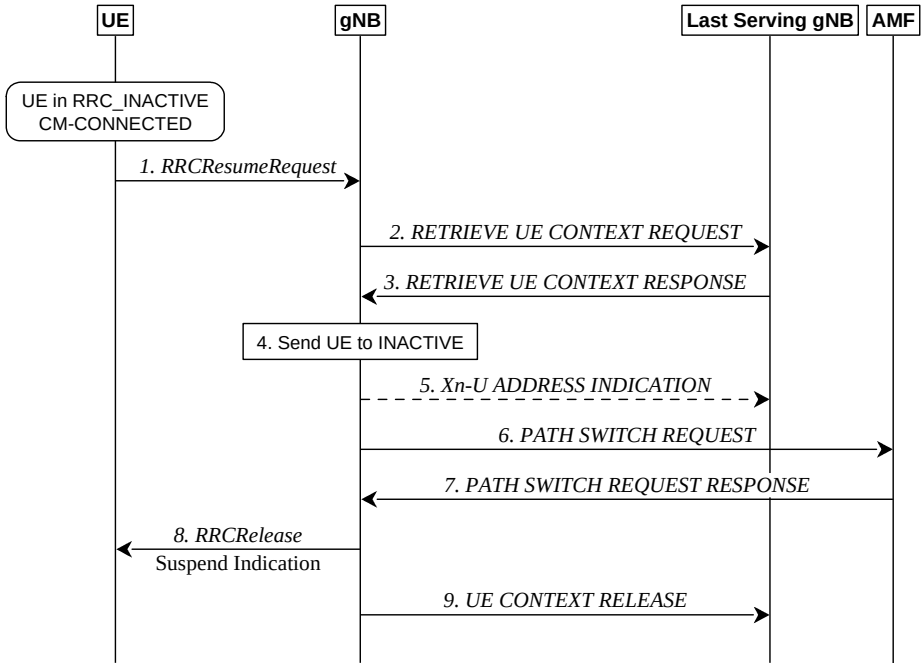


Figure 9.2.2.6-1: Resume request responded with Release with Redirect, with UE Context relocation

1. The UE resumes from RRC_INACTIVE, providing the I-RNTI allocated by the last serving gNB.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.
3. The last serving gNB provides the UE context.
4. The gNB may move the UE to RRC_CONNECTED (and the procedure follows step 4 of Figure 9.2.2.4.1-1), or send the UE back to RRC_IDLE (in which case an *RRCRelease* message is sent by the gNB), or send the UE back to RRC_INACTIVE, including a release with redirect indication (as assumed in the following).
5. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

6./7. The gNB performs path switch.

8. The gNB keeps the UE in RRC_INACTIVE state by sending *RRCRelease* with suspend indication, including redirection information (frequency layer the UE performs cell selection upon entering RRC_INACTIVE).
9. The gNB triggers the release of the UE resources at the last serving gNB.

NOTE 1: Upon receiving the release with redirect, the higher layers trigger a pending procedure so the UE tries to resume again after cell selection.

9.2.3 Mobility in RRC_CONNECTED

9.2.3.1 Overview

Network controlled mobility applies to UEs in RRC_CONNECTED and is categorized into two types of mobility: cell level mobility and beam level mobility. Beam level mobility includes intra-cell beam level mobility and inter-cell beam level mobility.

Cell Level Mobility requires explicit RRC signalling to be triggered, i.e. handover. For inter-gNB handover, the signalling procedures consist of at least the following elemental components illustrated in Figure 9.2.3.1-1:

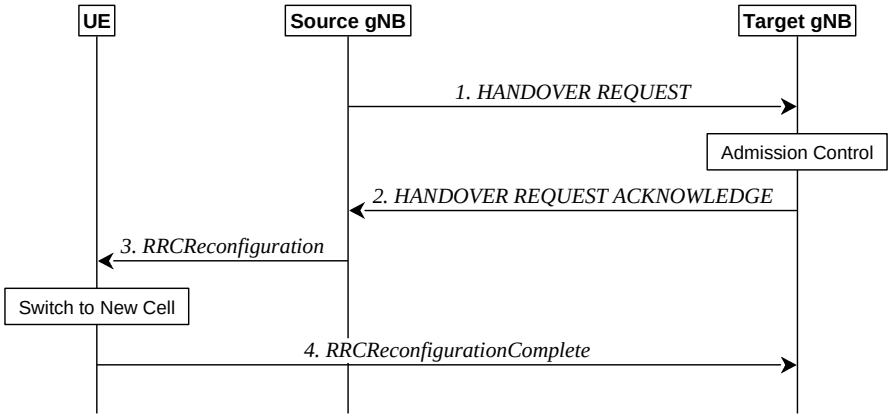


Figure 9.2.3.1-1: Inter-gNB handover procedures

1. The source gNB initiates handover and issues a HANDOVER REQUEST over the Xn interface.
2. The target gNB performs admission control and provides the new RRC configuration as part of the HANDOVER REQUEST ACKNOWLEDGE.
3. The source gNB provides the RRC configuration to the UE by forwarding the *RRCReconfiguration* message received in the HANDOVER REQUEST ACKNOWLEDGE. The *RRCReconfiguration* message includes at least cell ID and all information required to access the target cell so that the UE can access the target cell without reading system information. For some cases, the information required for contention-based and contention-free random access can be included in the *RRCReconfiguration* message. The access information to the target cell may include beam specific information, if any.
4. The UE moves the RRC connection to the target gNB and replies with the *RRCReconfigurationComplete*.

NOTE 1: User Data can also be sent in step 4 if the grant allows.

In case of DAPS handover, the UE continues the downlink user data reception from the source gNB until releasing the source cell and continues the uplink user data transmission to the source gNB until successful random access procedure to the target gNB.

Only source and target PCell are used during DAPS handover. CA, DC, SUL, multi-TRP, EHC, CHO, UDC, LTM, NR sidelink configurations and V2X sidelink configurations are released by the source gNB before the handover command is sent to the UE and are not configured by the target gNB until the DAPS handover has completed (i.e. at earliest in the same message that releases the source PCell).

The handover mechanism triggered by RRC requires the UE at least to reset the MAC entity and re-establish RLC, except for DAPS handover, where upon reception of the handover command, the UE:

- Creates a MAC entity for target;
- Establishes the RLC entity and an associated DTCH logical channel for target for each DRB configured with DAPS;
- For each DRB configured with DAPS, reconfigures the PDCP entity with separate security and ROHC functions for source and target and associates them with the RLC entities configured by source and target respectively;
- Retains the rest of the source configurations until release of the source.

The cell switch mechanism triggered by MAC, (i.e., LTM cell switch) requires the UE at least to reset the MAC entity. RLC and PDCP handling depends on the network configuration.

NOTE 2: Void.

NOTE 3: Void.

RRC managed handovers with and without PDCP entity re-establishment are both supported. For DRBs using RLC AM mode, PDCP can either be re-established together with a security key change or initiate a data recovery procedure without a key change. For DRBs using RLC UM mode, PDCP can either be re-established together with a security key

change or remain as it is without a key change. For SRBs, PDCP can either remain as it is, discard its stored PDCP PDUs/SDUs without a key change or be re-established together with a security key change.

Data forwarding, in-sequence delivery and duplication avoidance at handover can be guaranteed when the target gNB uses the same DRB configuration as the source gNB.

Timer based handover failure procedure is supported in NR. RRC connection re-establishment procedure is used for recovering from handover failure except in certain CHO, DAPS handover or LTM cell switch scenarios:

- When DAPS handover fails, the UE falls back to the source cell configuration, resumes the connection with the source cell, and reports DAPS handover failure via the source without triggering RRC connection re-establishment if the source link has not been released.

- When initial CHO execution attempt fails or HO fails, the UE performs cell selection, and if the selected cell is a CHO candidate and if network configured the UE to try CHO after handover/CHO failure, then the UE attempts CHO execution once, otherwise re-establishment is performed.

- When LTM execution attempt triggered by LTM cell switch command MAC CE fails or when the CLTM execution attempt by the UE fails, the UE performs cell selection and if the selected cell is an LTM candidate cell and if network configured the UE to try LTM after LTM execution failure, then the UE attempts RACH-based LTM execution once, otherwise re-establishment is performed.

NOTE 4: PDCP SN gap for SRB may exist upon LTM/CLTM attempt toward the selected cell after LTM/CLTM fails. It is up to network implementation to avoid the latency caused by the PDCP SN gap.

DAPS handover for FR2 to FR2 case is not supported in this release of the specification.

The handover of the IAB-MT in SA mode follows the same procedure as described for the UE. After the backhaul has been established, the handover of the IAB-MT is part of the intra-CU or inter-CU topology adaptation procedures defined in TS 38.401 [4]. Modifications to the configuration of BAP sublayer and higher protocol layers above the BAP sublayer are described in TS 38.401 [4].

The handover of the mobile IAB-MT follows the same procedure as described for the UE. After the backhaul has been established, the handover of the mobile IAB-MT is part of the mobile IAB-MT migration procedure defined in TS 38.401 [4].

Beam Level Mobility does not require explicit RRC signalling to be triggered. Beam level mobility can be within a cell, or between cells, the latter is referred to as inter-cell beam management (ICBM). For ICBM, a UE can receive or transmit UE dedicated channels/signals via a TRP associated with a PCI different from the PCI of a serving cell, while non-UE-dedicated channels/signals can only be received via a TRP associated with a PCI of the serving cell. The gNB provides via RRC signalling the UE with measurement configuration containing configurations of SSB/CSI resources and resource sets, reports and trigger states for triggering channel and interference measurements and reports. In case of ICBM, a measurement configuration includes SSB resources associated with PCIs different from the PCI of a serving cell. Beam Level Mobility is then dealt with at lower layers by means of physical layer and MAC layer control signalling, and RRC is not required to know which beam is being used at a given point in time.

SSB-based Beam Level Mobility is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWPs, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. SSB-based Beam Level Mobility can be also performed based on an NCD-SSB, if configured for the active DL BWP. Beam Level Mobility can be also performed based on CSI-RS, if configured for the active DL BWP.

For UE-initiated beam reporting, Mode A and Mode B are supported, where upon detection of an event, UE transmits a UE Initiated Report Indicator (UEIRI) indication in a PUCCH resource to indicate transmission of a beam report. Corresponding to the UEIRI indication, in Mode A, the UE transmits the beam report on a PUSCH indicated by a DCI, while in Mode B, the UE transmits the beam report on a type1 CG PUSCH associated to the PUCCH resource.

9.2.3.2 Handover

9.2.3.2.1 C-Plane Handling

The intra-NR RAN handover performs the preparation and execution phase of the handover procedure performed without involvement of the 5GC, i.e. preparation messages are directly exchanged between the gNBs. The release of the

resources at the source gNB during the handover completion phase is triggered by the target gNB. The figure below depicts the basic handover scenario where neither the AMF nor the UPF changes:

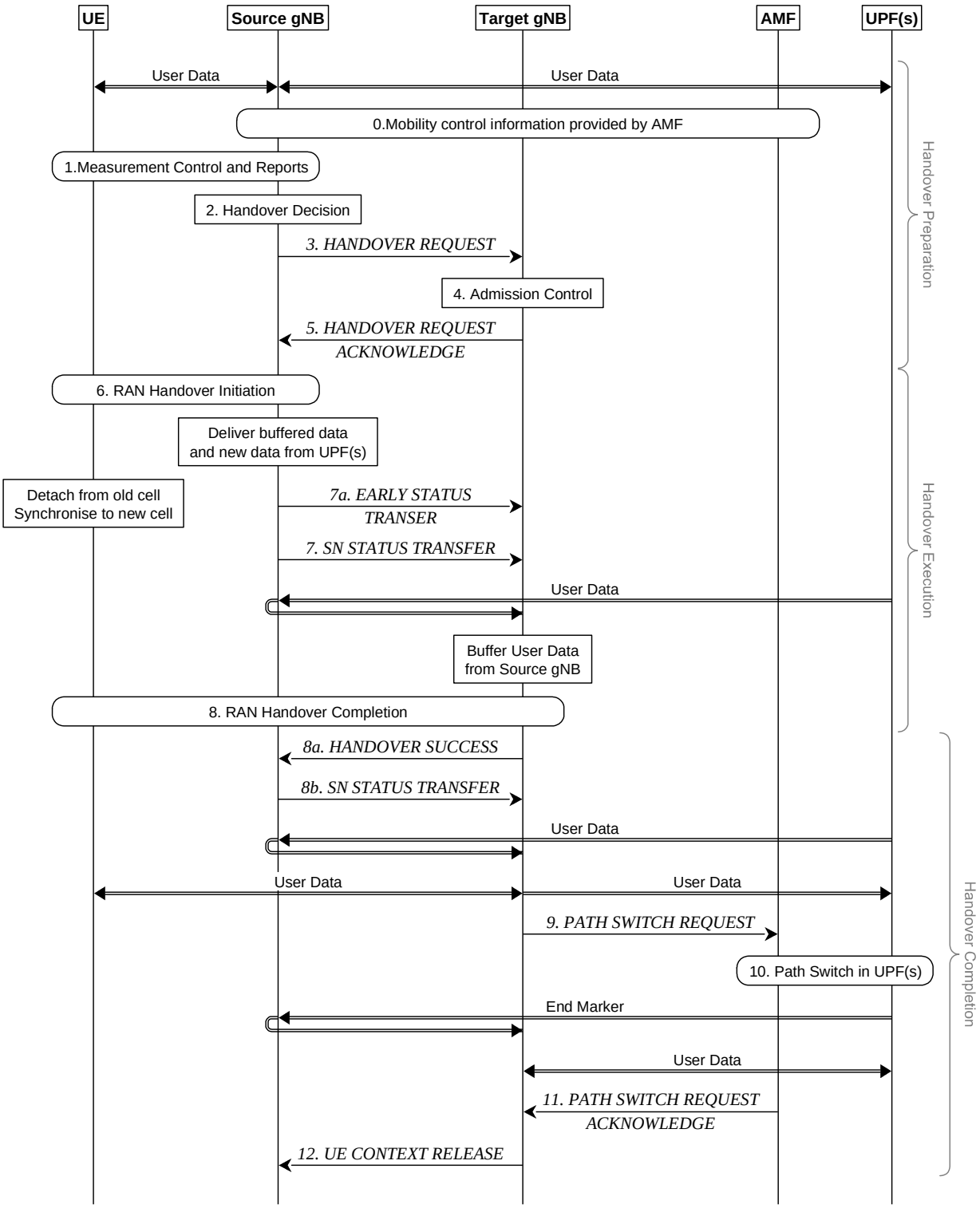


Figure 9.2.3.2.1-1: Intra-AMF/UPF Handover

0. The UE context within the source gNB contains information regarding roaming and access restrictions which were provided either at connection establishment or at the last TA update.

1. The source gNB configures the UE measurement procedures and the UE reports according to the measurement configuration.

2. The source gNB decides to handover the UE, based on *MeasurementReport* and RRM information.

3. The source gNB issues a Handover Request message to the target gNB passing a transparent RRC container with necessary information to prepare the handover at the target side. The information includes at least the target cell ID, KgNB*, the C-RNTI of the UE in the source gNB, RRM-configuration including UE inactive time, basic AS-configuration including *antenna Info and DL Carrier Frequency*, the current QoS flow to DRB mapping rules applied to the UE, the SIB1 information from source gNB, the UE capabilities for different RATs, PDU session related information, and can include the UE reported measurement information including beam-related information if available. The PDU session related information includes the slice information and QoS flow level QoS profile(s). The source gNB may also request a DAPS handover for one or more DRBs.

NOTE 1: After issuing a Handover Request, the source gNB should not reconfigure the UE, including performing Reflective QoS flow to DRB mapping.

4. Admission Control may be performed by the target gNB. Slice-aware admission control shall be performed if the slice information is sent to the target gNB. If the PDU sessions are associated with non-supported slices the target gNB shall reject such PDU Sessions.

5. The target gNB prepares the handover with L1/L2 and sends the HANDOVER REQUEST ACKNOWLEDGE to the source gNB, which includes a transparent container to be sent to the UE as an RRC message to perform the handover. The target gNB also indicates if a DAPS handover is accepted.

NOTE 2: As soon as the source gNB receives the HANDOVER REQUEST ACKNOWLEDGE, or as soon as the transmission of the handover command is initiated in the downlink, data forwarding may be initiated.

NOTE 3: For DRBs configured with DAPS, downlink PDCP SDUs are forwarded with SN assigned by the source gNB, until SN assignment is handed over to the target gNB in step 8b, for which the normal data forwarding follows as defined in 9.2.3.2.3.

6. The source gNB triggers the Uu handover by sending an *RRCReconfiguration* message to the UE, containing the information required to access the target cell: at least the target cell ID, the new C-RNTI, the target gNB security algorithm identifiers for the selected security algorithms. It can also include a set of dedicated RACH resources, the association between RACH resources and SSB(s), the association between RACH resources and UE-specific CSI-RS configuration(s), common RACH resources, and system information of the target cell, etc.

NOTE 4: For DRBs configured with DAPS, the source gNB does not stop transmitting downlink packets until it receives the HANDOVER SUCCESS message from the target gNB in step 8a.

NOTE 4a: CHO cannot be configured simultaneously with DAPS handover.

7a. For DRBs configured with DAPS, the source gNB sends the EARLY STATUS TRANSFER message. The DL COUNT value conveyed in the EARLY STATUS TRANSFER message indicates PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB. The source gNB does not stop assigning SNs to downlink PDCP SDUs until it sends the SN STATUS TRANSFER message to the target gNB in step 8b.

7. For DRBs not configured with DAPS, the source gNB sends the SN STATUS TRANSFER message to the target gNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of DRBs for which PDCP status preservation applies (i.e. for RLC AM). The uplink PDCP SN receiver status includes at least the PDCP SN of the first missing UL PDCP SDU and may include a bit map of the receive status of the out of sequence UL PDCP SDUs that the UE needs to retransmit in the target cell, if any. The downlink PDCP SN transmitter status indicates the next PDCP SN that the target gNB shall assign to new PDCP SDUs, not having a PDCP SN yet.

NOTE 5: In case of DAPS handover, the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status for a DRB with RLC-AM and not configured with DAPS may be transferred by the SN STATUS TRANSFER message in step 8b instead of step 7.

NOTE 6: For DRBs configured with DAPS, the source gNB may additionally send the EARLY STATUS TRANSFER message(s) between step 7 and step 8b, to inform discarding of already forwarded PDCP SDUs. The target gNB does not transmit forwarded downlink PDCP SDUs to the UE, whose COUNT is less than the conveyed DL COUNT value and discards them if transmission has not been attempted already.

8. The UE synchronises to the target cell and completes the RRC handover procedure by sending *RRCReconfigurationComplete* message to target gNB. In case of DAPS handover, the UE does not detach from the source cell upon receiving the *RRCReconfiguration* message. The UE releases the source resources and

configurations and stops DL/UL reception/transmission with the source upon receiving an explicit release from the target node.

NOTE 6a: From RAN point of view, the DAPS handover is considered to only be completed after the UE has released the source cell as explicitly requested from the target node. RRC suspend, a subsequent handover or inter-RAT handover cannot be initiated until the source cell has been released.

8a/b In case of DAPS handover, the target gNB sends the HANDOVER SUCCESS message to the source gNB to inform that the UE has successfully accessed the target cell. In return, the source gNB sends the SN STATUS TRANSFER message for DRBs configured with DAPS for which the description in step 7 applies, and the normal data forwarding follows as defined in 9.2.3.2.3.

NOTE 7: The uplink PDCP SN receiver status and the downlink PDCP SN transmitter status are also conveyed for DRBs with RLC-UM in the SN STATUS TRANSFER message in step 8b, if configured with DAPS.

NOTE 8: For DRBs configured with DAPS, the source gNB does not stop delivering uplink QoS flows to the UPF until it sends the SN STATUS TRANSFER message in step 8b. The target gNB does not forward QoS flows of the uplink PDCP SDUs successfully received in-sequence to the UPF until it receives the SN STATUS TRANSFER message, in which UL HFN and the first missing SN in the uplink PDCP SN receiver status indicates the start of uplink PDCP SDUs to be delivered to the UPF. The target gNB does not deliver any uplink PDCP SDUs which has an UL COUNT lower than the provided.

NOTE 9: Void.

9. The target gNB sends a PATH SWITCH REQUEST message to AMF to trigger 5GC to switch the DL data path towards the target gNB and to establish an NG-C interface instance towards the target gNB.

10. 5GC switches the DL data path towards the target gNB. The UPF sends one or more "end marker" packets on the old path to the source gNB per PDU session/tunnel and then can release any U-plane/TNL resources towards the source gNB.

11. The AMF confirms the PATH SWITCH REQUEST message with the PATH SWITCH REQUEST ACKNOWLEDGE message.

12. Upon reception of the PATH SWITCH REQUEST ACKNOWLEDGE message from the AMF, the target gNB sends the UE CONTEXT RELEASE to inform the source gNB about the success of the handover. The source gNB can then release radio and C-plane related resources associated to the UE context. Any ongoing data forwarding may continue.

The RRM configuration can include both beam measurement information (for layer 3 mobility) associated to SSB(s) and CSI-RS(s) for the reported cell(s) if both types of measurements are available. Also, if CA is configured, the RRM configuration can include the list of best cells on each frequency for which measurement information is available. And the RRM measurement information can also include the beam measurement for the listed cells that belong to the target gNB.

The common RACH configuration for beams in the target cell is only associated to the SSB(s). The network can have dedicated RACH configurations associated to the SSB(s) and/or have dedicated RACH configurations associated to CSI-RS(s) within a cell. The target gNB can only include one of the following RACH configurations in the Handover Command to enable the UE to access the target cell:

i) Common RACH configuration;

ii) Common RACH configuration + Dedicated RACH configuration associated with SSB;

iii) Common RACH configuration + Dedicated RACH configuration associated with CSI-RS.

The dedicated RACH configuration allocates RACH resource(s) together with a quality threshold to use them. When dedicated RACH resources are provided, they are prioritized by the UE and the UE shall not switch to contention-based RACH resources as long as the quality threshold of those dedicated resources is met. The order to access the dedicated RACH resources is up to UE implementation.

Upon receiving a handover command requesting DAPS handover, the UE suspends source cell SRBs, stops sending and receiving any RRC control plane signalling toward the source cell, and establishes SRBs for the target cell. The UE releases the source cell SRBs configuration upon receiving source cell release indication from the target cell after successful DAPS handover execution. When DAPS handover to the target cell fails and if the source cell link is

available, then the UE reverts back to the source cell configuration and resumes source cell SRBs for control plane signalling transmission.

9.2.3.2.2 U-Plane Handling

The U-plane handling during the Intra-NR-Access mobility activity for UEs in RRC_CONNECTED takes the following principles into account to avoid data loss during HO:

- During HO preparation, U-plane tunnels can be established between the source gNB and the target gNB;
- During HO execution, user data can be forwarded from the source gNB to the target gNB;
  - Forwarding should take place in order as long as packets are received at the source gNB from the UPF or the source gNB buffer has not been emptied.
- During HO completion:
  - The target gNB sends a path switch request message to the AMF to inform that the UE has gained access and the AMF then triggers path switch related 5GC internal signalling and actual path switch of the source gNB to the target gNB in UPF;
  - The source gNB should continue forwarding data as long as packets are received at the source gNB from the UPF or the source gNB buffer has not been emptied.

For RLC-AM bearers:

- For in-sequence delivery and duplication avoidance, PDCP SN is maintained on a per DRB basis and the source gNB informs the target gNB about the next DL PDCP SN to allocate to a packet which does not have a PDCP sequence number yet (either from source gNB or from the UPF).
- For security synchronisation, HFN is also maintained and the source gNB provides to the target one reference HFN for the UL and one for the DL i.e. HFN and corresponding SN.
- In both the UE and the target gNB, a window-based mechanism is used for duplication detection and reordering.
- The occurrence of duplicates over the air interface in the target gNB is minimised by means of PDCP SN based reporting at the target gNB by the UE. In uplink, the reporting is optionally configured on a per DRB basis by the gNB and the UE should first start by transmitting those reports when granted resources are in the target gNB. In downlink, the gNB is free to decide when and for which bearers a report is sent and the UE does not wait for the report to resume uplink transmission.
- The target gNB re-transmits and prioritizes all downlink data forwarded by the source gNB (i.e. the target gNB should first send all forwarded PDCP SDUs with PDCP SNs, then all forwarded downlink PDCP SDUs without SNs before sending new data from 5GC), excluding PDCP SDUs for which the reception was acknowledged through PDCP SN based reporting by the UE.

NOTE 1: Lossless delivery when a QoS flow is mapped to a different DRB at handover, requires the old DRB to be configured in the target cell. For in-order delivery in the DL, the target gNB should first transmit the forwarded PDCP SDUs on the old DRB before transmitting new data from 5GC on the new DRB. In the UL, the target gNB should not deliver data of the QoS flow from the new DRB to 5GC before receiving the end marker on the old DRB from the UE.

- The UE re-transmits in the target gNB all uplink PDCP SDUs starting from the oldest PDCP SDU that has not been acknowledged at RLC in the source, excluding PDCP SDUs for which the reception was acknowledged through PDCP SN based reporting by the target.
- In case of handovers involving Full Configuration, the following description below for RLC-UM bearers applies for RLC-AM bearers instead. Data loss may happen.

For RLC-UM bearers:

- The PDCP SN and HFN are reset in the target gNB, unless the bearer is configured with DAPS handover;
- No PDCP SDUs are retransmitted in the target gNB;

- The target gNB prioritises all downlink SDAP SDUs forwarded by the source gNB over the data from the core network;

NOTE 2: To minimise losses when a QoS flow is mapped to a different DRB at handover, the old DRB needs to be configured in the target cell. For in-order delivery in the DL, the target gNB should first transmit the forwarded PDCP SDUs on the old DRB before transmitting new data from 5GC on the new DRB. In the UL, the target gNB should not deliver data of the QoS flow from the new DRB to 5GC before receiving the end marker on the old DRB from the UE.

- The UE does not retransmit any PDCP SDU in the target cell for which transmission had been completed in the source cell.

For DAPS handover:

A DAPS handover can be used for an RLC-AM or RLC-UM bearer. For a DRB configured with DAPS, the following principles are additionally applied.

Downlink:

- During HO preparation, a forwarding tunnel is always established.

- The source gNB is responsible for allocating downlink PDCP SNs until the SN assignment is handed over to the target gNB and data forwarding in 9.2.3.2.3 takes place. That is, the source gNB does not stop assigning PDCP SNs to downlink packets until it receives the HANDOVER SUCCESS message and sends the SN STATUS TRANSFER message to the target gNB.

- Upon allocation of downlink PDCP SNs by the source gNB, it starts scheduling downlink data on the source radio link and also starts forwarding downlink PDCP SDUs along with assigned PDCP SNs to the target gNB.

- For security synchronisation, HFN is maintained for the forwarded downlink SDUs with PDCP SNs assigned by the source gNB. The source gNB sends the EARLY STATUS TRANSFER message to convey the DL COUNT value, indicating PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB.

- HFN and PDCP SN are maintained after the SN assignment is handed over to the target gNB. The SN STATUS TRANSFER message indicates the next DL PDCP SN to allocate to a packet which does not have a PDCP sequence number yet, even for RLC-UM.

- During handover execution period, the source and target gNBs separately perform ROHC header compression, ciphering, and adding PDCP header.

- During handover execution period, the UE continues to receive downlink data from both source and target gNBs until the source gNB connection is released by an explicit release command from the target gNB.

- During handover execution period, the UE PDCP entity configured with DAPS maintains separate security and ROHC header decompression functions associated with each gNB, while maintaining common functions for reordering, duplicate detection and discard, and PDCP SDUs in-sequence delivery to upper layers. PDCP SN continuity is supported for both RLC AM and UM DRBs configured with DAPS.

Uplink:

- The UE transmits UL data to the source gNB until the random access procedure toward the target gNB has been successfully completed. Afterwards the UE switches its UL data transmission to the target gNB.

- Even after switching its UL data transmissions towards the target gNB, the UE continues to send UL layer 1 CSI feedback, HARQ feedback, layer 2 RLC feedback, ROHC feedback, HARQ data (re-)transmissions, and RLC data (re-)transmissions to the source gNB.

- During handover execution period, the UE maintains separate security context and ROHC header compressor context for uplink transmissions towards the source and target gNBs. The UE maintains common UL PDCP SN allocation. PDCP SN continuity is supported for both RLC AM and UM DRBs configured with DAPS.

- During handover execution period, the source and target gNBs maintain their own security and ROHC header decompressor contexts to process UL data received from the UE.

- The establishment of a forwarding tunnel is optional.

- HFN and PDCP SN are maintained in the target gNB. The SN STATUS TRANSFER message indicates the COUNT of the first missing PDCP SDU that the target should start delivering to the 5GC, even for RLC-UM.

9.2.3.2.3 Data Forwarding

The following description depicts the data forwarding principles for intra-system handover.

The source NG-RAN node may suggest downlink data forwarding per QoS flow established for a PDU session and may provide information how it maps QoS flows to DRBs. The target NG-RAN node decides data forwarding per QoS flow established for a PDU Session.

If "lossless handover" is required and the QoS flows to DRB mapping applied at the target NG-RAN node allows applying for data forwarding the same QoS flows to DRB mapping as applied at the source NG-RAN node for a DRB and if all QoS flows mapped to that DRB are accepted for data forwarding, the target NG-RAN node establishes a downlink forwarding tunnel for that DRB.

For a DRB for which preservation of SN status applies, the target NG-RAN node may decide to establish an UL data forwarding tunnel.

The target NG-RAN node may also decide to establish a downlink forwarding tunnel for each PDU session. In this case the target NG-RAN node provides information for which QoS flows data forwarding has been accepted and corresponding UP TNL information for data forwarding tunnels to be established between the source NG-RAN node and the target NG-RAN node.

If QoS flows have been re-mapped at the source NG-RAN node and user packets along the old source mapping are still being processed at handover preparation, and if the source NG-RAN node has not yet received the SDAP end marker for certain QoS flows when providing the SN status to the target NG-RAN node, the source NG-RAN node provides the old side QoS mapping information for UL QoS flows to the target NG-RAN node for which no SDAP end marker was yet received. The target NG-RAN will receive for those QoS flows the end marker when the UE finalises to send UL user data according to the old source side mapping.

The source NG-RAN node may also propose to establish uplink forwarding tunnels for some PDU sessions in order to transfer SDAP SDUs corresponding to QoS flows for which flow re-mapping happened before the handover and the SDAP end marker has not yet been received, and for which user data was received at the source NG-RAN node via the DRB to which the QoS flow was remapped. If accepted the target NG-RAN node shall provide the corresponding UP TNL information for data forwarding tunnels to be established between the source NG-RAN node and the target NG-RAN node.

As long as data forwarding of DL user data packets takes place, the source NG-RAN node shall forward user data in the same forwarding tunnel, i.e.

- for any QoS flow accepted for data forwarding by the target NG-RAN node and for which a DRB DL forwarding tunnel was established for a DRB to which this QoS flow was mapped at the source NG-RAN node, any fresh packets of this QoS flow shall be forwarded as PDCP SDUs via the mapped DRB DL forwarding tunnel.

- for DRBs for which preservation of SN status applies, the source NG-RAN node may forward in order to the target NG-RAN node via the DRB DL forwarding tunnel all downlink PDCP SDUs with their SN corresponding to PDCP PDUs which have not been acknowledged by the UE.

NOTE: The SN of forwarded PDCP SDUs is carried in the "PDCP PDU number" field of the GTP-U extension header.

- for any QoS flow accepted for data forwarding by the target NG-RAN node for which a DL PDU session forwarding tunnel was established, the source NG-RAN node forwards SDAP SDUs as received on NG-U from the UPF.

If the data forwarding is performed and the source NG-RAN node receives SDAP SDUs with PDU Set Information Container in the GTP-U extension header on NG-U from the UPF and the target NG-RAN node supports PDU Set based handling, the source NG-RAN node forwards either the PDCP SDUs for DRB-level data forwarding or the SDAP SDUs for PDU-session-level data forwarding with the corresponding PDU Set Information Container in the GTP-U extension header to the target NG-RAN node.

For handovers involving Full Configuration, the source NG-RAN node behaviour is unchanged from the description above. In case a DRB DL forwarding tunnel was established, the target NG-RAN node may identify the PDCP SDUs for which delivery was attempted by the source NG-RAN node, by the presence of the PDCP SN in the forwarded GTP-U packet and may discard them.

As long as data forwarding of UL user data packets takes place for DRBs for which preservation of SN status applies the source NG-RAN node either:

- discards the uplink PDCP PDUs received out of sequence if the source NG-RAN node has not accepted the request from the target NG-RAN node for uplink forwarding or if the target NG-RAN node has not requested uplink forwarding for the bearer during the Handover Preparation procedure; or

- forwards to the target NG-RAN node via the corresponding DRB UL forwarding tunnel, the uplink PDCP SDUs with their SN corresponding to PDCP PDUs received out of sequence if the source NG-RAN node has accepted the request from the target NG-RAN node for uplink forwarding for the bearer during the Handover Preparation procedure, including PDCP SDUs corresponding to user data of those QoS flows, for which re-mapping happened for a QoS flow before the handover and the SDAP end marker has not yet been received at the source NG-RAN node.

As long as data forwarding of UL user data packets takes place for a PDU session, the source NG-RAN node forwards via the corresponding PDU session UL forwarding tunnel, the uplink SDAP SDUs corresponding to QoS flows for which flow re-mapping happened before the handover and the SDAP end marker has not yet been received at the source NG-RAN node, and which were received at the source NG-RAN node via the DRB to which the QoS flow was remapped.

For DRBs configured with DAPS handover, data forwarding after the source gNB receives the HANDOVER SUCCESS message from the target gNB follows the same behaviours as described above.

For DRBs configured with DAPS handover, before the source gNB receives the HANDOVER SUCCESS message:

- The source gNB may forward to the target gNB downlink PDCP SDUs with SNs assigned by the source gNB. No downlink PDCP SDU without a SN assigned or SDAP SDU is forwarded. No uplink PDCP SDU or SDAP SDU is forwarded.

- The source gNB sends the EARLY STATUS TRANSFER message to maintain HFN continuity by indicating PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB. The subsequent messages may be sent for discarding of already forwarded downlink PDCP SDUs in the target gNB.

- The source gNB does not stop transmitting downlink packets to the UE. The source gNB keeps forwarding to the 5GC the uplink SDAP SDUs successfully received in-sequence from the UE.

Handling of end marker packets:

- The source NG-RAN node receives one or several GTP-U end marker packets per PDU session from the UPF and replicates the end marker packets into each data forwarding tunnel when no more user data packets are to be forwarded over that tunnel.

- End marker packets sent via a data forwarding tunnel are applicable to all QoS flows forwarded via that tunnel. After end marker packets have been received over a forwarding tunnel, the target NG-RAN node can start taking into account the packets of QoS flows associated with that forwarding tunnel received at the target NG-RAN node from the NG-U PDU session tunnel.

9.2.3.3 Re-establishment procedure

A UE in RRC_CONNECTED may initiate the re-establishment procedure to continue the RRC connection when a failure condition occurs (e.g. radio link failure, reconfiguration failure, integrity check failure…).

The following figure describes the re-establishment procedure started by the UE:

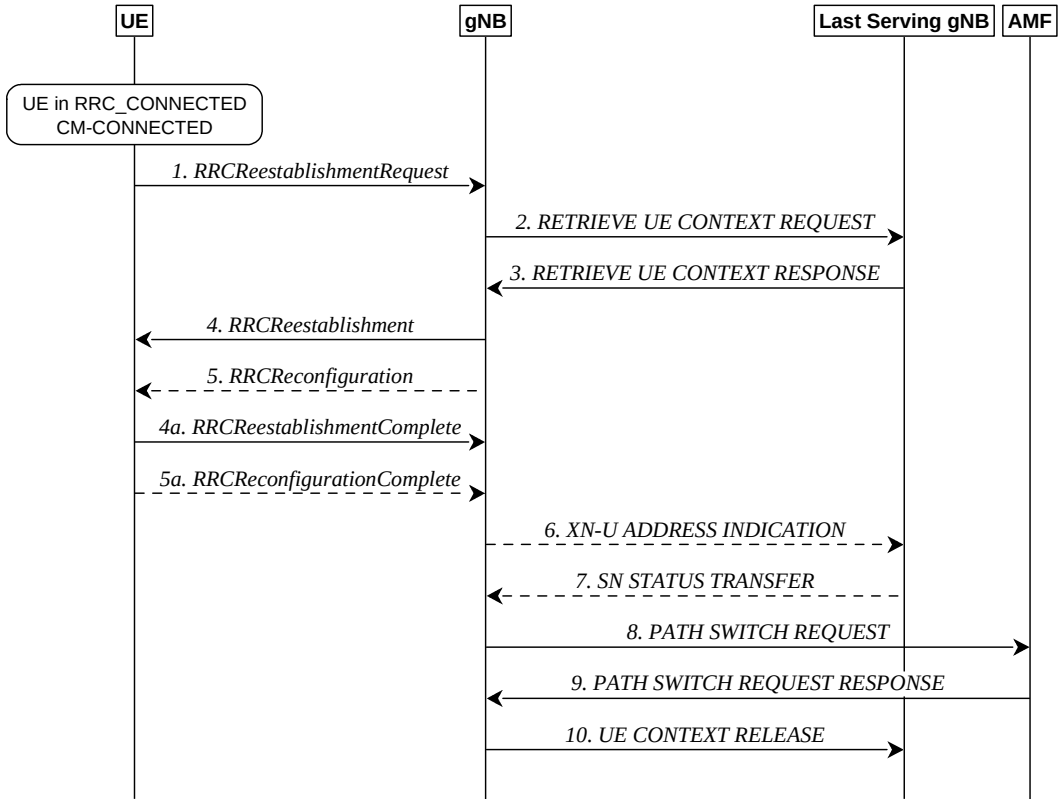


Figure 9.2.3.3-1: Re-establishment procedure

1. The UE re-establishes the connection, providing the UE Identity (PCI+C-RNTI) to the gNB where the trigger for the re-establishment occurred.
2. If the UE Context is not locally available, the gNB, requests the last serving gNB to provide UE Context data.
3. The last serving gNB provides UE context data.

4/4a. The gNB continues the re-establishment of the RRC connection. The message is sent on SRB1.

5/5a. The gNB may perform the reconfiguration to re-establish SRB2 and DRBs when the re-establishment procedure is ongoing.

6/7. If loss of user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses, and the last serving gNB provides the SN status to the gNB.

8/9. The gNB performs path switch.

10. The gNB triggers the release of the UE resources at the last serving gNB.

The IAB-MT in SA mode follows the same re-establishment procedure as described for the UE. After the backhaul has been established, the re-establishment procedure of the IAB-MT is part of the intra-CU backhaul RLF recovery procedure for IAB-nodes defined in TS 38.401 [4]. Modifications to the configuration of BAP sublayer and higher protocol layers above the BAP sublayer are described in TS 38.401 [4].

9.2.3.4 Conditional Handover

9.2.3.4.1 General

A Conditional Handover (CHO) is defined as a handover that is executed by the UE when one or more handover execution conditions are met. The UE starts evaluating the execution condition(s) upon receiving the CHO configuration, and stops evaluating the execution condition(s) once a handover is executed.

The following principles apply to CHO:

- The CHO configuration contains the configuration of CHO candidate cell(s) generated by the candidate gNB(s) and execution condition(s) generated by the source gNB.

- An execution condition may consist of one or two trigger condition(s) (CHO events A3/A5, as defined in [12]). Only single RS type is supported and at most two different trigger quantities (e.g. RSRP and RSRQ, RSRP and SINR, etc.) can be configured simultaneously for the evalution of CHO execution condition of a single candidate cell.

- Before any CHO execution condition is satisfied, upon reception of HO command (without CHO configuration) or LTM cell switch command MAC CE, the UE executes the HO procedure as described in clause 9.2.3.2 or LTM cell switch procedure as described in clause 9.2.3.5, regardless of any previously received CHO configuration.

- While executing CHO, i.e. from the time when the UE starts synchronization with target cell, UE does not monitor source cell.

CHO is also supported for the IAB-MT in context of intra- and inter-donor IAB-node migration and BH RLF recovery.

CHO is not supported for NG-C based handover in this release of the specification.

9.2.3.4.2 C-plane handling

As in intra-NR RAN handover, in intra-NR RAN CHO, the preparation and execution phase of the conditional handover procedure is performed without involvement of the 5GC; i.e. preparation messages are directly exchanged between gNBs. The release of the resources at the source gNB during the conditional handover completion phase is triggered by the target gNB. The figure below depicts the basic conditional handover scenario where neither the AMF nor the UPF changes:

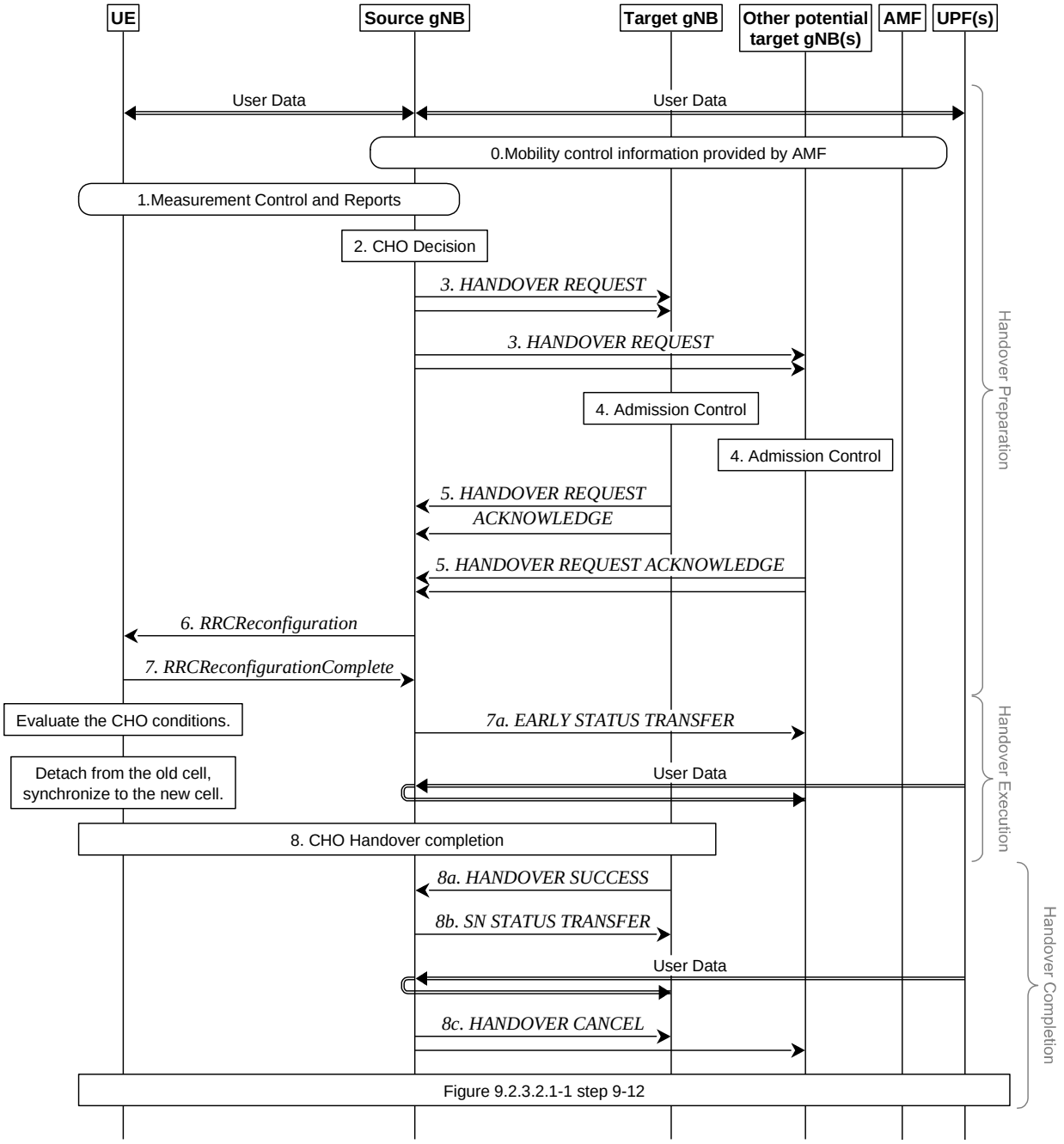


Figure 9.2.3.4.2-1: Intra-AMF/UPF Conditional Handover

0/1. Same as step 0, 1 in Figure 9.2.3.2.1-1 of clause 9.2.3.2.1.

2. The source gNB decides to use CHO.

3. The source gNB requests CHO for one or more candidate cells belonging to one or more candidate gNBs. A CHO request message is sent for each candidate cell.

4. Same as step 4 in Figure 9.2.3.2.1-1 of clause 9.2.3.2.1.

5. The candidate gNB(s) sends CHO response (HO REQUEST ACKNOWLEDGE) including configuration of CHO candidate cell(s) to the source gNB. The CHO response message is sent for each candidate cell.

6. The source gNB sends an *RRCReconfiguration* message to the UE, containing the configuration of CHO candidate cell(s) and CHO execution condition(s).

NOTE 1: CHO configuration of candidate cells can be followed by another reconfiguration from the source gNB.

NOTE 1a: A configuration of a CHO candidate cell cannot contain a DAPS handover configuration.

7. The UE sends an *RRCReconfigurationComplete* message to the source gNB.

7a If early data forwarding is applied, the source gNB sends the EARLY STATUS TRANSFER message.

8. The UE maintains connection with the source gNB after receiving CHO configuration, and starts evaluating the CHO execution conditions for the candidate cell(s). If at least one CHO candidate cell satisfies the corresponding CHO execution condition, the UE detaches from the source gNB, applies the stored corresponding configuration for that selected candidate cell, synchronises to that candidate cell and completes the RRC handover procedure by sending *RRCReconfigurationComplete* message to the target gNB. The UE releases stored CHO configurations after successful completion of RRC handover procedure.

8a/b The target gNB sends the HANDOVER SUCCESS message to the source gNB to inform that the UE has successfully accessed the target cell. In return, the source gNB sends the SN STATUS TRANSFER message following the principles described in step 7 of Intra-AMF/UPF Handover in clause 9.2.3.2.1.

NOTE 2: Late data forwarding may be initiated as soon as the source gNB receives the HANDOVER SUCCESS message.

8c. The source gNB sends the HANDOVER CANCEL message toward the other signalling connections or other candidate target gNBs, if any, to cancel CHO for the UE.

9.2.3.4.3 U-plane handling

The U-plane handling for Conditional Handover follows the same principles for DAPS handover in 9.2.3.2.2, if early data forwarding is applied, except that, in case of Full Configuration, HFN and PDCP SN are reset in the target gNB after the SN assignment is handed over to the target gNB. If late data forwarding is applied, the U-plane handling follows the RLC-AM or RLC-UM bearer principles defined in 9.2.3.2.2.

9.2.3.4.4 Data Forwarding

If late data forwarding is applied, the source NG-RAN node initiates data forwarding once it knows which target NG-RAN node the UE has successfully accessed. In that case the behavior of the Conditional Handover data forwarding follows the same behavior as defined in 9.2.3.2.3 for the intra-system handover data forwarding, except the behavior for DRBs configured with DAPS handover.

If early data forwarding is applied instead, the source NG-RAN node initiates data forwarding before the UE executes the handover, to a candidate target node of interest. The behavior of early data forwarding for the Conditional Handover follows the same principles for DRBs configured with DAPS handover in the intra-system handover as defined in 9.2.3.2.3.

9.2.3.5 L1/L2 Triggered Mobility

9.2.3.5.1 General

LTM is a procedure in which a gNB receives L1 or L3 measurement report(s) from a UE, and on their basis the gNB may change UE serving cell by a cell switch command signalled via a MAC CE. The cell switch command indicates an LTM candidate configuration that the gNB previously prepared and provided to the UE through RRC signalling. Then the UE switches to the target configuration according to the cell switch command. The LTM procedure can be used to reduce the mobility latency as described in Annex G.

When configured by the network, it is possible to activate TCI states of one or multiple cells that are different from the current serving cell. For instance, the TCI states of the LTM candidate cells can be activated in advance before any of those cells become the serving cell. This allows the UE to be DL synchronized with those cells, thereby facilitating a faster cell switch to one of those cells when cell switch is triggered. All the activated TCI states except those received in the cell switch command are deactivated upon LTM cell switch execution.

When configured by the network, it is possible to initiate UL TA acquisition (called early TA) procedure of one or multiple cells that are different from the current serving cells. If the cell has the same N_{TA} as the current serving cells or N_{TA}=0, early TA acquisition procedure is not required. The network may request the UE to perform early TA acquisition of a candidate cell before a cell switch. The early TA acquisition procedure is triggered by PDCCH order as specified in clause 9.2.6 or realized through UE-based TA measurement as configured by RRC. In the former case, the

gNB/gNB-DU to which the candidate cell belongs calculates the TA value and sends it to the gNB/gNB-DU to which the serving cell belongs via gNB-CU. The serving cell sends the TA value in the LTM cell switch command MAC CE when triggering LTM cell switch. In the latter case, the UE performs TA measurement for the candidate cells after being configured by RRC but the exact time the UE performs TA measurement is up to UE implementation. The UE applies the TA value measured by itself and performs RACH-less LTM upon receiving the cell switch command, if it does not include any valid TA value. The network may also send a TA value in the LTM cell switch command MAC CE without early TA acquisition.

When two TAG IDs are configured for an LTM candidate cell, the gNB-DU to which the LTM candidate cell belongs assigns the same TAG ID pointer value for each TRP to be used by the UEs. Also when two TAG IDs are configured for an LTM candidate cell, UE-based TA measurement is not configured.

Depending on the availability of a valid TA value, the UE performs either a RACH-less LTM or RACH-based LTM cell switch. If the valid TA value is provided in the cell switch command, the UE applies the TA value as instructed by the network. In the case where UE-based TA measurement is configured, but no valid TA value is provided in the cell switch command, the UE applies the valid TA value by itself if available. The UE performs RACH-less LTM cell switch upon receiving the cell switch command whenever a valid TA value is available. If no valid TA value is available, the UE performs RACH-based LTM cell switch.

Regardless of whether the UE is configured for UE-based TA measurement for a certain candidate cell, it will still follow the PDCCH order, which includes performing a random access procedure towards one or more candidate cells. This also applies to the candidate cells for which the UE is capable of deriving TA values by itself. Additionally, regardless of whether the UE has already performed a random access procedure towards the candidate cells, it will still follow the UE-based measurement configuration if configured by the network.

For RACH-less LTM, the UE accesses the target cell using either a configured grant or a dynamic grant. The configured grant is provided in the LTM candidate configuration, and the UE selects the configured grant occasion associated with the beam indicated in the cell switch command. Upon initiation of LTM cell switch to the target cell, the UE starts to monitor PDCCH on the target cell for dynamic scheduling. Before RACH-less LTM procedure completion, the UE shall not trigger random access procedure if it does not have a valid PUCCH resource for triggered SRs. In case of dynamic grant scheduling, the network can include in the cell switch command signalled via a MAC CE the SR configuration ID which indicates to the UE the scheduling request configuration and physical layer resources on PUCCH where the UE may send the scheduling request during an LTM cell switch procedure.

The following principles apply to LTM:

- Security keys can be changed upon an LTM cell switch based on network indication;
- Subsequent LTM is supported.

LTM supports intra-gNB mobility, and inter-gNB mobility. LTM supports both intra-frequency and inter-frequency mobility, including mobility to inter-frequency cell that is not a current serving cell. LTM is supported only for licensed spectrum. The following scenarios are supported:

- PCell change in non-CA scenario and non-DC scenario;
- PCell and SCell(s) change in CA scenario;
- Dual connectivity scenarios:
  - PCell change together with MCG SCells(s) change and intra-SN PSCell change;
  - PSCell change together with SCG SCell(s) change with or without MN involvement.

NOTE: LTM for simultaneous PCell and inter-SN PSCell change is not supported. Inter-gNB LTM configuration for MN and SN at the same time is also not supported.

While the UE has stored LTM candidate configurations the UE can also execute any L3 handover except for DAPS handover. In the RRC message which the UE applies for any L3 handover (except DAPS), LTM candidate configurations can be added/modified/released by the target cell.

9.2.3.5.2 C-Plane Handling

Cell switch command is conveyed in a MAC CE, which contains the necessary information to perform the LTM cell switch.

The overall procedure for intra-gNB LTM is shown in Figure 9.2.3.5.2-1 below. Subsequent LTM is done by repeating the early synchronization, LTM cell switch execution, and LTM cell switch completion steps without the need to release, reconfigure or add other LTM candidate configurations after each LTM cell switch completion. The general procedure over the air interface is applicable to SCG LTM. Further details of SCG LTM can be found in TS 37.340 [21].

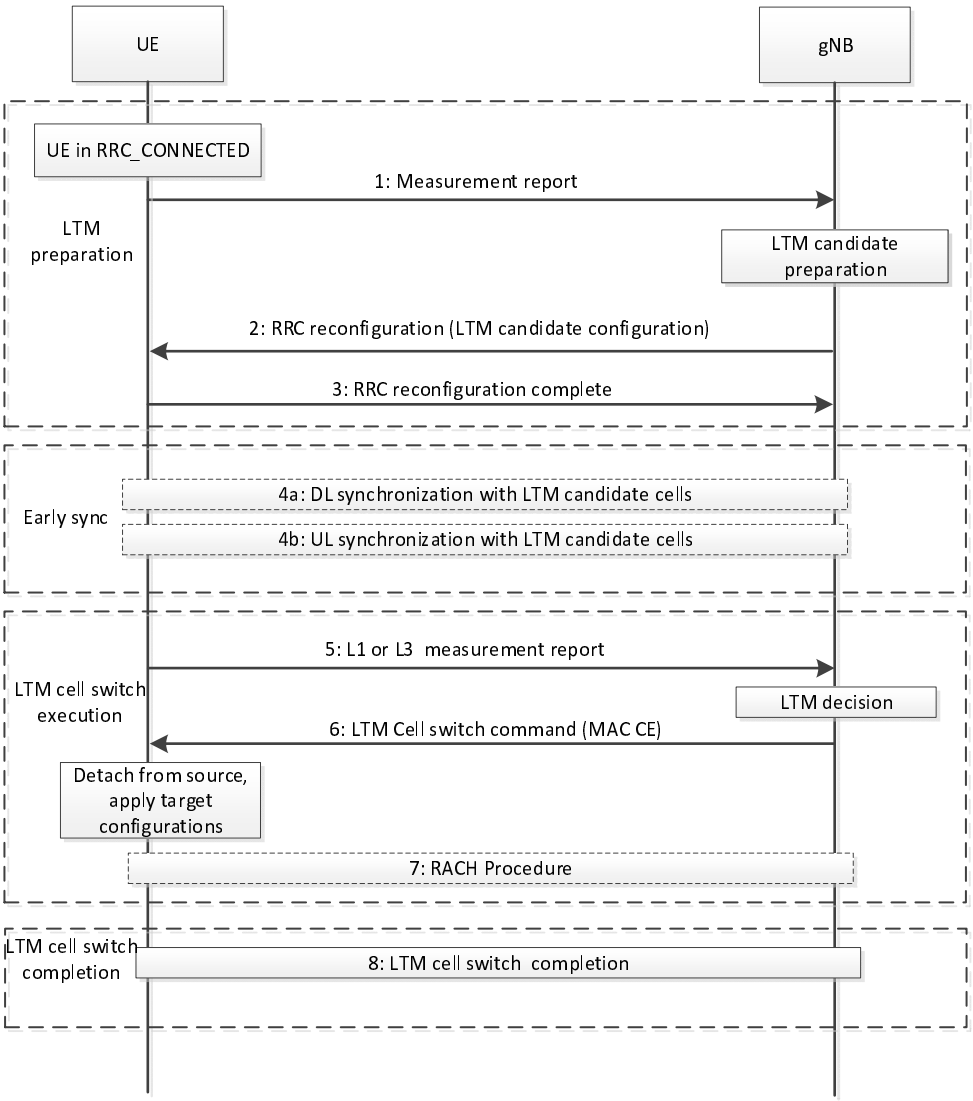


Figure 9.2.3.5.2-1. Signalling procedure for intra-gNB LTM

The procedure for intra-gNB LTM is as follows:

1. The UE sends a *MeasurementReport* message to the gNB. The gNB decides to configure LTM and initiates LTM preparation.

2. The gNB transmits an *RRCReconfiguration* message to the UE including the LTM candidate configurations.

3. The UE stores the LTM candidate configurations and transmits an *RRCReconfigurationComplete* message to the gNB.

4a. The UE performs DL synchronization with the LTM candidate cell(s) before receiving the cell switch command. The UE may activate and deactivate TCI states of LTM candidate cell(s), as triggered by the gNB and defined in TS 38.133 [13].

4b. The UE may perform UL synchronization with LTM candidate cell(s) before receiving the cell switch command, by using UE-based TA measurement, if configured, and/or by transmitting a preamble towards the candidate cell, as triggered by the gNB. When UE-based TA measurement is configured, UE acquires the TA value(s) of the candidate cell(s) by measurement. UE performs early TA acquisition with the candidate cell(s) as requested

by the network before receiving the cell switch command as specified in clause 9.2.6 and TS 38.133 [13]. This is done via CFRA triggered by a PDCCH order from the source cell, following which the UE sends preamble towards the indicated candidate cell. In order to minimize the data interruption of the source cell due to CFRA towards the candidate cell(s), the UE does not receive random access response from the network for the purpose of TA value acquisition and the TA value of the candidate cell is indicated in the cell switch command. The UE does not maintain the TA timer for the candidate cell and relies on network implementation to guarantee the TA validity.

5. The UE performs L1 measurements on the configured LTM candidate cell(s) and transmits L1 measurement reports to the gNB. L1 measurement should be performed as long as RRC reconfiguration (step 2) is applicable. The UE can also perform L3 measurement reporting to the gNB, including beam level measurement results on cell(s) which are configured as LTM candidate cell(s) according to the received network configuration.

6. The gNB decides to execute cell switch to a target cell and transmits an LTM cell switch command MAC CE triggering cell switch by including a target configuration ID which indicates the index of the candidate configuration of the target cell, a beam indicated with a TCI state or beams indicated with DL and UL TCI states, and a timing advance command for the target cell, if available. The UE switches to the target cell and applies the candidate configuration indicated by the target configuration ID.

7. The UE performs the random access procedure towards the target cell, if UE does not have valid TA of the target cell as specified in clause 5.18.35 of TS 38.321[6].

8. The UE completes the LTM cell switch procedure by sending *RRCReconfigurationComplete* message to target cell. If the UE has performed a RA procedure in step 7 the UE considers that LTM cell switch execution is successfully completed when the random access procedure is successfully completed. For RACH-less LTM, the UE considers that LTM cell switch execution is successfully completed when the UE determines that the network has successfully received its first UL data.

The steps 4-8 can be performed multiple times for subsequent LTM cell switch executions using the LTM candidate configuration(s) provided in step 2.

The overall procedure for inter-gNB LTM is shown in Figure 9.2.3.5.2-2 below.

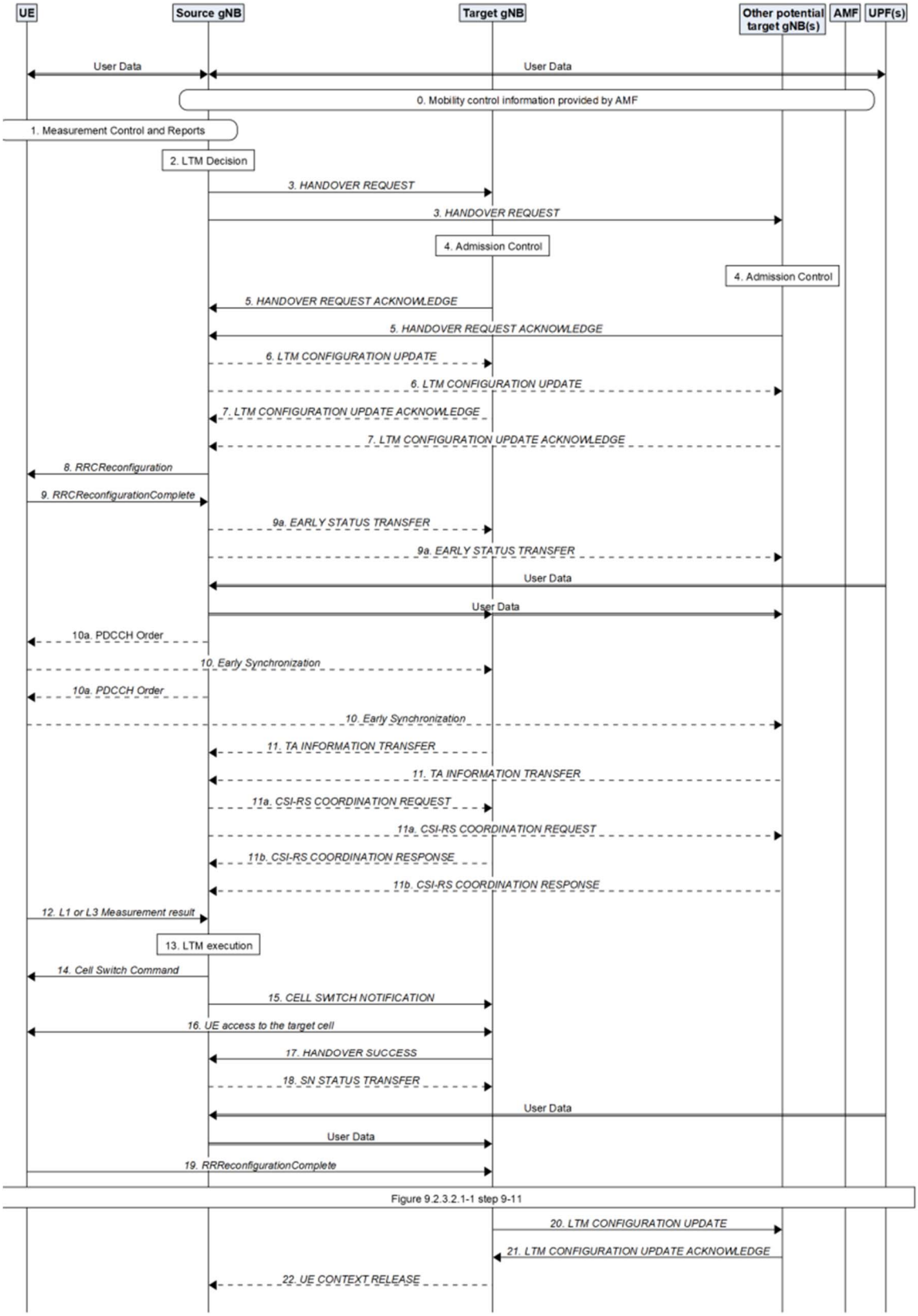


Figure 9.2.3.5.2-2. Signalling procedure for inter-gNB LTM

The procedure for inter-gNB LTM is as follows:

1. The UE sends a MeasurementReport message (L3 measurement result) to the source gNB containing measurements of neighbouring cells.

2. The source gNB decides to configure LTM.

3. The source gNB requests LTM for one or more candidate cells belonging to the source gNB and/or one or more candidate gNB(s). For inter-gNB LTM, the source gNB initiates a HANDOVER REQUEST message per candidate cell containing one candidate cell ID and may contain the CSI resource configuration for subsequent LTM. For both intra and inter-gNB LTM, the source gNB may request the candidate cell(s)/gNB(s) to provide the CSI-RS resource configuration for L1 RSRP measurement. The source gNB may include the proposed LTM no security change related information, and the proposed L2 reset configuration information. For inter-gNB LTM, the source gNB includes the same source NG-RAN node UE XnAP ID for all the HANDOVER REQUEST messages to one candidate gNB.

4. Admission Control may be performed by the candidate cells(s)/gNB(s).

5. The candidate gNB(s) prepares and provides the LTM configuration(s) to the source gNB. For inter-gNB LTM, the candidate gNB(s) respond(s) with HANDOVER REQUEST ACKNOWLEDGE message to the source gNB including the generated RRC configurations for the accepted candidate cell. For both intra and inter-gNB LTM, the candidate gNB(s) may include the CSI-RS resource configuration for early CSI acquisition, and upon request, may also include additional information related to the CSI-RS resource configuration for L1 measurement and early sync information. The candidate gNB(s) also responds with the selected LTM no security change related information. For inter-gNB LTM, each candidate gNB includes the same target NG-RAN node UE XnAP ID for all the HANDOVER REQUEST ACKNOWLEDGE messages it responds. The candidate gNB may respond the selected L2 reset configuration information upon request.

6. The source gNB sends an LTM CONFIGURATION UPDATE message to the candidate gNB(s) to update the LTM configurations of candidate cell(s). The source gNB may include the common CSI resource configuration, the LTM configuration ID mapping list and the LTM security information.

7. The candidate gNB(s) sends the LTM CONFIGURATION UPDATE ACKNOWLEDGE message to the source gNB. The candidate gNB(s) may provide the CSI report configuration. The candidate gNB may also include the CSI report configuration for early CSI acquisition of the candidate cell(s).

NOTE 1: Step 6 may also be triggered after step 14, or after step 17 by implementation for subsequent LTM.

NOTE 2: Step 6 and Step 7 are triggered if early CSI acquisition is applied.

8. The source gNB sends an *RRCReconfiguration* message to the UE.

9. The UE stores the LTM candidate configurations and sends an *RRCReconfigurationComplete* message to the source gNB.

NOTE 3: Void.

9a. If early data forwarding is applied, the source gNB sends the EARLY STATUS TRANSFER message to the candidate gNB(s).

10/11. Early DL and UL synchronization to some LTM candidate cell(s) may be performed. The source gNB may activate or deactivate the TCI states of the candidate LTM cells. Depending on network configuration, the UE may perform early UL synchronization with LTM candidate cell(s), by using UE-based TA measurement, if configured, and/or by transmitting a preamble towards the candidate cell, as triggered by the source gNB. With a network triggered UL synchronization, a PDCCH order is received from the source cell to trigger CFRA to a candidate cell, the UE performs early TA acquisition by sending preamble towards the indicated candidate cell. In order to minimize the data interruption on the source cell due to CFRA towards the indicated candidate cell(s), the UE does not receive random access response from the network for the purpose of TA value acquisition. The candidate gNB(s) sends the TA INFORMATION TRANSFER message to the source gNB instead.

11a/11b. The source gNB may initiate a CSI-RS COORDINATION REQUEST message to request the candidate gNB(s) to activate or deactivate semi-persistent CSI-RS resources for Layer 1 measurements and/or for early CSI acquisition. The candidate gNB(s) respond to the source gNB with the CSI-RS COORDINATION RESPONSE message indicating whether the requested CSI-RS resources are activated or deactivated.

NOTE 3a: Step 11a/11b may be triggered by implementation after step 9.

NOTE 3b: The Handover Cancel procedure may be initiated either before or after the cell switch by the serving gNB.

12. The UE performs L1 or L3 measurements on the configured LTM candidate cell(s) and transmits L1 or L3 measurement reports to the source gNB, if configured. L1 or L3 measurement should be performed as long as RRC reconfiguration (step 8) is applicable.

13. The source gNB determines to initiate LTM. L3 measurement can also be used to determine this step.

14. The source gNB decides to execute cell switch to a target cell and transmits an LTM cell switch command MAC CE triggering cell switch by including a target configuration ID which indicates the index of the candidate configuration, a beam indicated with a TCI state or beams indicated with DL and UL TCI states, and a TA command for the target cell. In case of a security context change, the LTM cell switch command MAC CE also contains the NCC value. The UE switches to the target cell and applies the candidate configuration indicated by the target configuration ID. In case of security context change, the UE generates and applies the new security keys based on the received NCC value.

NOTE 4: Up to implementation, data forwarding and SN Status Transfer may be initiated once the source gNB triggers the inter-gNB LTM cell switch for the UE in Step 14.

15. The source gNB sends the CELL SWITCH NOTIFICATION message to the target gNB to indicate the initiation of Cell Switch command to the UE. The source gNB may inform the acquired TA related information.

NOTE 4a: The order in which step 14 and step 15 are executed is up to implementation.

16. The UE performs the random access procedure towards the target cell, if UE does not have valid TA of the target cell as specified in clause 5.18.35 of TS 38.321[6].

17/18. The target gNB sends the HANDOVER SUCCESS message to the source gNB to inform that the UE has successfully accessed the target cell. In return, the source gNB sends the SN STATUS TRANSFER message following the principles described in step 7 of Intra-AMF/UPF Handover in clause 9.2.3.2.1.

NOTE 5: Late data forwarding may be initiated as soon as the source gNB receives the HANDOVER SUCCESS message.

NOTE 6: The source gNB may initiate the CSI-RS Coordination procedure to deactivate the semi-persistent CSI-RS resource(s) of candidate cell(s) on the candidate gNB(s) after the UE successfully accesses the target cell.

19. The UE completes the LTM cell switch procedure by sending *RRCReconfigurationComplete* message to target cell. If the UE has performed a RA procedure in step 16 the UE considers that LTM cell switch execution is successfully completed when the random access procedure is successfully completed. For RACH-less LTM, the UE considers that LTM cell switch execution is successfully completed when the UE determines that the network has successfully received its first UL data

NOTE 7: Steps 17/18 and 19 do not have to occur one after the other. The target gNB may send the HANDOVER SUCCESS message to the source gNB after receiving the *RRCReconfigurationComplete* message.

20. The new source gNB (i.e., the target gNB) sends the LTM CONFIGURATION UPDATE message to the candidate gNBs. This message includes the new security key(s) to be used with the UE.

21. The candidate gNB(s) responds with the LTM CONFIGURATION UPDATE ACKNOWLEDGE message to the new source gNB.

22. The new source gNB may send the UE CONTEXT RELEASE message to inform the old source gNB to release radio and C-plane related resources associated to the UE context if no LTM candidate cell(s) exist in the old source gNB. Any ongoing data forwarding may continue.

The steps 9a-22 can be performed multiple times for subsequent LTM cell switch executions using the LTM candidate configuration(s) provided in step 8.

The procedure over the air interface described in Figure 9.2.3.5.2-1 is applicable to both intra-gNB LTM and inter-gNB LTM. The overall LTM procedures over F1-C interface are captured in TS 38.401[4].

9.2.3.5.3 U-Plane Handling

After receiving an LTM cell switch command MAC CE, the UE performs MAC reset. Whether the UE performs RLC re-establishment and PDCP data recovery during cell switch is explicitly controlled by the network through RRC signalling.

9.2.3.6 RACH-less handover

RACH-less handover is supported for an intra-gNB handover procedure in TN and NTN. RACH-less handover is also supported for an inter-gNB handover procedure in the case of NTN or mobile IAB-DU migration procedure. The RACH-less handover procedure applies the following functionality:

- The UE uses the same timing advance value (i.e., N_{TA} value) at the target cell as in the source cell or timing advance value (i.e., N_{TA} value) of 0.
- The handover command for the UE may contain a beam identifier for the beam to be used by the UE at the target cell. The beam may be determined based on a UE measurement report and/or left up to gNB implementation, e.g., using the target cell's knowledge about the beam(s) used by the UE at the co-located source cell.
- The handover command may include a configured UL grant. UE can fallback to RACH when there is no valid configured uplink grant. Alternatively, an UL grant is dynamically signalled by the target cell.
- The UE transmits the *RRCReconfigurationComplete* message using the configured or dynamically signalled UL grant. Successful UL data reception on the target cell terminates the RACH-less handover execution.

9.2.3.7 Conditional L1/L2 Triggered Mobility

9.2.3.7.1 General

CLTM cell switch is executed by the UE when L1-based or L3-based LTM cell switch execution conditions are met. The same LTM procedures as described in clause 9.2.3.5.1 on network activation of TCI states for DL synchronization and on configuration and initiation of UL TA acquisition (via PDCCH order) are also applicable for CLTM. CLTM can coexist with network triggered L3 HO, CHO and network triggered PSCell change, while the coexistence of CLTM and DAPS HO is not supported. The overall procedure for CLTM is as shown in Figure 9.2.3.7.1-1:

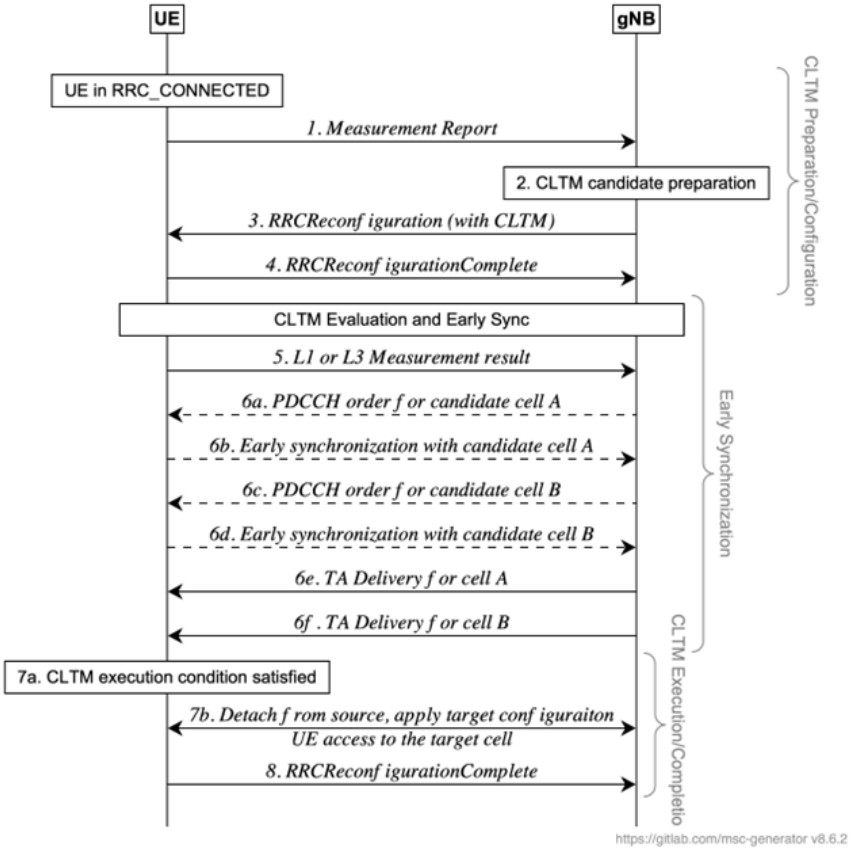


Figure 9.2.3.7.1-1. Signalling procedure for CLTM

The procedure for CLTM is as follows:

1. The UE sends a MeasurementReport message to the gNB. The gNB decides to configure CLTM and initiates CLTM preparation.

2. The source gNB can request the candidate cells to provide conditional execution configurations and the candidate cells provide the conditional configuration including their own execution conditions, to be used in subsequent CLTM.

3. The source gNB sends an *RRCReconfiguration* message to the UE and this includes the CLTM configurations of candidate cells as well as the execution condition for the CLTM.

4. The UE stores the CLTM candidate configurations and transmits an *RRCReconfigurationComplete* message to the gNB. The UE starts evaluating the execution conditions based on the provided configuration.

5/6. Early DL and UL synchronization to some LTM candidate cell(s) may be performed. The source gNB may activate or deactivate the TCI states of the candidate LTM cells. The source gNB can trigger early synchronization (for example, based on the L1 or L3 measurement reports from the UE, if configured) to the UE and steps 4a/4b from figure 9.2.3.5.2-1 are applicable here as well. In addition, the source gNB can provide the TA value for each of the candidate cells the UE has performed UL synchronization with. Depending on network configuration, the UE may perform early UL synchronization with CLTM candidate cell(s), by using UE-based TA measurement, if configured.

7. The CLTM execution condition is satisfied at the UE and on (at least) one satisfied candidate LTM cell, the UE performs the CLTM execution by applying the configuration of the satisfied LTM candidate cell. If the UE has valid TA as part of the UL early synchronization from step 6, the UE skips RACH. Otherwise, RACH is performed as part of the CLTM execution.

8. The UE completes the CLTM cell switch procedure by sending *RRCReconfigurationComplete* message to the switched LTM cell. For RACH-based CLTM, the UE considers that CLTM cell switch execution is successfully completed when the random access procedure is successfully completed. For RACH-less CLTM, the UE considers that CLTM cell switch execution is successfully completed when the UE determines that the network

has successfully received its first UL data. The UE does not release any valid TA value(s) of LTM candidate cells with CLTM configuration.

The steps 5-8 can be performed multiple times for subsequent CLTM cell switch executions using the CLTM candidate configuration(s) provided in step 2.

The following principles apply to CLTM:

- CLTM is supported for intra-gNB LTM when DC is not configured. Inter-gNB CLTM is not supported;
- CLTM can be RACH-based or RACH-less. RACH-based CLTM includes CFRA and CBRA, and only CG based RACH-less CLTM is supported;
- U-Plane handling from clause 9.2.3.5.3 applies to CLTM as well and since there is no LTM cell switch command MAC CE reception for CLTM, the UE performs MAC reset as part of the CLTM execution.

9.2.4 Measurements

In RRC_CONNECTED, both layer 1 (L1) and layer 3 (L3) based measurements are supported, L1 measurement reporting is evaluated based on beam quality and L3 measurement reporting is evaluated based on cell quality.

For L3 based measurement, the UE measures multiple beams (at least one) of a cell and the measurements results (power values) are averaged to derive the cell quality. In doing so, the UE is configured to consider a subset of the detected beams. Filtering takes place at two different levels: at the physical layer to derive beam quality and then at RRC level to derive cell quality from multiple beams. Cell quality from beam measurements is derived in the same way for the serving cell(s) and for the non-serving cell(s). Measurement reports may contain the measurement results of the *X* best beams if the UE is configured to do so by the gNB.

For L1 based measurement used in LTM event-triggered measurement, the UE measures the beams configured for LTM. Filtering takes place at the physical layer to derive the beam quality. The measurement reports are sent using MAC CE and contain the measurement results of the *X* (at least one) beams.

The corresponding high-level measurement model is described below:

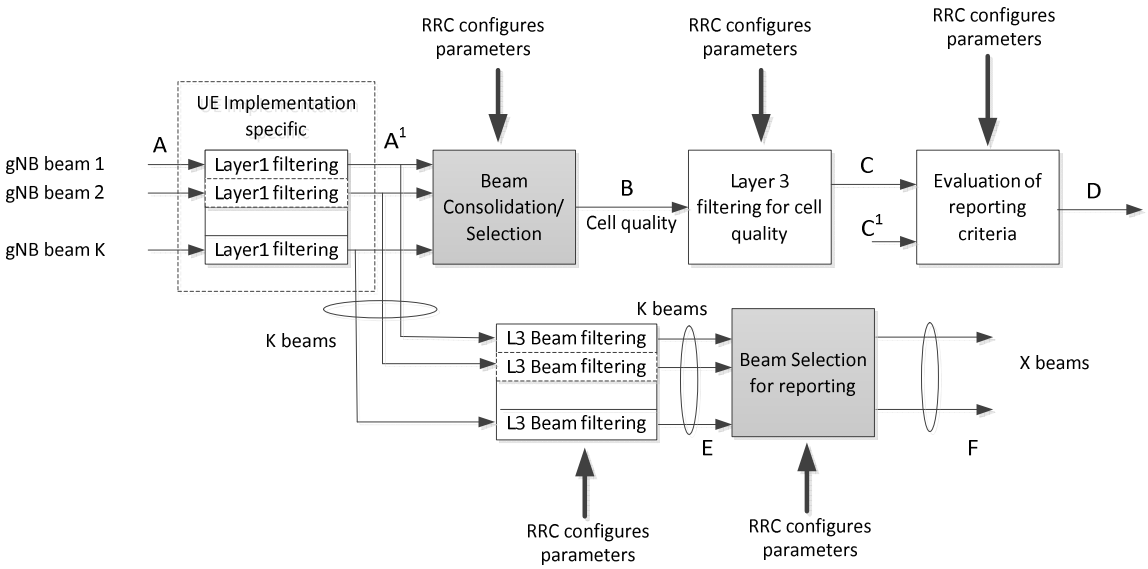


Figure 9.2.4-1: Measurement Model

NOTE 1: K beams correspond to the measurements on SSB or CSI-RS resources configured for L3 mobility by gNB and detected by UE at L1.

- **A**: measurements (beam specific samples) internal to the physical layer.

- **Layer 1 filtering**: internal layer 1 filtering of the inputs measured at point A. Exact filtering is implementation dependent. How the measurements are actually executed in the physical layer (inputs A and Layer 1 filtering) is not constrained by the standard.

- **A^1**: measurements (i.e. beam specific measurements) reported by layer 1 to layer 3 after layer 1 filtering.

- **Beam Consolidation/Selection**: beam specific measurements are consolidated to derive cell quality. The behaviour of the Beam consolidation/selection is standardised and the configuration of this module is provided by RRC signalling. Reporting period at B equals one measurement period at A^1.

- **B**: a measurement (i.e. cell quality) derived from beam-specific measurements reported to layer 3 after beam consolidation/selection.

- **Layer 3 filtering for cell quality**: filtering performed on the measurements provided at point B. The behaviour of the Layer 3 filters is standardised and the configuration of the layer 3 filters is provided by RRC signalling. Filtering reporting period at C equals one measurement period at B.

- **C**: a measurement after processing in the layer 3 filter. The reporting rate is identical to the reporting rate at point B. This measurement is used as input for one or more evaluation of reporting criteria.

- **Evaluation of reporting criteria**: checks whether actual measurement reporting is needed at point D. The evaluation can be based on more than one flow of measurements at reference point C e.g. to compare between different measurements. This is illustrated by input C and C^1. The UE shall evaluate the reporting criteria at least every time a new measurement result is reported at point C, C^1. The reporting criteria are standardised and the configuration is provided by RRC signalling as specified in TS 38.331 [12].

- **D**: measurement report information (message) sent on the radio interface.

- **L3 Beam filtering**: filtering performed on the measurements (i.e. beam specific measurements) provided at point A^1. The behaviour of the beam filters is standardised and the configuration of the beam filters is provided by RRC signalling. Filtering reporting period at E equals one measurement period at A^1.

- **E**: a measurement (i.e. beam-specific measurement) after processing in the beam filter. The reporting rate is identical to the reporting rate at point A^1. This measurement is used as input for selecting the X measurements to be reported.

- **Beam Selection for beam reporting**: selects the X measurements from the measurements provided at point E. The behaviour of the beam selection is standardised and the configuration of this module is provided by RRC signalling.

- **F**: beam measurement information included in measurement report (sent) on the radio interface.

Layer 1 filtering introduces a certain level of measurement averaging. How and when the UE exactly performs the required measurements is implementation specific to the point that the output at B fulfils the performance requirements set in TS 38.133 [13]. Layer 3 filtering for cell quality and related parameters used are specified in TS 38.331 [12] and do not introduce any delay in the sample availability between B and C. Measurement at point C, C^1 is the input used in the event evaluation. L3 Beam filtering and related parameters used are specified in TS 38.331 [12] and do not introduce any delay in the sample availability between A^1 and E.

The high-level model for LTM event-triggered measurement is described below:

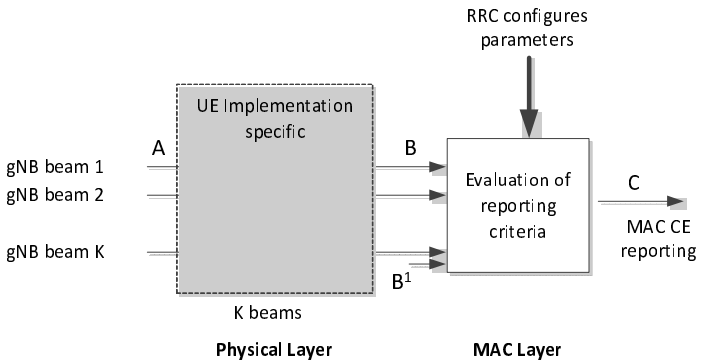


Figure 9.2.4-2: LTM Event-triggered Measurement Model

NOTE 1a: K beams correspond to the measurements on SSB or CSI-RS resources configured for LTM by gNB and detected by UE at L1.

- **A:** measurements (beam specific samples) internal to the physical layer.
- **Layer 1 filtering:** internal layer 1 filtering of the inputs measured at point A. Exact filtering is implementation dependent. How the measurements are actually executed in the physical layer (inputs A and Layer 1 filtering) is not constrained by the standard.
- **B:** a measurement after layer 1 filtering. This beam measurement is used as input for one or more evaluation of LTM event triggering and reporting criteria.
- **Evaluation of reporting criteria:** checks whether actual measurement reporting is needed at point C. The evaluation can be based on more than one flow of measurements at reference point B e.g. to compare between different measurements. This is illustrated by input B and B1. The UE shall evaluate the reporting criteria at least every time a new measurement result is reported at point B, B1. The reporting criteria are standardised and the configuration is provided by RRC signalling specified in TS 38.331 [12].
- **C:** LTM MAC CE measurement report information (message) sent on the radio interface.

Measurement reports for L3 based measurements are characterized by the following:

- Measurement reports include the measurement identity of the associated measurement configuration that triggered the reporting;
- Cell and beam measurement quantities to be included in measurement reports are configured by the network;
- The number of non-serving cells to be reported can be limited through configuration by the network;
- Cells belonging to an exclude-list configured by the network are not used in event evaluation and reporting, and conversely when an allow-list is configured by the network, only the cells belonging to the allow-list are used in event evaluation and reporting;
- Beam measurements to be included in measurement reports are configured by the network (beam identifier only, measurement result and beam identifier, or no beam reporting).

Measurement reports for LTM event triggered measurements are characterized by the following:

- Measurement reports include the reporting configuration identity that triggered the reporting;
- The max number of beam and the beam measurement quantities to be included in measurement reports are configured by network;
- The current beam of the serving cell to be included in measurement reports are configured by the network;
- When multi-TRP is configured for the serving cell, the UE uses the best beam of the current beams for LTM event evaluation and reporting. It is up to the UE implementation how to choose the best beam.

Intra-frequency neighbour (cell) measurements and inter-frequency neighbour (cell) measurements are defined as follows:

- SSB based intra-frequency measurement: a measurement is defined as an SSB based intra-frequency measurement provided the SSB frequency configured in the measurement object associated with the serving cell and the center frequency of the SSB of the neighbour cell are the same, and the subcarrier spacing of the two SSBs is also the same.
- SSB based inter-frequency measurement: a measurement is defined as an SSB based inter-frequency measurement provided the SSB frequency configured in the measurement object associated with the serving cell and the center frequency of the SSB of the neighbour cell are different, or the subcarrier spacing of the two SSBs is different. The SSBs of the same center frequency have the same subcarrier spacing in this release.

NOTE 2: For SSB based measurements, one measurement object corresponds to one SSB. The UE considers different SSBs as different cells, except if SSB and OD-SSB in different frequencies are associated with the same SCell.

NOTE 2a: If a UE is configured to perform serving cell measurements based on an NCD-SSB configured in its active BWP, this NCD-SSB is considered as the SSB of the serving cell in the definition of intra-frequency and inter-frequency measurements as above.

NOTE 2b: The above measurement object associated with the serving cell refers to the serving cell measurement object for OD-SSB when SSB is absent and OD-SSB is activated, or when SSB and OD-SSB have a different frequency and OD-SSB is activated. Otherwise, it refers to the serving cell measurement object for SSB.

- CSI-RS based intra-frequency measurement: a measurement is defined as a CSI-RS based intra-frequency measurement provided that:
  - The subcarrier spacing of CSI-RS resources on the neighbour cell configured for measurement is the same as the SCS of CSI-RS resources on the serving cell indicated for measurement; and
  - For 60kHz subcarrier spacing, the CP type of CSI-RS resources on the neighbour cell configured for measurement is the same as the CP type of CSI-RS resources on the serving cell indicated for measurement; and
  - The centre frequency of CSI-RS resources on the neighbour cell configured for measurement is the same as the centre frequency of CSI-RS resource on the serving cell indicated for measurement.
- CSI-RS based inter-frequency measurement: a measurement is defined as a CSI-RS based inter-frequency measurement if it is not a CSI-RS based intra-frequency measurement.

NOTE 3: Extended CP for CSI-RS based measurement is not supported in this release.

- CSI-RS based intra-frequency L1 measurement for LTM: a measurement is defined as a CSI-RS based intra-frequency L1 measurement for LTM provided that:
  - The subcarrier spacing of the CSI-RS resources of the LTM candidate cell(s) configured for L1 measurement is the same as the subcarrier spacing of active DL BWP; and
  - For 60kHz subcarrier spacing, the CP type of the CSI-RS resource of LTM candidate cell(s) configured for L1 measurement is the same as the CP type of active DL BWP; and
  - At least 48 RBs of the CSI-RS resource of LTM candidate cell(s) configured for L1 measurement are included within the active DL BWP.
- CSI-RS based inter-frequency L1 measurement for LTM: a CSI-RS L1 based measurement for LTM is defined as a CSI-RS based inter-frequency L1 measurement for LTM if it is not a CSI-RS based intra-frequency measurement for LTM.

Whether a measurement is non-gap-assisted or gap-assisted depends on the capability of the UE, the active BWP of the UE and the current operating frequency:

- For SSB based inter-frequency measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided in the following cases:
  - If the UE only supports per-UE measurement gaps;
  - If the UE supports per-FR measurement gaps and any of the serving cells are in the same frequency range of the measurement object.
- For SSB based intra-frequency measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided in the following case:
  - If the serving cell is associated with SSB, other than the initial BWP, if any of the UE configured BWPs do not contain the frequency domain resources of the SSB associated to the initial DL BWP, and are not configured with NCD-SSB for serving cell measurement;

NOTE 4: When the serving cell is associated with both SSB and OD-SSB in different frequency, "the SSB associated to the initial DL BWP" includes both SSB and OD-SSB.

  - If the serving cell is not associated with SSB (i.e. SSB-less SCell), if the initial BWP or any of the UE configured BWPs do not contain the SSB frequency configured in the measurement object associated with the serving cell, and are not configured with NCD-SSB for serving cell measurement.

- For CSI-RS based intra-frequency measurement, no measurement gap is needed;
- For CSI-RS based inter-frequency measurement, a measurement gap configuration is always provided in the following cases:
  - If the UE only supports per-UE measurement gaps;
  - If the UE supports per-FR measurement gaps and any of the serving cells are in the same frequency range of the measurement object.

In non-gap-assisted scenarios, the UE shall be able to carry out such measurements without measurement gaps. In gap-assisted scenarios, the UE cannot be assumed to be able to carry out such measurements without measurement gaps.

Network may request the UE to measure NR and/or E-UTRA carriers in RRC_IDLE or RRC_INACTIVE via system information or via dedicated measurement configuration in *RRCRelease*. If the UE was configured to perform measurements of NR and/or E-UTRA carriers while in RRC_IDLE or in RRC_INACTIVE, it may provide an indication of the availability of corresponding measurement results to the gNB in the *RRCSetupComplete* message. The network may request the UE to report those measurements after security activation. The request for the measurements can be sent by the network immediately after transmitting the Security Mode Command (i.e. before the reception of the Security Mode Complete from the UE).

If the UE was configured to perform measurements of NR and/or E-UTRA carriers while in RRC_INACTIVE, the gNB can request the UE to provide corresponding measurement results in the *RRCResume* message and then the UE can include the available measurement results in the *RRCResumeComplete* message. Alternatively, the UE may provide an indication of the availability of the measurement results to the gNB in the *RRCResumeComplete* message and the gNB can then request the UE to provide these measurement results.

9.2.5 Paging

Paging allows the network to reach UEs in RRC_IDLE and in RRC_INACTIVE state through *Paging* messages, and to notify UEs in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED state of system information change (see clause 7.3.3) and ETWS/CMAS indications (see clause 16.4) through *Short Messages*. Both *Paging* messages and *Short Messages* are addressed with P-RNTI on PDCCH, but while the former is sent on PCCH, the latter is sent over PDCCH directly (see clause 6.5 of TS 38.331 [12]).

While in RRC_IDLE the UE monitors the paging channels for CN-initiated paging. While in RRC_INACTIVE with no ongoing SDT procedure (see clause 18.0) the UE monitors paging channels for RAN-initiated paging and CN-initiated paging. A UE need not monitor paging channels continuously though; Paging DRX is defined where the UE in RRC_IDLE or RRC_INACTIVE is only required to monitor paging channels during one Paging Occasion (PO) per DRX cycle (see TS 38.304 [10]). The Paging DRX cycles are configured by the network:

1) For CN-initiated paging, a default cycle is broadcast in system information;
2) For CN-initiated paging, a UE specific cycle can be configured via NAS signalling;
3) For RAN-initiated paging, a UE-specific cycle is configured via RRC signalling;

- The UE uses the shortest of the DRX cycles applicable i.e. a UE in RRC_IDLE uses the shortest of the first two cycles above, while a UE in RRC_INACTIVE uses the shortest of the three.

The POs of a UE for CN-initiated and RAN-initiated paging are based on the same UE ID, resulting in overlapping POs for both. The number of different POs in a DRX cycle is configurable via system information and a network may distribute UEs to those POs based on their IDs.

While in RRC_CONNECTED and while in RRC_INACTIVE with ongoing SDT procedure, the UE monitors the paging channels in any PO signalled in system information for SI change indication and PWS notification. In case of BA, a UE in RRC_CONNECTED only monitors paging channels on the active BWP with common search space configured.

For operation with shared spectrum channel access, a UE can be configured for an additional number of PDCCH monitoring occasions in its PO to monitor for paging. However, when the UE detects a PDCCH transmission within the UE's PO addressed with P-RNTI, the UE is not required to monitor the subsequent PDCCH monitoring occasions within this PO.

If Paging Cause is included in the Paging message, a UE in RRC_IDLE or RRC_INACTIVE state may use the Paging Cause as per TS 23.501[3].

To reduce the probability of potential paging loss due to incomplete UE Radio Capability for Paging, the gNB may update the UE Radio Capability for Paging towards the AMF during the initial context setup procedure as specified in TS 38.413 [26].

Paging optimization for UEs in CM_IDLE: at UE context release, the NG-RAN node may provide the AMF with a list of recommended cells and NG-RAN nodes as assistance info for subsequent paging. The AMF may also provide Paging Attempt Information consisting of a Paging Attempt Count and the Intended Number of Paging Attempts and may include the Next Paging Area Scope. If Paging Attempt Information is included in the Paging message, each paged NG-RAN node receives the same information during a paging attempt. The Paging Attempt Count shall be increased by one at each new paging attempt. The Next Paging Area Scope, when present, indicates whether the AMF plans to modify the paging area currently selected at next paging attempt. If the UE has changed its state to CM CONNECTED the Paging Attempt Count is reset.

Paging optimization for UEs in RRC_INACTIVE: at RAN Paging, the serving NG-RAN node provides RAN Paging area information. The serving NG-RAN node may also provide RAN Paging attempt information. Each paged NG-RAN node receives the same RAN Paging attempt information during a paging attempt with the following content: Paging Attempt Count, the intended number of paging attempts and the Next Paging Area Scope. The Paging Attempt Count shall be increased by one at each new paging attempt. The Next Paging Area Scope, when present, indicates whether the serving NG_RAN node plans to modify the RAN Paging Area currently selected at next paging attempt. If the UE leaves RRC_INACTIVE state the Paging Attempt Count is reset.

UE power saving for paging monitoring: in order to reduce UE power consumption due to false paging alarms, the group of UEs monitoring the same PO can be further divided into multiple subgroups. With subgrouping, a UE shall monitor PDCCH in its PO for paging if the subgroup to which the UE belongs is paged as indicated via associated PEI and/or LP-WUS. UE configured with LP-WUS also monitors a common codepoint associated with all subgroups in a PO. If a UE's subgroup ID is not indicated in the received PEI and/or LP-WUS, then the UE is not required to monitor its PO. If a UE's subgroup ID is not supported in a cell or if the UE is unable to monitor the associated PEI and/or LP-WUS occasion corresponding to its PO, it shall monitor the paging in its PO. If the UE is configured with both LP-WUS and PEI, and the UE's subgroup ID for LP-WUS is not supported in a cell or if the UE is unable to monitor the LP-WUS it monitors the following PEI or paging in its PO.

The gNB configures entry and exit conditions to monitor LP-WUS in system information. The UE may start monitoring LP-WUS when measurements using the MR are above the configured entry threshold(s), and the measurements using the LR are above the entry threshold(s), if configured. Exit conditions for LP-WUS monitoring are based on LR as specified in TS 38.304 [10]. LP-WUS monitoring can be disabled in the UE via NAS signalling. If LP-WUS disable indication via NAS signalling is absent LP-WUS monitoring is enabled, as described in TS 23.501 [3].

These subgroups have the following characteristics:

- They are formed based on either CN controlled subgrouping or UE ID based subgrouping;
- If CN controlled subgroup ID is not provided from AMF, UE ID based subgrouping is used if supported by the UE and network;
- The RRC state (RRC_IDLE or RRC_INACTIVE state) does not impact which subgroup the UE belongs to;
- Subgrouping support for a cell is broadcast in the system information as one of the following: Only CN controlled subgrouping supported, only UE ID based subgrouping supported, or both CN controlled subgrouping and UE ID based subgrouping supported;
- Total number of subgroups allowed in a cell is up to 8 for PEI and up to 31 for LP-WUS and represents the sum of CN controlled and UE ID based subgrouping configured by the network;
- A UE configured with CN controlled subgroup ID applies CN controlled subgroup ID if the cell supports CN controlled subgrouping; otherwise, it derives UE ID based subgroup ID if the cell supports only UE ID based subgrouping.

PEI or LP-WUS associated with subgroups has the following characteristics:

- If the PEI or LP-WUS monitoring is supported by the UE, it shall at least support UE ID based subgrouping method;
  - PEI monitoring can be limited via system information to the last used cell (i.e., the cell in which the UE most recently received *RRCRelease* without indicating that the last used cell for PEI shall not be updated);
  - A PEI-capable UE shall store its last used cell information;
  - gNBs supporting the PEI monitoring to the last used cell function provide the UE's last used cell information to the AMF in the NG-AP UE Context Release Complete message for PEI capable UEs, as described in TS 38.413 [26];
  - UE that expects MBS group notification shall ignore the PEI and LP-WUS and the UE shall monitor paging in its PO.

For LP-WUS, the maximum number of subgroups per PO is dependent on the number of PO(s) associated with one LO as specified in TS 38.331 [12]. The typical area in which the PO-to-LO association is the same is up to network configuration.

CN controlled subgrouping: For CN controlled subgrouping, AMF is responsible for assigning subgroup ID to the UE. The total number of subgroups for CN controlled subgrouping which can be configured, e.g. by OAM is up to 8 for PEI and up to 31 for LP-WUS. It is assumed that the same number of CN controlled subgroups is used at least within the registration area or the entire PLMN. It is assumed that CN controlled subgrouping support is homogeneous within a TA.

The following figure describes the procedure for CN controlled subgrouping for PEI and LP-WUS:

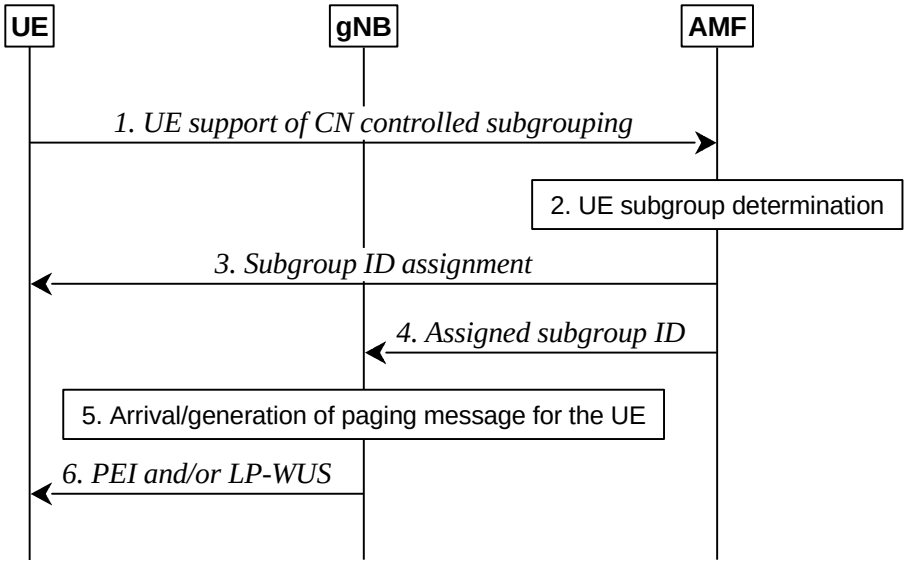


Figure 9.2.5-1: Procedure for CN controlled subgrouping

1. The UE indicates its support of CN controlled subgrouping via NAS signalling.
2. If the UE supports CN controlled subgrouping, the AMF determines the subgroup ID assignment for the UE.
3. The AMF sends subgroup ID to the UE via NAS signalling.
4. The AMF informs the gNB about the CN assigned subgroup ID for paging the UE in RRC_IDLE/ RRC_INACTIVE state.
5. When the paging message for the UE is received from the CN or is generated by the gNB, the gNB determines the PO and the associated PEI and/or LP-WUS occasion for the UE.
6. Before the UE is paged in the PO, the gNB transmits the associated PEI and/or LP-WUS and indicates the corresponding CN controlled subgroup of the UE that is to be paged using PEI and/or LP-WUS.

UE ID based subgrouping: For UE ID based subgrouping, the gNB and UE can determine the subgroup ID based on the UE ID and the total number of subgroups for UE ID based subgrouping in the cell. The total number of subgroups for UE ID based subgrouping is decided by the gNB for each cell and can be different in different cells. Up to 31 subgroups are supported for LP-WUS. The following figure describes the procedure for UE ID based subgrouping:

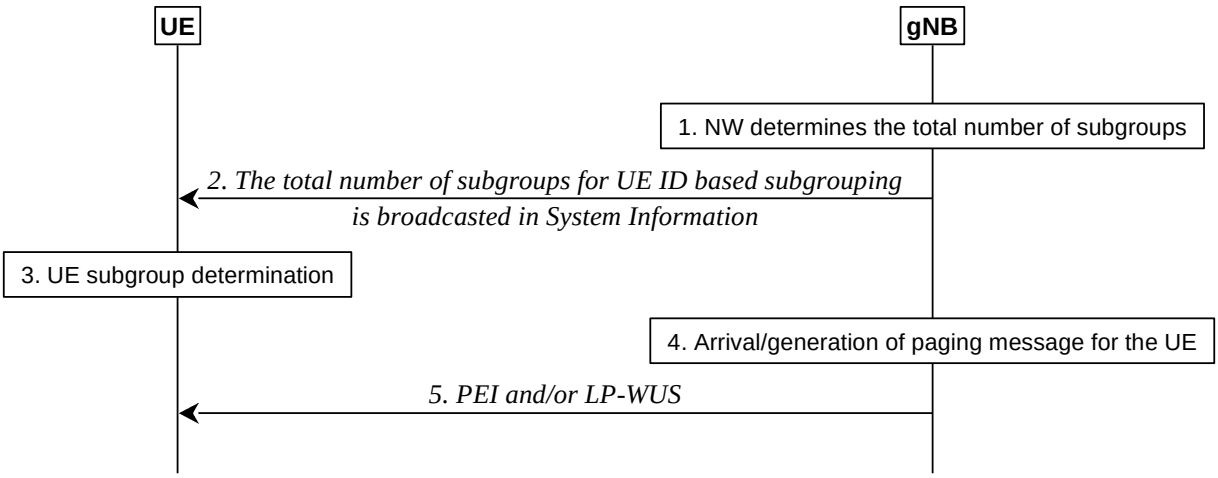


Figure 9.2.5-2: Procedure for UE ID based subgrouping

1. The gNB determines the total number of subgroups for UE ID based subgrouping in a cell.
2. The gNB broadcasts the total number of subgroups for UE ID based subgrouping in a cell.
3. UE determines its subgroup in a cell.
4. When paging message for the PEI and/or LP-WUS capable UE is received from the CN at the gNB or is generated by the gNB, the gNB determines the PO and the associated PEI and/or LP-WUS occasion for the UE.
5. Before the UE is paged in the PO, the gNB transmits the associated PEI and/or LP-WUS and indicates the corresponding subgroup derived based on UE ID of the UE that is paged using PEI and/or LP-WUS.

Paging adaptation for network energy saving for UEs in RRC_IDLE and RRC_INACTIVE: in order to increase gNB sleeping time, the value of N and Ns are extended to increase the number of POs per PF with sparser PFs. The UE supporting paging adaptation shall monitor PDCCH in POs separately signalled for paging adaptation, if configured. The UE supporting paging adaptation and PEI and/or LP-WUS can monitor PEIs and/or LP-WUS separately signalled for paging adaptation, if configured.

9.2.6 Random Access Procedure

The random access procedure is triggered by a number of events:

- Initial access from RRC_IDLE;
- RRC Connection Re-establishment procedure;
- DL or UL data arrival, during RRC_CONNECTED or during RRC_INACTIVE while SDT procedure (see clause 18.0) is ongoing, when UL synchronisation status is "non-synchronised";
- UL data arrival, during RRC_CONNECTED or during RRC_INACTIVE while SDT procedure is ongoing, when there are no PUCCH resources for SR available;
- Handover, except for when RACH-less HO is configured;
- SR failure;
- Explicit request by RRC upon synchronous reconfiguration;
- RRC Connection Resume procedure from RRC_INACTIVE;
- To establish time alignment for a primary or a secondary TAG;

- Request for Other SI (see clause 7.3);
- Request for OD-SIB1 (see clause 7.3);
- Beam failure recovery;
- Consistent UL LBT failure on SpCell;
- SDT in RRC_INACTIVE (see clause 18);
- Positioning purpose during RRC_CONNECTED requiring random access procedure, e.g., when timing advance is needed for UE positioning;
- Early UL synchronization with an LTM candidate cell;
- RACH-based LTM cell switch.

Two types of random access procedure are supported: 4-step RA type with MSG1 and 2-step RA type with MSGA. Both types of RA procedure support contention-based random access (CBRA) and contention-free random access (CFRA) as shown on Figure 9.2.6-1 below.

The UE selects the type of random access at initiation of the random access procedure based on network configuration:

- when CFRA resources are not configured, an RSRP threshold is used by the UE to select between 2-step RA type and 4-step RA type;
- when CFRA resources for 4-step RA type are configured, UE performs random access with 4-step RA type;
- when CFRA resources for 2-step RA type are configured, UE performs random access with 2-step RA type.

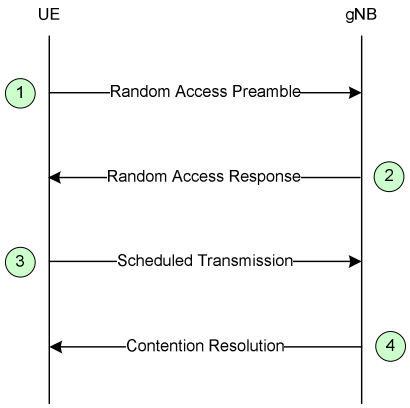
The network does not configure CFRA resources for 4-step and 2-step RA types at the same time for a Bandwidth Part (BWP). CFRA with 2-step RA type is only supported for handover.

The MSG1 of the 4-step RA type consists of a preamble on PRACH. After MSG1 transmission, the UE monitors for a response from the network within a configured window. For CFRA, dedicated preamble for MSG1 transmission is assigned by the network and upon receiving random access response from the network, the UE ends the random access procedure as shown in Figure 9.2.6-1(c). For CBRA, upon reception of the random access response, the UE sends MSG3 using the UL grant scheduled in the response and monitors contention resolution as shown in Figure 9.2.6-1(a). If contention resolution is not successful after MSG3 (re)transmission(s), the UE goes back to MSG1 transmission.

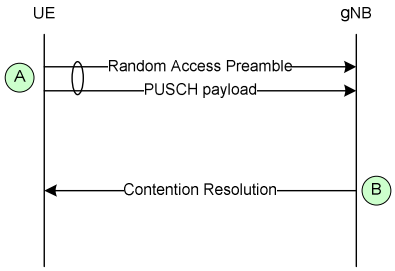
The MSGA of the 2-step RA type includes a preamble on PRACH and a payload on PUSCH. After MSGA transmission, the UE monitors for a response from the network within a configured window. For CFRA, dedicated preamble and PUSCH resource are configured for MSGA transmission and upon receiving the network response, the UE ends the random access procedure as shown in Figure 9.2.6-1(d). For CBRA, if contention resolution is successful upon receiving the network response, the UE ends the random access procedure as shown in Figure 9.2.6-1(b); while if fallback indication is received in MSGB, the UE performs MSG3 transmission using the UL grant scheduled in the fallback indication and monitors contention resolution as shown in Figure 9.2.6-2. If contention resolution is not successful after MSG3 (re)transmission(s), the UE goes back to MSGA transmission.

If the random access procedure with 2-step RA type is not completed after a number of MSGA transmissions, the UE can be configured to switch to CBRA with 4-step RA type.

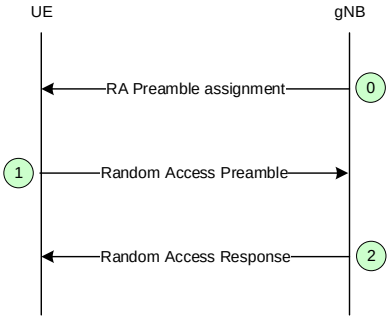
For the random access procedure towards an LTM candidate cell for early UL TA acquisition, CFRA triggered by a PDCCH order is used. The UE sends MSG1 towards the cell without monitoring for a response from it as shown in Figure 9.2.6-1 (e). To support UE power ramping, the UE may perform MSG1 retransmission as indicated by the network.



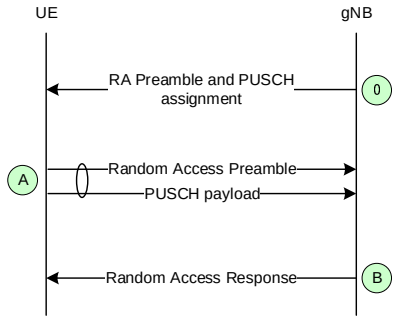
(a) CBRA with 4-step RA type



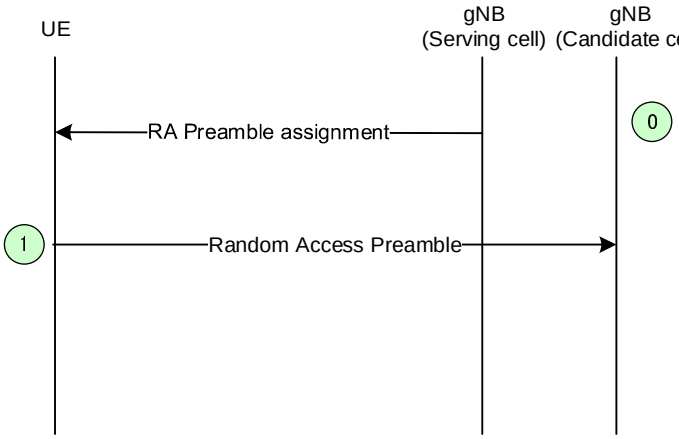
(b) CBRA with 2-step RA type



(c) CFRA with 4-step RA type



(d) CFRA with 2-step RA type



(e) CFRA without network response with 4-step RA type

Figure 9.2.6-1: Random Access Procedures

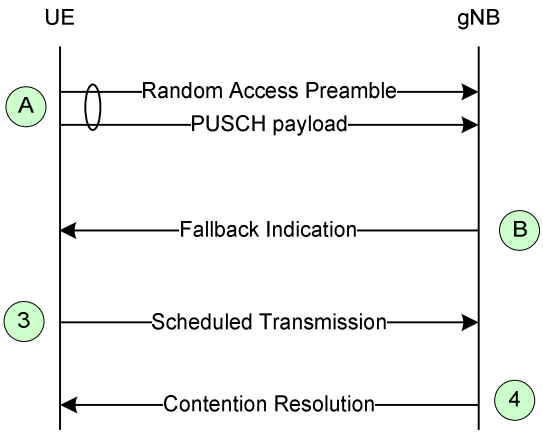


Figure 9.2.6-2: Fallback for CBRA with 2-step RA type

For random access in a cell configured with SUL, the network can explicitly signal which carrier to use (UL or SUL). Otherwise, the UE selects the SUL carrier if and only if the measured quality of the DL is lower than a broadcast threshold. UE performs carrier selection before selecting between 2-step and 4-step RA type. The RSRP threshold for selecting between 2-step and 4-step RA type can be configured separately for UL and SUL. Once started, all uplink transmissions of the random access procedure remain on the selected carrier.

The network can associate a set of RACH resources with feature(s) applicable to a Random Access procedure: Network Slicing (see clause 16.3), (e)RedCap (see clause 16.13), SDT (see clause 18), and NR coverage enhancement (see clause 19). A set of RACH resources associated with a feature is only valid for random access procedures applicable to at least that feature; and a set of RACH resources associated with several features is only valid for random access procedures having at least all of these features. The UE selects the set(s) of applicable RACH resources, after uplink carrier (i.e. NUL or SUL) and BWP selection and before selecting the RA type.

When CA is configured, random access procedure with 2-step RA type is only performed on SpCell while contention resolution can be cross-scheduled by the SpCell.

When CA is configured, for random access procedure with 4-step RA type, the first three steps of CBRA always occur on the SpCell while contention resolution (step 4) can be cross-scheduled by the SpCell. The three steps of a CFRA started on the SpCell remain on the SpCell. CFRA on SCell can only be initiated by the gNB to establish timing advance for a secondary TAG: the procedure is initiated by the gNB with a PDCCH order (step 0) that is sent on an activated SCell of the secondary TAG, preamble transmission (step 1) takes place on the SCell, and Random Access Response (step 2) takes place on SpCell.

When two TAG IDs are configured for the serving cell, the TAG for which the TA command is applied is indicated in Random Access Response message or in MSGB. To establish timing advance for the other PTAG, CFRA is initiated by the gNB with a PDCCH order.

9.2.7 Radio Link Failure

In RRC_CONNECTED, the UE performs Radio Link Monitoring (RLM) in the active BWP based on reference signals (SSB/CSI-RS) and signal quality thresholds configured by the network. SSB-based RLM is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWP, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and, if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. Besides, SSB-based RLM can be also performed based on a non-cell defining SSB, if configured for the active DL BWP. RLM can be also performed based on CSI-RS, if configured for the active DL BWP. In case of DAPS handover, the UE continues the detection of radio link failure at the source cell until the successful completion of the random access procedure to the target cell.

The UE declares Radio Link Failure (RLF) when one of the following criteria are met:

- Expiry of a radio problem timer started after indication of radio problems from the physical layer (if radio problems are recovered before the timer is expired, the UE stops the timer); or

- Expiry of a timer started upon triggering a measurement report for a measurement identity for which the timer has been configured while another radio problem timer is running; or

- Random access procedure failure; or
- RLC failure; or
- Detection of consistent uplink LBT failures for operation with shared spectrum channel access as described in 5.6.1; or
- For IAB-MT, the reception of a BH RLF indication received from its parent node.

After RLF is declared, the UE:

- stays in RRC_CONNECTED;
- in case of DAPS handover, for RLF in the source cell:
  - stops any data transmission or reception via the source link and releases the source link, but maintains the source RRC configuration;
  - if handover failure is then declared at the target cell, the UE:
    - selects a suitable cell and then initiates RRC re-establishment;
    - enters RRC_IDLE if a suitable cell was not found within a certain time after handover failure was declared.
- in case of CHO, for RLF in the source cell:
  - selects a suitable cell and if the selected cell is a CHO candidate and if network configured the UE to try CHO after RLF then the UE attempts CHO execution once, otherwise re-establishment is performed;
  - enters RRC_IDLE if a suitable cell was not found within a certain time after RLF was declared.
- in case of MCG LTM, for RLF in the source cell:
  - selects a suitable cell and if the selected cell is an LTM candidate cell and if network configured the UE to try LTM after RLF then the UE attempts RACH-based LTM execution once, otherwise re-establishment is performed;
  - enters RRC_IDLE if a suitable cell was not found within a certain time after RLF was declared.
- otherwise, for RLF in the serving cell or in case of DAPS handover, for RLF in the target cell before releasing the source cell:
  - selects a suitable cell and then initiates RRC re-establishment;
  - enters RRC_IDLE if a suitable cell was not found within a certain time after RLF was declared.

When RLF occurs at the IAB BH link, the same mechanisms and procedures are applied as for the access link. This includes BH RLF detection and RLF recovery.

The IAB-DU can transmit a BH RLF detection indication to its child nodes in the following cases:

- The collocated IAB-MT initiates RRC re-establishment;
- The collocated IAB-MT is dual-connected, detects BH RLF on a BH link, and cannot perform UL re-routing for any traffic. This includes the scenario of an IAB-node operating in EN-DC or NR-DC, which uses only one link for backhauling and has BH RLF on this BH link;
- The collocated IAB-MT has received a BH RLF detection indication from a parent node, and there is no remaining backhaul link that is unaffected by the BH RLF condition indicated.

Upon reception of the BH RLF detection indication, the child node may perform local rerouting for upstream traffic, if possible, over an available BH link.

If the IAB-DU has transmitted a BH RLF detection indication to a child node due to an RLF condition on the collocated IAB-MT's parent link, and the collocated IAB-MT's subsequent RLF recovery is successful, the IAB-DU may transmit a BH RLF recovery indication to this child node.

If the IAB-DU has transmitted a BH RLF detection indication to a child node due to the reception of a BH RLF detection indication by the collocated IAB-MT, and the collocated IAB-MT receives a BH RLF recovery indication, the IAB-DU may also transmit a BH RLF recovery indication to this child node.

Upon reception of the BH RLF recovery indication, the child node reverts the actions triggered by the reception of the previous BH RLF detection indication.

In case the RRC re-establishment procedure fails, the IAB-node may transmit a BH RLF indication to its child nodes. The BH RLF detection indication, BH RLF recovery indication and BH RLF indication are transmitted as BAP Control PDUs.

9.2.8 Beam failure detection and recovery

For beam failure detection, the gNB configures the UE with beam failure detection reference signals (SSB or CSI-RS) and the UE declares beam failure when the number of beam failure instance indications from the physical layer reaches a configured threshold before a configured timer expires. For beam failure detection in multi-TRP operation, the gNB configures the UE with two sets of beam failure detection reference signals, and the UE declares beam failure for a TRP / BFD-RS set when the number of beam failure instance indications associated with the corresponding set of beam failure detection reference signals from the physical layer reaches a configured threshold before a configured timer expires.

SSB-based Beam Failure Detection is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWPs, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and, if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. Besides, SSB-based Beam Failure Detection can be also performed based on the non-cell defining SSB, if configured for the active DL BWP. Beam Failure Detection can be also performed based on CSI-RS, if configured for the active DL BWP.

After beam failure is detected on SpCell, the UE:

- triggers beam failure recovery by initiating a Random Access procedure on the SpCell;
- selects a suitable beam to perform beam failure recovery (if the gNB has provided dedicated Random Access resources for certain beams, those will be prioritized by the UE).
- includes an indication of a beam failure on SpCell in a BFR MAC CE if the Random Access procedure involves contention-based random access.

Upon completion of the Random Access procedure, beam failure recovery for SpCell is considered complete.

After beam failure is detected on an SCell, the UE:

- triggers beam failure recovery by initiating a transmission of a BFR MAC CE for this SCell;
- selects a suitable beam for this SCell (if available) and indicates it along with the information about the beam failure in the BFR MAC CE.

Upon reception of a PDCCH indicating an uplink grant for a new transmission for the HARQ process used for the transmission of the BFR MAC CE, beam failure recovery for this SCell is considered complete.

After beam failure is detected for a BFD-RS set of a Serving Cell, the UE:

- triggers beam failure recovery by initiating a transmission of a BFR MAC CE for this BFD-RS set;
- selects a suitable beam for this BFD-RS set (if available) and indicates whether the suitable (new) beam is found or not along with the information about the beam failure in the BFR MAC CE for this BFD-RS set.

Upon reception of a PDCCH indicating an uplink grant for a new transmission for the HARQ process used for the transmission of the BFR MAC CE for this BFD-RS set, beam failure recovery for this BFD-RS set is considered complete.

After beam failure is detected for both BFD-RS sets of SpCell concurrently, the UE:

- triggers beam failure recovery by initiating a Random Access procedure on the SpCell;

- selects a suitable beam for each failed BFD-RS set (if available) and indicates whether the suitable (new) beam is found or not along with the information about the beam failure in the BFR MAC CE for each failed BFD-RS set;

- upon completion of the Random Access procedure, beam failure recovery for both BFD-RS sets of SpCell is considered complete.

9.2.9 Timing Advance

In RRC_CONNECTED, the gNB is responsible for maintaining the timing advance to keep the L1 synchronised. Serving cells having UL to which the same timing advance applies and using the same timing reference cell are grouped in a TAG. Each TAG contains at least one serving cell with configured uplink, and the mapping of each serving cell to a TAG is configured by RRC.

For the primary TAG the UE uses the SpCell as timing reference, except with shared spectrum channel access where an SCell can also be used in certain cases (see clause 7.1, TS 38.133 [13]). In a secondary TAG, the UE may use any of the activated SCells of this TAG as a timing reference cell, but should not change it unless necessary.

Timing advance updates are signalled by the gNB to the UE via MAC CE commands. Such commands restart a TAG-specific timer which indicates whether the L1 can be synchronised or not: when the timer is running, the L1 is considered synchronised, otherwise, the L1 is considered non-synchronised (in which case uplink transmission can only take place through MSG1/MSGA).

When two TAG IDs are configured for the SpCell, both TAGs are regarded as primary TAG.

9.2.10 Extended DRX for RRC_IDLE and RRC_INACTIVE

When extended DRX (eDRX) is used, the following applies:

- For RRC_INACTIVE, eDRX configuration for RAN paging is decided and configured by NG-RAN. In RRC_INACTIVE the UE monitors both RAN and CN paging;

- For RRC_IDLE, eDRX for CN paging is configured by upper layers. In RRC_IDLE the UE monitors only CN paging;

- Information on whether eDRX for CN paging and RAN paging is allowed on the cell is provided separately in system information;

- The maximum value of the eDRX cycle is 10485.76 seconds (2.91 hours) while the minimum value of the eDRX cycle is 2.56 seconds;

- The hyper SFN (H-SFN) is broadcast by the cell and increments by one when the SFN wraps around;

- Paging Hyperframe (PH) refers to the H-SFN in which the UE starts monitoring paging according to DRX during a Paging Time Window (PTW). The PH and PTW are determined based on a formula (see TS 38.304 [10]) that is known by the AMF, UE and NG-RAN;

- H-SFN, PH and PTW are used if the eDRX cycle is greater than 10.24 seconds;

- When the RRC_IDLE eDRX cycle is longer than the system information modification period, the UE verifies that stored system information remains valid before resuming/establishing an RRC connection.

NOTE: When emergency PDU session resources are established and if the gNB decides to release the UE into RRC_INACTIVE state, it should not configure the Extended DRX. The gNB recognizes the emergency PDU session resources based on special ARP value of a QoS flow as specified in TS 23.501 [3].

9.3 Inter RAT

9.3.1 NR-E-UTRA mobility: Intra 5GC

9.3.1.1 Cell Reselection

Cell reselection is characterised by the following:

- Cell reselection between NR RRC_IDLE and E-UTRA RRC_IDLE is supported;
- Cell reselection from NR RRC_INACTIVE to E-UTRA RRC_IDLE is supported.

9.3.1.2 Handover

Inter RAT mobility is characterised by the following:

- The Source RAT configures Target RAT measurement and reporting.
- The source RAT decides on the preparation initiation and provides the necessary information to the target RAT in the format required by the target RAT:
  - For handover preparation from E-UTRA to NR, the source RAT issues a handover preparation request message to the target RAT passing a transparent RRC container with necessary information to prepare the handover at the target side. The information for the target RAT is the same type as specified in clause 9.2.3.2.1 including the current QoS flow to DRB mapping applied to the UE and RRM configuration.
  - The details of RRM configuration are the same type as specified for NR in clause 9.2.3.2.1 including beam measurement information for the listed cells if the measurements are available.
- Radio resources are prepared in the target RAT before the handover.
- The RRC reconfiguration message from the target RAT is delivered to the source RAT via a transparent container, and is passed to the UE by the source RAT in the handover command:
  - The inter-RAT handover command message carries the same type of information required to access the target cell as specified for NR baseline handover in clause 9.2.3.2.1.
- The in-sequence and lossless handover is supported for the handover between gNB and ng-eNB.
- Both Xn and NG based inter-RAT handover between NG-RAN nodes is supported. Whether the handover is over Xn or CN is transparent to the UE.
- In order to keep the SDAP and PDCP configurations for in-sequence and lossless inter-RAT handover, delta-configuration for the radio bearer configuration is used.

9.3.1.3 Measurements

Inter RAT measurements in NR for this use case are limited to E-UTRA.

Whether a measurement is non-gap-assisted or gap-assisted depends on the capability of the UE and the current operating frequency:

- For E-UTRA Inter RAT measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided when:
  - The UE only supports per-UE measurement gaps; or
  - The UE supports per-FR measurement gaps and at least one of the NR serving cells is in FR1.

9.3.2 NR-E-UTRA mobility: From 5GC to EPC

9.3.2.1 Cell Reselection

Cell reselection is characterised by the following:

- Cell reselection between NR RRC_IDLE and E-UTRA RRC_IDLE is supported;
- Cell reselection from NR RRC_INACTIVE to E-UTRA RRC_IDLE is supported.

9.3.2.2 Handover and redirection

The source NG-RAN node decides between handover or redirection to EPS based on radio criteria and availability of the N26 interface.

NOTE: Information about the availability of the N26 interface may be configured by OAM at the NG-RAN.

Inter RAT handover is characterised by the following:

- The Source RAT configures Target RAT measurement and reporting.
- The source RAT decides on the preparation initiation and provides the necessary information to the target RAT in the format required by the target RAT.
- Radio resources are prepared in the target RAT before the handover.
- The RRC reconfiguration message from the target RAT is delivered to the source RAT via a transparent container, and is passed to the UE by the source RAT in the handover command.
- In-sequence and lossless handovers are not supported.
- Security procedures for handover to E-UTRA/EPC should follow E-UTRA handover procedures.

9.3.2.3 Measurements

Inter RAT measurements in NR for this use case are limited to E-UTRA.

Whether a measurement is non-gap-assisted or gap-assisted depends on the capability of the UE and the current operating frequency:

- For E-UTRA Inter RAT measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided when:
  - The UE only supports per-UE measurement gaps; or
  - The UE supports per-FR measurement gaps and at least one of the NR serving cells is in FR1.

9.3.2.4 Data Forwarding for the Control Plane

Control plane handling for inter-System data forwarding from 5GS to EPS follows the following key principles:

- Only forwarding of downlink data is supported.
- PDU session information at the serving NG-RAN node contains mapping information per QoS Flow to a corresponding E-RAB.
- At handover preparation, the source NG-RAN node shall decide which mapped E-RABs are proposed to be subject to data forwarding and provide this information in the source-to-target container to the target eNB. Based on availability of direct data forwarding path the source NG-RAN node may request to apply direct data forwarding by indicating direct data forwarding path availability to the 5GC.
- The target eNB assigns forwarding TEID/TNL address(es) for the E-RAB(s) for which it accepts data forwarding.

- In case of indirect data forwarding, a single data forwarding tunnel is established between the source NG-RAN node and UPF per PDU session for which at least data for a single QoS Flow is subject to data forwarding.

- In case of direct data forwarding, the source NG-RAN node receives a TEID/TNL address for each E-RAB accepted for data forwarding as assigned by the target eNB.

9.3.2.5 Data Forwarding for the User Plane

In case of indirect data forwarding, user plane handling for inter-System data forwarding from 5GS to EPS follows the following key principles:

- For the QoS flows accepted for data forwarding, the NG-RAN node initiates data forwarding to the UPF by the corresponding PDU session data forwarding tunnel(s).

- The UPF maps forwarded data received from the per PDU session data forwarding tunnel(s) to the mapped EPS bearer(s) removing the QFI.

- Handling of end marker packets:

    - The source NG-RAN node receives one or several end marker packets per PDU session from the UPF. When there are no more data packets to be forwarded for QoS flows mapped to an E-RAB, the source NG-RAN node sends one or several end markers including one QFI (by means of the PDU Session User Plane protocol TS 38.415 [30]) of those QoS flows mapped to that E-RAB and sends the end marker packets to the UPF over the PDU session tunnel. From the included QFI in the end markers and its mapping to an EPS bearer ID, the UPF knows which EPS bearer tunnel it needs to forward the end-markers to the SGW. The QFI is removed in the end marker packets sent to the SGW.

In case of direct data forwarding, user plane handling for inter-System data forwarding from 5GS to EPS follows the following key principles:

- For the QoS flows accepted for data forwarding, the source NG-RAN node maps data received from the NG-U PDU session tunnel to the respective E-RAB data forwarding tunnel and forwards each user packet as PDCP SDU without PDCP SN and QFI information.

- The source NG-RAN node receives one or several GTP-U end marker packets per PDU session from the UPF and replicates the end marker packets into each E-RAB data forwarding tunnel when no more user data packets are to be forwarded over that tunnel.

9.3.3 NR-E-UTRA mobility: From EPC to 5GC

9.3.3.1 Data Forwarding for the Control Plane

Control plane handling for inter-System data forwarding from EPS to 5GS follows the following key principles:

- Only forwarding of downlink data is supported.

- The target NG-RAN node receives in the Handover Request message the mapping between E-RAB ID(s) and QoS Flow ID(s). It decides whether to accept the data forwarding for E-RAB IDs proposed for forwarding within the Source NG-RAN Node to Target NG-RAN Node Transparent Container. Based on availability of direct data forwarding path the source eNB may request to apply direct data forwarding by indicating direct data forwarding availability to the CN.

- In case of indirect data forwarding:

    - The target NG-RAN node assigns a TEID/TNL address for each PDU session for which at least one QoS flow is involved in the accepted data forwarding.

    - The target NG-RAN node sends the Handover Request Acknowledge message in which it indicates the list of PDU sessions and QoS flows for which it has accepted the data forwarding.

    - A single data forwarding tunnel is established between the UPF and the target NG-RAN node per PDU session for which at least data for a single QoS Flow is subject to data forwarding.

    - The source eNB receives in the Handover Command message the list of E-RAB IDs for which the target NG-RAN node has accepted data forwarding of corresponding PDU sessions and QoS flows.

- In case of direct data forwarding:

    - The source eNB indicates direct path availability to the CN. The source eNB's decision is indicated by the CN to the target NG-RAN node.

    - The target NG-RAN node assigns a TEID/TNL address for each E-RAB it accepted for data forwarding.

    - The source eNB receives in the Handover Command message the list of E-RAB IDs for which the target NG-RAN node has accepted data forwarding.

9.3.3.2 Data Forwarding for the User Plane

In case of indirect data forwarding, user plane handling for inter-System data forwarding from EPS to 5GS follows the following key principles:

- For each E-RAB accepted for data forwarding, the source eNB forwards data to the SGW in the corresponding E-RAB tunnel and the SGW forwards the received data to the UPF in the E-RAB tunnel.

- The UPF maps the forwarded data received from an E-RAB tunnel to the corresponding mapped PDU session tunnel, adding a QFI value (by means of the PDU Session User Plane protocol TS 38.415 [30]).

- The target NG-RAN node maps a forwarded packet to the corresponding DRB based on the received QFI value. It prioritizes the forwarded packets over the fresh packets for those QoS flows.

- Handling of end marker packets:

    - The UPF/PGW-U sends one or several end marker packets to the SGW per EPS bearer. The SGW forwards the received end markers per EPS bearer to the source eNB. When there are no more data packets to be forwarded for an E-RAB, the source eNB forwards the received end markers in the EPS bearer tunnel to the SGW and the SGW forwards them to the UPF. The UPF adds one QFI (by means of the PDU Session User Plane protocol TS 38.415 [30]) among the QoS flows mapped to that E-RAB to the end markers and sends those end markers to the target NG-RAN node in the per PDU session tunnel. When the target NG-RAN node receives an end marker with a QFI added, the target NG-RAN node starts to transmit the data packets of all QoS flows mapped to the corresponding E-RAB received from the core network towards the UE.

In case of direct data forwarding, user plane handling for inter-System data forwarding from EPS to 5GS follows the following key principles:

- For each E-RAB accepted for data forwarding, the source node forwards data to the target NG-RAN node in the corresponding E-RAB data forwarding tunnel.

- Until a GTP-U end marker packet is received, the target NG-RAN node prioritizes the forwarded packets over the fresh packets for those QoS flows which are involved in the accepted data forwarding.

NOTE: The target NG-RAN node should remove the forwarded PDCP SNs if received in the forwarded GTP-U packets, and deliver the forwarded PDCP SDUs to the UE.

9.3.4 NR-UTRA mobility

9.3.4.1 Handover with SRVCC operation

The source NR node decides to handover the UE with ongoing IMS voice from NR to UTRAN according the following principles:

- The source NR node determines that the UE supports UTRA and requests the UE to send its UTRA radio access capabilities to the NG-RAN;

- The source NR node configures target RAT measurement and reporting;

- The source NR node determines based on the radio conditions and the indication that SRVCC operation is possible that handover to UTRAN should be initiated;

- The source NR node initiates the handover preparation only for the ongoing IMS voice and provides the indication to AMF that the handover is towards UTRAN together with the target UTRAN Node ID. The source NR node also provides an indication to the target UTRAN that the incoming handover originates from 5G. The SRVCC proceeds as specified in TS 23.216 [34];

- The source NR node ensures that the size of the source-to-target container does not exceed the limits that can be handled by the interfaces involved in the handover;

NOTE: For SRVCC handover, the size limit of the inter-node source-to-target container is 2560 octets (see AN-APDU in TS 29.002 [44]).

- Radio resources are prepared in the target RAT before the handover;

- The RRC reconfiguration message from the target RAT is delivered to the source NR node via a transparent container and is passed to the UE by the source NR node in the handover command;

- In-sequence and lossless handovers are not supported;

- Only voice bearer is handed over to target RAT;

- Security procedures for handover to UTRA follows the procedures as specified in TS 33.501 [5];

- Only handover to UTRA-FDD is supported.

9.3.4.2 Measurements

Inter RAT measurements are performed for UTRA.

For a UE configured with UTRA Inter RAT measurements, a measurement gap configuration is always provided when:

- The UE only supports per-UE measurement gaps; or

- The UE supports per-FR measurement gaps and at least one of the NR serving cells is in FR1.

9.4 Roaming and Access Restrictions

The roaming and access restriction information for a UE includes information on restrictions to be applied for subsequent mobility action during CM-CONNECTED state. It may be provided by the AMF and also may be updated by the AMF later.

It includes the forbidden RAT, the forbidden area and the service area restrictions as specified in TS 23.501 [3]. It also includes serving PLMN/SNPN and may include a list of equivalent PLMNs or a list of equivalent SNPNs. It may also include PNI-NPN mobility restrictions (i.e. list of CAGs allowed for the UE and whether the UE can also access non-CAG cells). The gNB shall consider that roaming or access to CAG cells is only allowed if PNI-NPN mobility information is available for the UE.

Upon receiving the roaming and access restriction information for a UE, if applicable, the gNB should use it to determine whether to apply restriction handling for subsequent mobility action, e.g., handover, redirection.

If the roaming and access restriction information is not available for a UE at the gNB, the gNB shall consider that there is no restriction for subsequent mobility actions except for the PNI-NPN mobility as described in TS 23.501 [3].

Only if received over NG or Xn signalling, the roaming and access restriction information shall be propagated over Xn by the source gNB during Xn handover or by the old gNB during UE context retrieval. If the Xn handover results in a change of serving PLMN (to an equivalent PLMN), the source gNB shall replace the serving PLMN with the identity of the target PLMN and move the serving PLMN to the equivalent PLMN list, before propagating the roaming and access restriction information. If the Xn handover results in a change of serving SNPN (to an equivalent SNPN), the source gNB shall replace the serving SNPN with the identity of the target SNPN and move the serving SNPN to the equivalent SNPN list, before propagating the roaming and access restriction information.

If NG-RAN nodes with different versions of the XnAP or NGAP protocol are deployed, information provided by the 5GC within the NGAP Mobility Restriction List may be lost in the course of Xn mobility. In order to avoid such loss of information at Xn handover or UE context retrieval due to a source NG-RAN node or an old NG-RAN node not able to recognise the entire content, the source NG-RAN node or the old NG-RAN node may provide an 5GC Mobility

Restriction List Container to the target NG-RAN node or the new NG-RAN node, containing the Mobility Restriction List as received from the 5GC. The target NG-RAN node or the new NG-RAN node shall use the information contained in the 5GC Mobility Restriction List Container as the Mobility Restriction List, except for the Serving PLMN/SNPN and the Equivalent PLMNs/SNPNs, which the NG-RAN node shall use from the XnAP Mobility Restriction List. The 5GC Mobility Restriction List Container may be propagated at future Xn handover and UE context retrieval.

10 Scheduling

10.1 Basic Scheduler Operation

In order to utilise radio resources efficiently, MAC in gNB includes dynamic resource schedulers that allocate physical layer resources for the downlink and the uplink. In this clause, an overview of the scheduler is given in terms of scheduler operation, signalling of scheduler decisions, and measurements.

Scheduler Operation:

- Taking into account the UE buffer status and the QoS requirements of each UE and associated radio bearers, schedulers assign resources between UEs;
- Schedulers may assign resources taking account the radio conditions at the UE identified through measurements made at the gNB and/or reported by the UE;
- Resource assignment consists of radio resources (resource blocks).

Signalling of Scheduler Decisions:

- UEs identify the resources by receiving a scheduling (resource assignment) channel.

Measurements to Support Scheduler Operation:

- Uplink buffer status reports (measuring the data that is buffered in the logical channel queues in the UE) are used to provide support for QoS-aware packet scheduling;
- Power headroom reports (measuring the difference between the nominal UE maximum transmit power and the estimated power for uplink transmission) are used to provide support for power aware packet scheduling.

10.2 Downlink Scheduling

In the downlink, the gNB can dynamically allocate resources to UEs via the C-RNTI on PDCCH(s). A UE always monitors the PDCCH(s) in order to find possible assignments when its downlink reception is enabled (activity governed by DRX and cell DTX when configured). When CA is configured, the same C-RNTI applies to all serving cells.

The gNB may pre-empt an ongoing PDSCH transmission to one UE with a latency-critical transmission to another UE. The gNB can configure UEs to monitor interrupted transmission indications using INT-RNTI on a PDCCH. If a UE receives the interrupted transmission indication, the UE may assume that no useful information to that UE was carried by the resource elements included in the indication, even if some of those resource elements were already scheduled to this UE.

In addition, with Semi-Persistent Scheduling (SPS), the gNB can allocate downlink resources for the initial HARQ transmissions to UEs: RRC defines the periodicity of the configured downlink assignments while PDCCH addressed to CS-RNTI can either signal and activate the configured downlink assignment, or deactivate it; i.e. a PDCCH addressed to CS-RNTI indicates that the downlink assignment can be implicitly reused according to the periodicity defined by RRC, until deactivated.

NOTE: When required, retransmissions are explicitly scheduled on PDCCH(s).

The dynamically allocated downlink reception overrides the configured downlink assignment in the same serving cell, if they overlap in time. Otherwise a downlink reception according to the configured downlink assignment is assumed, if activated.

The UE may be configured with up to 8 active configured downlink assignments for a given BWP of a serving cell. When more than one is configured:

- The network decides which of these configured downlink assignments are active at a time (including all of them); and
- Each configured downlink assignment is activated separately using a DCI command and deactivation of configured downlink assignments is done using a DCI command, which can either deactivate a single configured downlink assignment or multiple configured downlink assignments jointly.

10.3 Uplink Scheduling

In the uplink, the gNB can dynamically allocate resources to UEs via the C-RNTI on PDCCH(s). A UE always monitors the PDCCH(s) in order to find possible grants for uplink transmission when its downlink reception is enabled (activity governed by DRX and cell DTX when configured). When CA is configured, the same C-RNTI applies to all serving cells.

The gNB may cancel a PUSCH transmission, or a repetition of a PUSCH transmission, or an SRS transmission of a UE for another UE with a latency-critical transmission. The gNB can configure UEs to monitor cancelled transmission indications using CI-RNTI on a PDCCH. If a UE receives the cancelled transmission indication, the UE shall cancel the PUSCH transmission from the earliest symbol overlapped with the resource or the SRS transmission overlapped with the resource indicated by cancellation (see clause 11.2A of TS 38.213 [38]).

In addition, with Configured Grants, the gNB can allocate uplink resources for the initial HARQ transmissions and HARQ retransmissions to UEs. Two types of configured uplink grants are defined:

- With Type 1, RRC directly provides the configured uplink grant (including the periodicity).
- With Type 2, RRC defines the periodicity of the configured uplink grant while PDCCH addressed to CS-RNTI can either signal and activate the configured uplink grant, or deactivate it; i.e. a PDCCH addressed to CS-RNTI indicates that the uplink grant can be implicitly reused according to the periodicity defined by RRC, until deactivated.

If the UE is not configured with enhanced intra-UE overlapping resources prioritization, the dynamically allocated uplink transmission overrides the configured uplink grant in the same serving cell, if they overlap in time. Otherwise an uplink transmission according to the configured uplink grant is assumed, if activated.

If the UE is configured with enhanced intra-UE overlapping resources prioritization, in case a configured uplink grant transmission overlaps in time with dynamically allocated uplink transmission or with another configured uplink grant transmission in the same serving cell, the UE prioritizes the transmission based on the comparison between the highest priority of the logical channels that have data to be transmitted and which are multiplexed or can be multiplexed in MAC PDUs associated with the overlapping resources. Similarly, in case a configured uplink grant transmissions or a dynamically allocated uplink transmission overlaps in time with a scheduling request transmission, the UE prioritizes the transmission based on the comparison between the priority of the logical channel which triggered the scheduling request and the highest priority of the logical channels that have data to be transmitted and which are multiplexed or can be multiplexed in MAC PDU associated with the overlapping resource. In case the MAC PDU associated with a deprioritized transmission has already been generated, the UE keeps it stored to allow the gNB to schedule a retransmission. The UE may also be configured by the gNB to transmit the stored MAC PDU as a new transmission using a subsequent resource of the same configured uplink grant configuration when an explicit retransmission grant is not provided by the gNB.

Retransmissions other than repetitions are explicitly allocated via PDCCH(s) or via configuration of a retransmission timer.

The UE may be configured with up to 12 active configured uplink grants for a given BWP of a serving cell. When more than one is configured, the network decides which of these configured uplink grants are active at a time (including all of them). Each configured uplink grant can either be of Type 1 or Type 2. For Type 2, activation and deactivation of configured uplink grants are independent among the serving cells. When more than one Type 2 configured grant is configured, each configured grant is activated separately using a DCI command and deactivation of Type 2 configured grants is done using a DCI command, which can either deactivate a single configured grant configuration or multiple configured grant configurations jointly.

When SUL is configured, the network should ensure that an active configured uplink grant on SUL does not overlap in time with another active configured uplink grant on the other UL configuration.

For both dynamic grant and configured grant, for a transport block, two or more repetitions can be in one slot, or across slot boundary in consecutive available slots with each repetition in one slot. For both dynamic grant and configured grant Type 2, the number of repetitions can be also dynamically indicated in the L1 signalling. The dynamically indicated number of repetitions shall override the RRC configured number of repetitions, if both are present.

10.4 Measurements to Support Scheduler Operation

Measurement reports are required to enable the scheduler to operate in both uplink and downlink. These include transport volume and measurements of a UEs radio environment.

Uplink buffer status reports (BSR) are needed to provide support for QoS-aware packet scheduling. In NR, uplink buffer status reports refer to the data that is buffered in for a group of logical channels (LCG) in the UE. Four formats are used for reporting in uplink:

- A short format to report only one BSR (of one LCG);
- A flexible long format to report several BSRs (up to all eight LCGs);
- An extended short format to report one BSR (of one LCG);
- An extended long format to report several BSRs (up to all 256 LCGs).

NOTE: The Extended versions of the BSR formats can only be used by IAB nodes.

Uplink buffer status reports are transmitted using MAC signalling. When a BSR is triggered (e.g. when new data arrives in the transmission buffers of the UE), a Scheduling Request (SR) can be transmitted by the UE (e.g. when no resources are available to transmit the BSR).

For IAB, the Pre-emptive BSR can be configured on the backhaul links. The Pre-emptive BSR is sent based on expected data rather than buffered data, as described in clause 4.7.3.3.

Power headroom reports (PHR) are needed to provide support for power-aware packet scheduling. In NR, three types of reporting are supported: a first one for PUSCH transmission, a second one for PUSCH and PUCCH transmission in an LTE Cell Group in EN-DC (see TS 37.340 [21]) and a third one for SRS transmission on SCells configured with SRS only. In case of CA, when no transmission takes place on an activated SCell, a reference power is used to provide a virtual report. To allow network to detect UL power reduction, the PHR reports may also contain Power Management Maximum Power Reduction (P-MPR, see TS 38.101-2 [35]) information that UE uses to ensure UE compliance with the Maximum Permissible Exposure (MPE) exposure regulation for FR2, which is set for limiting RF exposure on human body. Power headroom reports are transmitted using MAC signalling.

10.5 Rate Control

10.5.1 Downlink

In downlink, for GBR flows, the gNB guarantees the GFBR and ensures that the MFBR is not exceeded while for non-GBR flows, it ensures that the UE-AMBR is not exceeded (see clause 12). When configured for a GBR flow, the gNB also ensures that the MDBV is not exceeded. When received and supported, the gNB in addition ensures that the UE-Slice-MBR is not exceeded as specified in TS 23.501 [3].

10.5.2 Uplink

The UE has an uplink rate control function which manages the sharing of uplink resources between logical channels. RRC controls the uplink rate control function by giving each logical channel a priority, a prioritised bit rate (PBR), and a buffer size duration (BSD). The values signalled need not be related to the ones signalled via NG to the gNB. In addition, mapping restrictions can be configured (see clause 16.1.2).

The uplink rate control function ensures that the UE serves the logical channel(s) in the following sequence:

1. All relevant logical channels in decreasing priority order up to their PBR;
2. All relevant logical channels in decreasing priority order for the remaining resources assigned by the grant.

NOTE 1: In case the PBRs are all set to zero, the first step is skipped and the logical channels are served in strict priority order: the UE maximises the transmission of higher priority data.

NOTE 2: The mapping restrictions tell the UE which logical channels are relevant for the grant received. If no mapping restrictions are configured, all logical channels are considered.

NOTE 3: Through radio protocol configuration and scheduling, the gNB can guarantee the GFBR(s) and ensure that any of the MFBR(s), the UE-AMBR and, when supported and feasible, the UE-Slice-MBR is not exceeded in uplink (see clause 12).

NOTE 4: The mapping restrictions allows the gNB to fulfil the MDBV requirements through scheduling at least for the case where logical channels are mapped to separate serving cells.

If more than one logical channel have the same priority, the UE shall serve them equally.

10.6 Activation/Deactivation Mechanism

To enable reasonable UE battery consumption when CA is configured, an activation/deactivation mechanism of Cells is supported. When an SCell is deactivated, the UE does not need to receive the corresponding PDCCH or PDSCH, cannot transmit in the corresponding uplink, nor is it required to perform CQI measurements. Conversely, when an SCell is active, the UE shall receive PDSCH and PDCCH (if the UE is configured to monitor PDCCH from this SCell) and is expected to be able to perform CQI measurements. NG-RAN ensures that while PUCCH SCell (a Secondary Cell configured with PUCCH) is deactivated, SCells of secondary PUCCH group (a group of SCells whose PUCCH signalling is associated with the PUCCH on the PUCCH SCell) should not be activated. NG-RAN ensures that SCells mapped to PUCCH SCell are deactivated before the PUCCH SCell is changed or removed.

When reconfiguring the set of serving cells:

- SCells added to the set are initially activated or deactivated;
- SCells which remain in the set (either unchanged or reconfigured) do not change their activation status (*activated* or *deactivated*).

At handover, LTM cell switch execution or connection resume from RRC_INACTIVE:

- SCells are activated or deactivated.

To enable reasonable UE battery consumption when BA is configured, only one UL BWP for each uplink carrier and one DL BWP or only one DL/UL BWP pair can be active at a time in an active serving cell, all other BWPs that the UE is configured with being deactivated. On deactivated BWPs, the UE does not monitor the PDCCH, does not transmit on PUCCH, PRACH and UL-SCH.

To enable fast SCell activation when CA is configured, one dormant BWP can be configured for an SCell. If the active BWP of the activated SCell is a dormant BWP, the UE stops monitoring PDCCH and transmitting SRS/PUSCH/PUCCH on the SCell but continues performing CSI measurements, AGC and beam management, if configured. A DCI is used to control entering/leaving the dormant BWP for one or more SCell(s) or one or more SCell group(s).

The dormant BWP is one of the UE's dedicated BWPs configured by network via dedicated RRC signalling. The SpCell and PUCCH SCell cannot be configured with a dormant BWP.

To enable fast SCell activation when CA is configured, aperiodic CSI-RS for tracking for fast SCell activation can be configured for an SCell to assist AGC and time/frequency synchronization. A MAC CE is used to trigger activation of one or more SCell(s) and trigger the aperiodic CSI-RS for tracking for fast SCell activation for a (set of) deactivated SCell(s).

To reduce unknown SCell activation delay, the measurement reporting for fast unknown SCell activation can be configured. The RRC measurement report is initiated when UE receives SCell Activation MAC CE to activate, at least, one SCell which is unknown SCell and has the valid L3 measurement result according to the requirements specified in

clause 6.3 of TS 38.133 [13]. In addition, the delay requirement of unknown SCell activation can be reduced by beam sweeping factor reduction or shorter measurement interval based on UE capability as specified in TS 38.133 [13].

10.7 E-UTRA-NR Cell Resource Coordination

An NR cell may use spectrum that overlaps or is adjacent to spectrum in use for E-UTRA cells. In this case network signalling enables coordination of TDM and FDM cell resources between MAC in the gNB and the corresponding entity in the ng-eNB. Both the gNB and the ng-eNB can trigger the E-UTRA - NR Cell Resource Coordination procedure over Xn to its peer node.

10.8 Cross Carrier Scheduling

Cross-carrier scheduling with the Carrier Indicator Field (CIF) allows the PDCCH of a serving cell to schedule resources on another serving cell but with the following restrictions:

- When cross-carrier scheduling from an SCell to SpCell is not configured, SpCell can only be scheduled via its PDCCH;
- When cross-carrier scheduling from an SCell to SpCell is configured:
  - PDCCH on that SCell can schedule SpCell's PDSCH and PUSCH;
  - PDCCH on the SpCell can schedule SpCell's PDSCH and PUSCH but cannot schedule PDSCH and PUSCH on any other cell;
  - Only one SCell can be configured to be used for cross-carrier scheduling to SpCell.
- When an SCell is configured with a PDCCH, that cell's PDSCH and PUSCH are always scheduled by the PDCCH on this SCell;
- When an SCell is not configured with a PDCCH, that SCell's PDSCH and PUSCH are always scheduled by a PDCCH on another serving cell;
- The scheduling PDCCH and the scheduled PDSCH/PUSCH can use the same or different numerologies.

10.9 IAB Resource Configuration

If the IAB-DU and the IAB-MT of an IAB-node are subject to a half-duplex constraint, correct transmission/reception by one cannot be guaranteed during transmission/reception by the other and vice versa, e.g., when collocated and operating in the same frequency. If an IAB-node supports enhanced frequency or spatial multiplexing capabilities, additional multiplexing modes can be supported, i.e., simultaneous operation of IAB-MT Rx / IAB-DU Rx, IAB-MT Tx / IAB-DU Tx, IAB-MT Rx / IAB-DU Tx, IAB-MT Tx / IAB-DU Rx. An IAB-node can report its duplexing constraints between the IAB-MT and the collocated IAB-DU via F1AP. An IAB-node can indicate via F1AP whether or not FDM is required for an enhanced multiplexing operation.

The scheduler on an IAB-DU or IAB-donor-DU complies with the gNB-DU resource configuration received via F1AP, which defines the usage of scheduling resources to account for the aforementioned duplexing constraint.

The resource configuration assigns an attribute of hard, soft or unavailable to each symbol of each DU cell. Transmission/reception can occur for symbols configured as hard, whereas scheduling cannot occur, except for some special cases, for symbols configures as unavailable. For symbols configured as soft, scheduling can occur conditionally on an explicit indication of availability by the parent node via DCI format 2_5, or on an implicit determination of availability by the IAB-node. The implicit determination of availability is determined by the IAB-node depending on whether or not the operation of the IAB-DU would have an impact on the collocated IAB-MT.

The resource configuration can be shared among neighbouring IAB-nodes and IAB-donors to facilitate interference management, dual connectivity, and enhanced multiplexing.

To facilitate transitioning from IAB-MT to IAB-DU operation and vice versa, guard symbols can be used to overcome potentially misaligned symbol boundaries between the IAB-MT operation and the IAB-DU operation (e.g., IAB-MT Rx boundaries are not aligned with the IAB-DU Tx boundaries). Specifically, an IAB-node can indicate to a parent node a

number of desired guard symbols, while the parent node can indicate to the IAB-node the number of actually provided guard symbols for specific transitions.

An IAB-node supporting enhanced multiplexing capabilities, i.e., IAB-MT Rx / IAB-DU Rx, IAB-MT Tx / IAB-DU Tx, IAB-MT Rx / IAB-DU Tx, IAB-MT Tx / IAB-DU Rx, can provide via MAC-CE to a parent node information to facilitate scheduling for enhanced multiplexing operation by the IAB-node, specifically:

- recommended IAB-MT's Tx/Rx beams;
- desired IAB-MT Tx PSD range;
- desired parent node's IAB-DU Tx power adjustment;
- required IAB-MT's uplink transmission timing mode.

Correspondingly, the parent node can provide information via MAC-CE to the IAB-node to facilitate enhanced multiplexing at the IAB-node and/or at the parent node:

- restricted IAB-DU Tx beams;
- actual parent node's IAB-DU Tx power adjustment;
- IAB-MT's uplink transmission timing mode.

10.10 Autonomous Denial for IDC

The network may configure a long-term denial rate per CG by dedicated RRC signalling to limit the amount of NR UL autonomous denials. Once configured by the network, the UE can autonomously deny NR UL transmission. Otherwise, the UE shall not perform any NR UL autonomous denials for IDC.

10.11 Multi-cell scheduling by a single DCI

Multi-cell scheduling by a single DCI allows the PDCCH of a serving cell to schedule PDSCH(s)/PUSCH(s) on one or more serving cells with the single DCI but with the following restrictions:

- When a serving cell is configured with a PDCCH which schedules PDSCH(s)/PUSCH(s) on a cell set, the PUSCH/PDSCH on serving cells in the cell set is always scheduled by a PDCCH on the serving cell;
- When SpCell is configured with a PDCCH which schedules PDSCH(s)/PUSCH(s) on serving cells in a cell set, that SpCell's PDSCH and PUSCH cannot be scheduled by a PDCCH on an SCell;
- When an SCell is configured with a PDCCH which schedules PDSCH(s)/PUSCH(s) on serving cells in a cell set, SpCell is not included in the cell set;
- The scheduling PDCCH and the scheduled PDSCH(s)/PUSCH(s) can use the same or different numerologies;
- The co-scheduled PDSCH(s) with a PDCCH can use the same or different numerologies;
- The co-scheduled PUSCH(s) with a PDCCH can use the same or different numerologies.

11 UE Power Saving

The PDCCH monitoring activity of the UE in RRC connected mode is governed by DRX, BA, DCP, cell DTX (see clause 15.4.2.3) and LP-WUS.

When DRX is configured, the UE does not have to continuously monitor PDCCH. DRX is characterized by the following:

- **on-duration**: duration that the UE waits for, after waking up, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;

- **inactivity-timer**: duration that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it can go back to sleep. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions);
- **LP-WUS PDCCH monitoring timer**: duration that the UE waits for, after woken up by LP-WUS, to receive PDCCH. In case this timer is configured the UE does not start the on-duration timer. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;
- **retransmission-timer**: duration until a retransmission can be expected;
- **cycle**: specifies the periodic repetition of the on-duration followed by a possible period of inactivity (see figure 11-1 below);
- **active-time**: total duration that the UE monitors PDCCH. This includes the "on-duration" of the DRX cycle, the time UE is performing continuous reception while the inactivity timer has not expired, the time when the UE is performing continuous reception while waiting for a retransmission opportunity and the time UE is performing continuous reception while the LP-WUS PDCCH monitoring timer has not expired.

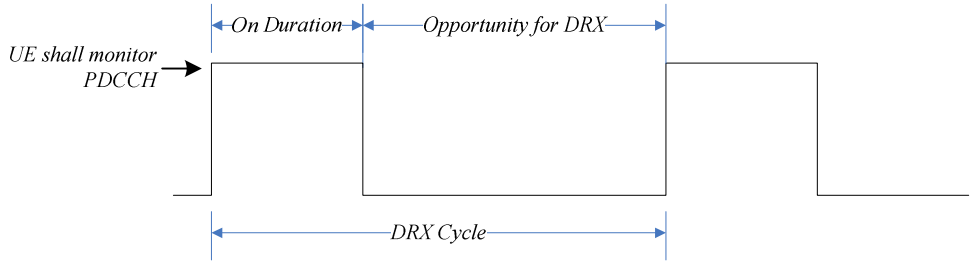


Figure 11-1: DRX Cycle

UE can be configured with LP-WUS for power saving in all RRC states. A LP-WUS is transmitted based on OOK and overlaid OFDM sequence(s) over OOK ON symbols and can carry up to 5 information bits and one codepoint out of up to 32 codepoints. A UE supports detection of LP-WUS information carried by OOK and/or overlaid OFDM sequences. In RRC_IDLE and RRC_INACTIVE, the same information is delivered by OOK and overlaid OFDM sequences. For LP-WUS, the number of OOK symbols within an OFDM symbol can be configured as 1, 2 or 4. For RRC_IDLE and RRC_INACTIVE, a UE monitors two codepoints for LP-WUS. In RRC_CONNECTED, a UE can be configured to monitor up to 8 codepoints for LP-WUS.

A SL UE can be configured with DRX, in which case, PDCCH providing SL grants can be send to the UE only during its active time.

When BA is configured, the UE only has to monitor PDCCH on the one active BWP i.e. it does not have to monitor PDCCH on the entire DL frequency of the cell. A BWP inactivity timer (independent from the DRX inactivity-timer described above) is used to switch the active BWP to the default one: the timer is restarted upon successful PDCCH decoding and the switch to the default BWP takes place when it expires.

In addition, the UE may be indicated, when configured accordingly, whether it is required to monitor or not the PDCCH during the next occurrence of the on-duration by a DCP monitored on the active BWP. If the UE does not detect a DCP on the active BWP, it does not monitor the PDCCH during the next occurrence of the on-duration, unless it is explicitly configured to do so in that case.

A UE can only be configured to monitor DCP when connected mode DRX is configured, and at occasion(s) at a configured offset before the on-duration. If short DRX cycle is configured, DCP is not applicable when short DRX cycle is used. More than one monitoring occasion can be configured before the on-duration. The UE does not monitor DCP on occasions occurring during active-time, measurement gaps, MUSIM gaps, BWP switching, or when it monitors response for a CFRA preamble transmission for beam failure recovery (see clause 9.2.6), in which case it monitors the PDCCH during the next on-duration. If no DCP is configured in the active BWP, UE follows normal DRX operation.

When CA is configured, DCP or LP-WUS is only configured on the PCell and/or PSCell.

One DCP can be configured to control PDCCH monitoring during on-duration for one or more UEs independently.

A UE configured with DRX in RRC_CONNECTED can be configured with LP-WUS. The UE does not monitor LP-WUS during active-time, measurement gaps, MUSIM gaps, BWP switching, or when it monitors response for a CFRA

preamble transmission for beam failure recovery (see clause 9.2.6). If LP-WUS is detected, the UE shall start the on-duration timer or LP-WUS PDCCH monitoring timer to start PDCCH monitoring and enter active-time:

- If the UE is configured to start on-duration timer after LP-WUS reception, the UE monitors LP-WUS at occasion(s) at a configured offset before the on-duration, and the UE does not monitor LP-WUS when short DRX cycle is used. If the UE is unable to monitor the LP-WUS occasion, it shall start the on-duration timer.

- If the UE is configured to start LP-WUS PDCCH monitoring timer after LP-WUS reception, the UE monitors LP-WUS at occasion(s) according to the configured periodicity and offset which can be same or different from the periodicity and offset configured for C-DRX cycle, and the UE monitors LP-WUS regardless of which DRX cycle is used. It the UE is unable to monitor the LP-WUS occasion(s), the LP-WUS PDCCH monitoring timer is not started.

Three candidate values for minimum time gap are supported for UE in RRC_CONNECTED to report via capability signalling, where the minimum time gap is between the LP-WUS reception and MR to start PDCCH monitoring. gNB configures the time offset between LP-WUS monitoring and the corresponding PDCCH monitoring.

When LP-WUS is configured, the next available uplink resources determined by the MAC entity (e.g. PUCCH resource for SR, PRACH occasion, and CG resource) occur when MR is activated.

Power saving in RRC_IDLE and RRC_INACTIVE can also be achieved by UE relaxing neighbour cells RRM measurements when it meets the criteria determining it is in low mobility and/or not at cell edge. When UE is configured with both high speed measurements and RRM measurement relaxation as specified in TS 38.331 [12], it is up to UE implementation whether to apply the FR1 high speed RRM requirements or the relaxed RRM requirements when the low mobility related criterion is configured and fulfilled as specified in TS 38.133 [13].

Power saving in RRC_IDLE and RRC_INACTIVE can also be achieved by allowing UEs supporting LP-WUS to relax serving cell measurements on MR, further relax neighbour cell measurements on MR and/or offload serving cell measurements from MR to LR. Conditions to further relax neighbour and relax serving cell measurements are based on MR, optionally LR measurements and optionally on low mobility criterion as specified in TS 38.304 [10]. Entry condition for offloading serving cell measurements from MR to LR is based on MR, optionally LR measurements and optionally on low mobility criterion as specified in TS 38.304 [10]. Exit conditions for offloading serving cell measurements from MR to LR are based on LR measurements as specified in TS 38.304 [10].

Editor's Note: The UE behaviour when low mobility is configured, but the UE does not support low mobility, is FFS.

For UE in RRC_IDLE and RRC_INACTIVE configured with LP-WUS, LP-SS is supported for UE LR to maintain synchronization and perform serving cell RRM measurements. LP-SS transmission is based on OOK with or without overlaid OFDM sequence. For UE capable of detecting overlaid OFDM sequence by LR, PSS/SSS can be used for UE LR to maintain synchronization and perform serving cell RRM measurements. For LP-SS, the number of OOK symbols within an OFDM symbol can be configured as 1, 2 or 4 and the number can be same or larger than LP-WUS. LP-SS is not supported in RRC_CONNECTED.

For UE in RRC_IDLE and RRC_INACTIVE configured with LP-WUS, the frequency resource of LP-WUS and LP-SS can be configured within or outside the initial DL BWP in the carrier where the UE monitors paging. For UE in RRC_CONNECTED, the frequency resource of LP-WUS can be configured within or outside the UE active DL BWP, where the support of LP-WUS monitoring outside active DL BWP is optional.

For UE in RRC_IDLE and RRC_INACTIVE configured with LP-WUS, three candidate values for wake-up delay are supported for UE to report via capability signalling, where wake-up delay is defined as the minimum time gap between the LP-WUS reception and MR to start PDCCH monitoring. gNB can configure one or two time offset values between the reference PF of the PO and the associated LP-WUS monitoring occasions. If at least one of the configured time offset values are no smaller than the wake-up delay that UE reports, the UE monitors LP-WUS monitoring occasions corresponding to the smallest time offset value that is no smaller than its reported wake-up delay, otherwise, the UE does not monitor LP-WUS and monitors PO.

UE is not required to support simultaneous reception using LR and MR, where LR is used for LP-WUS monitoring and MR is used for transmission and/or reception of all other NR signals/channels in RRC_CONNECTED within the same cell group.

NOTE: It is up to UE implementation to implement LR in the same or different physical receiver as MR.

UE power saving may be enabled by adapting the DL maximum number of MIMO layers by BWP switching.

Power saving is also enabled during active-time via cross-slot scheduling, which facilitates UE to achieve power saving with the assumption that it won't be scheduled to receive PDSCH, triggered to receive A-CSI or transmit a PUSCH scheduled by the PDCCH until the minimum scheduling offsets K0 and K2. Dynamic adaptation of the minimum scheduling offsets K0 and K2 is controlled by PDCCH.

Serving Cells of a MAC entity may be configured by RRC in two DRX groups with separate DRX parameters. When RRC does not configure a secondary DRX group, there is only one DRX group and all Serving Cells belong to that one DRX group. When two DRX groups are configured, each Serving Cell is uniquely assigned to either of the two groups. The DRX parameters that are separately configured for each DRX group are on-duration and inactivity-timer.

A UE supporting LP-WUS can be configured with two DRX groups where the UE can be configured to start either on-duration timer or the LP-WUS PDCCH monitoring timer after detecting LP-WUS to enter active-time. After LP-WUS detection the corresponding timer is started in both of the DRX groups. In addition to on-duration and inactivity-timer, the LP-WUS PDCCH monitoring timer is separately configured for each DRX group. The UE monitors LP-WUS only when both DRX groups are outside active-time.

UE power saving in RRC_IDLE/RRC_INACTIVE may be achieved by providing the configuration for TRS with CSI-RS for tracking in TRS occasions. The TRS in TRS occasions may allow UEs in RRC_IDLE/RRC_INACTIVE to sleep longer before waking-up for its paging occasion. The TRS occasions configuration is provided in either SIB17 or SIB17bis. The availability of TRS in the TRS occasions is indicated by L1 availability indication. These TRSs may also be used by the UEs configured with eDRX.

UE power saving may be achieved by UE relaxing measurements for RLM/BFD. When configured, UE determines whether it is in low mobility state and/or whether its serving cell radio link quality is better than a threshold. The configuration for low mobility and good serving cell quality criterion is provided through dedicated RRC signalling.

RLM and BFD relaxation may be enabled/disabled separately through RRC Configuration. Additionally, RLM relaxation may be enabled/disabled on per Cell Group basis while BFD relaxation may be enabled/disabled on per serving cell basis.

The UE is only allowed to perform RLM and/or BFD relaxation when relaxed measurement criterion for low mobility and/or for good serving cell quality is met. If configured to do so, the UE shall trigger reporting of its RLM and/or BFD relaxation status through UE assistance information if the UE changes its respective RLM and/or BFD relaxation status while meeting the UE minimum requirements specified in TS 38.133 [13].

UE power saving may also be achieved through PDCCH monitoring adaptation mechanisms when configured by the network, including skipping of PDCCH monitoring and Search space set group (SSSG) switching. In this case UE does not monitor PDCCH during the PDCCH skipping duration except for the cases as specified in TS 38.213 [38], or monitors PDCCH according to the search space sets applied in SSSG.

12 QoS

12.1 Overview

The **5G QoS model** is based on QoS Flows (see TS 23.501 [3]) and supports both QoS Flows that require guaranteed flow bit rate (GBR QoS Flows) and QoS Flows that do not require guaranteed flow bit rate (non-GBR QoS Flows). At NAS level (see TS 23.501 [3]), the QoS flow is thus the finest granularity of QoS differentiation in a PDU session. A QoS flow is identified within a PDU session by a QoS Flow ID (QFI) carried in an encapsulation header over NG-U.

The **QoS architecture** in NG-RAN, both for NR connected to 5GC and for E-UTRA connected to 5GC, is depicted in the Figure 12-1 and described in the following:

- For each UE, 5GC establishes one or more PDU Sessions;
- Except for NB-IoT, IAB-MT in SA mode, and NCR-MT, for each UE, the NG-RAN establishes at least one Data Radio Bearers (DRB) together with the PDU Session and additional DRB(s) for QoS flow(s) of that PDU session can be subsequently configured (it is up to NG-RAN when to do so);
- If NB-IoT UE supports NG-U data transfer, the NG-RAN may establish Data Radio Bearers (DRB) together with the PDU Session and one PDU session maps to only one DRB;

- The NG-RAN maps packets belonging to different PDU sessions to different DRBs;
- NAS level packet filters in the UE and in the 5GC associate UL and DL packets with QoS Flows;
- AS-level mapping rules in the UE and in the NG-RAN associate UL and DL QoS Flows with DRBs.

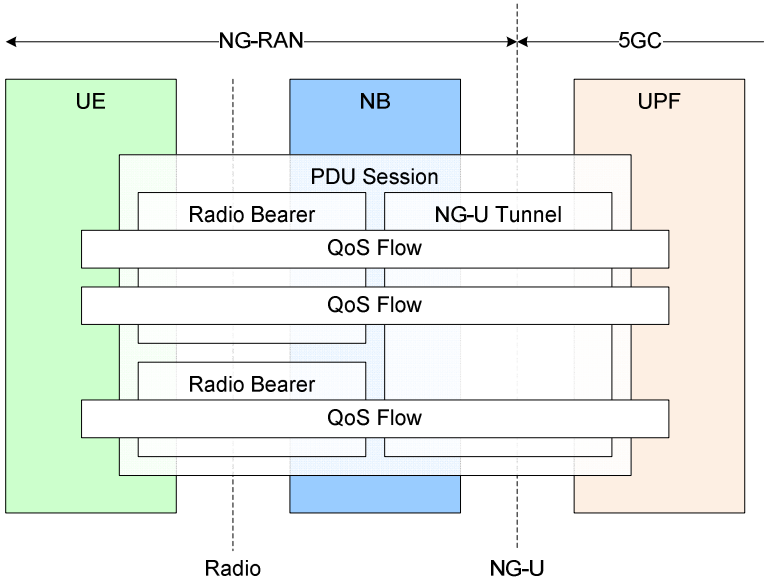


Figure 12-1: QoS architecture

NG-RAN and 5GC ensure quality of service (e.g. reliability and target delay) by mapping packets to appropriate QoS Flows and DRBs. Hence there is a 2-step mapping of IP-flows to QoS flows (NAS) and from QoS flows to DRBs (Access Stratum).

At **NAS level**, a QoS flow is characterised by a QoS profile provided by 5GC to NG-RAN and QoS rule(s) provided by 5GC to the UE. The QoS profile is used by NG-RAN to determine the treatment on the radio interface while the QoS rules dictates the mapping between uplink User Plane traffic and QoS flows to the UE. A QoS flow may either be GBR or Non-GBR depending on its profile. The QoS profile of a QoS flow contains QoS parameters, for instance (see TS 23.501 [3]):

- For each QoS flow:
  - A 5G QoS Identifier (5QI);
  - An Allocation and Retention Priority (ARP).
- In case of a GBR QoS flow only:
  - Guaranteed Flow Bit Rate (GFBR) for both uplink and downlink;
  - Maximum Flow Bit Rate (MFBR) for both uplink and downlink;
  - Maximum Packet Loss Rate for both uplink and downlink;
  - Delay Critical Resource Type;
  - Notification Control.

NOTE: The Maximum Packet Loss Rate (UL, DL) is only provided for a GBR QoS flow belonging to voice media.

- In case of Non-GBR QoS only:
  - Reflective QoS Attribute (RQA): the RQA, when included, indicates that some (not necessarily all) traffic carried on this QoS flow is subject to reflective quality of service (RQoS) at NAS;
  - Additional QoS Flow Information.

The QoS parameter Notification Control indicates whether notifications are requested from the RAN when the GBR QoS can no longer (or again) be fulfilled for a QoS Flow, as specified in TS 23.501 [3]. If, for a given GBR QoS Flow, notification control is enabled and the RAN determines that the GBR QoS cannot be guaranteed, RAN shall send a notification towards SMF and keep the QoS Flow (i.e. while the NG-RAN is not delivering the requested GBR QoS for this QoS Flow), unless specific conditions at the NG-RAN require the release of the NG-RAN resources for this GBR QoS Flow, e.g. due to Radio link failure or RAN internal congestion. When applicable, NG-RAN sends a new notification, informing SMF that the GBR QoS can be guaranteed again.

If Alternative QoS parameters Sets are received with the Notification Control parameter, the NG-RAN may also include in the notification a reference corresponding to the QoS Parameter Set which it can currently fulfil as specified in TS 23.501 [3]. The target NG-RAN node may include in the notification control indication the reference to the QoS Parameter Set which it can currently fulfil over Xn to the source NG-RAN node during handover.

In addition, an Aggregate Maximum Bit Rate is associated to each PDU session (Session-AMBR), to each UE (UE-AMBR) and to each slice per UE (UE-Slice-MBR). The Session-AMBR limits the aggregate bit rate that can be expected to be provided across all Non-GBR QoS Flows for a specific PDU Session and is ensured by the UPF. The UE-AMBR limits the aggregate bit rate that can be expected to be provided across all Non-GBR QoS Flows of a UE and is ensured by the RAN (see clause 10.5.1). The UE-Slice-MBR limits the aggregate bit rate that can be expected to be provided across all GBR and Non-GBR QoS Flows corresponding to PDU Sessions of the UE for the same slice (S-NSSAI) as specified in TS 23.501 [3] and is ensured by the RAN (see clause 10.5.1).

The 5QI is associated to QoS characteristics giving guidelines for setting node specific parameters for each QoS Flow. Standardized or pre-configured 5G QoS characteristics are derived from the 5QI value and are not explicitly signalled. Signalled QoS characteristics are included as part of the QoS profile. The QoS characteristics consist for instance of (see TS 23.501 [3]):

- Priority level;
- Packet Delay Budget (including Core Network Packet Delay Budget);
- Packet Error Rate;
- Averaging window;
- Maximum Data Burst Volume.

At **Access Stratum** level, the data radio bearer (DRB) defines the packet treatment on the radio interface (Uu). A DRB serves packets with the same packet forwarding treatment. The QoS flow to DRB mapping by NG-RAN is based on QFI and the associated QoS profiles (i.e. QoS parameters and QoS characteristics). Separate DRBs may be established for QoS flows requiring different packet forwarding treatment, or several QoS Flows belonging to the same PDU session can be multiplexed in the same DRB.

In the uplink, the mapping of QoS Flows to DRBs is controlled by mapping rules which are signalled in two different ways:

- Reflective mapping: for each DRB, the UE monitors the QFI(s) of the downlink packets and applies the same mapping in the uplink; that is, for a DRB, the UE maps the uplink packets belonging to the QoS flows(s) corresponding to the QFI(s) and PDU Session observed in the downlink packets for that DRB. To enable this reflective mapping, the NG-RAN marks downlink packets over Uu with QFI.
- Explicit Configuration: QoS flow to DRB mapping rules can be explicitly signalled by RRC.

The UE always applies the latest update of the mapping rules regardless of whether it is performed via reflecting mapping or explicit configuration.

When a QoS flow to DRB mapping rule is updated, the UE sends an end marker on the old bearer.

In the downlink, the QFI is signalled by NG-RAN over Uu for the purpose of RQoS and if neither NG-RAN, nor the NAS (as indicated by the RQA) intend to use reflective mapping for the QoS flow(s) carried in a DRB, no QFI is signalled for that DRB over Uu. In the uplink, NG-RAN can configure the UE to signal QFI over Uu.

For each PDU session, a default DRB may be configured: if an incoming UL packet matches neither an RRC configured nor a reflective mapping rule, the UE then maps that packet to the default DRB of the PDU session. For non-GBR QoS flows, the 5GC may send to the NG-RAN the Additional QoS Flow Information parameter associated with

certain QoS flows to indicate that traffic is likely to appear more often on them compared to other non-GBR QoS flows established on the same PDU session.

Within each PDU session, it is up to NG-RAN how to map multiple QoS flows to a DRB. The NG-RAN may map a GBR flow and a non-GBR flow, or more than one GBR flow to the same DRB, but mechanisms to optimise these cases are not within the scope of standardization.

12.2 Explicit Congestion Notification

The gNB and the UE support of the Explicit Congestion Notification (ECN) is specified in clause 5 of [27].

13 Security

13.1 Overview and Principles

The following principles apply to NR connected to 5GC security, see TS 33.501 [5]:

- For user data (DRBs), ciphering provides user data confidentiality and integrity protection provides user data integrity;
- For RRC signalling (SRBs), ciphering provides signalling data confidentiality and integrity protection signalling data integrity;

NOTE: Ciphering and integrity protections are optionally configured except for RRC signalling for which integrity protection is always configured. Ciphering and integrity protection can be configured per DRB but all DRBs belonging to a PDU session for which the User Plane Security Enforcement information indicates that UP integrity protection is required (see TS 23.502 [22]), are configured with integrity protection.

- For key management and data handling, any entity processing cleartext shall be protected from physical attacks and located in a secure environment;
- The gNB (AS) keys are cryptographically separated from the 5GC (NAS) keys;
- Separate AS and NAS level Security Mode Command (SMC) procedures are used;
- A sequence number (COUNT) is used as input to the ciphering and integrity protection and a given sequence number must only be used once for a given key (except for identical re-transmission) on the same radio bearer in the same direction.

The keys are organised and derived as follows:

- Key for AMF:
  - K_{AMF} is a key derived by ME and SEAF from K_{SEAF}.
- Keys for NAS signalling:
  - K_{NASint} is a key derived by ME and AMF from K_{AMF}, which shall only be used for the protection of NAS signalling with a particular integrity algorithm;
  - K_{NASenc} is a key derived by ME and AMF from K_{AMF}, which shall only be used for the protection of NAS signalling with a particular encryption algorithm.

Key for gNB:

- K_{gNB} is a key derived by ME and AMF from K_{AMF}. K_{gNB} is further derived by ME and source gNB when performing horizontal or vertical key derivation.

Keys for UP traffic:

- K_{UPenc} is a key derived by ME and gNB from K_{gNB}, which shall only be used for the protection of UP traffic between ME and gNB with a particular encryption algorithm;

- K_{UPint} is a key derived by ME and gNB from K_{gNB}, which shall only be used for the protection of UP traffic between ME and gNB with a particular integrity algorithm.

Keys for RRC signalling:

- K_{RRCint} is a key derived by ME and gNB from K_{gNB}, which shall only be used for the protection of RRC signalling with a particular integrity algorithm;

- K_{RRCenc} is a key derived by ME and gNB from K_{gNB}, which shall only be used for the protection of RRC signalling with a particular encryption algorithm.

Intermediate keys:

- NH is a key derived by ME and AMF to provide forward security.

- K_{gNB}* is a key derived by ME and gNB when performing a horizontal or vertical key derivation.

The primary authentication enables mutual authentication between the UE and the network and provide an anchor key called K_{SEAF}. From K_{SEAF}, K_{AMF} is created during e.g. primary authentication or NAS key re-keying and key refresh events. Based on K_{AMF}, K_{NASint} and K_{NASenc} are then derived when running a successful NAS SMC procedure.

Whenever an initial AS security context needs to be established between UE and gNB, AMF and the UE derive a K_{gNB} and a Next Hop parameter (NH). The K_{gNB} and the NH are derived from the K_{AMF}. A NH Chaining Counter (NCC) is associated with each K_{gNB} and NH parameter. Every K_{gNB} is associated with the NCC corresponding to the NH value from which it was derived. At initial setup, the K_{gNB} is derived directly from K_{AMF}, and is then considered to be associated with a virtual NH parameter with NCC value equal to zero. At initial setup, the derived NH value is associated with the NCC value one. On handovers, the basis for the K_{gNB} that will be used between the UE and the target gNB, called K_{gNB}*, is derived from either the currently active K_{gNB} or from the NH parameter. If K_{gNB}* is derived from the currently active K_{gNB}, this is referred to as a horizontal key derivation and is indicated to UE with an NCC that does not increase. If the K_{gNB}* is derived from the NH parameter, the derivation is referred to as a vertical key derivation and is indicated to UE with an NCC increase. Finally, K_{RRCint}, K_{RRCenc}, K_{UPint} and K_{UPenc} are derived based on K_{gNB} after a new K_{gNB} is derived. This is depicted on Figure 13.1-1 below:

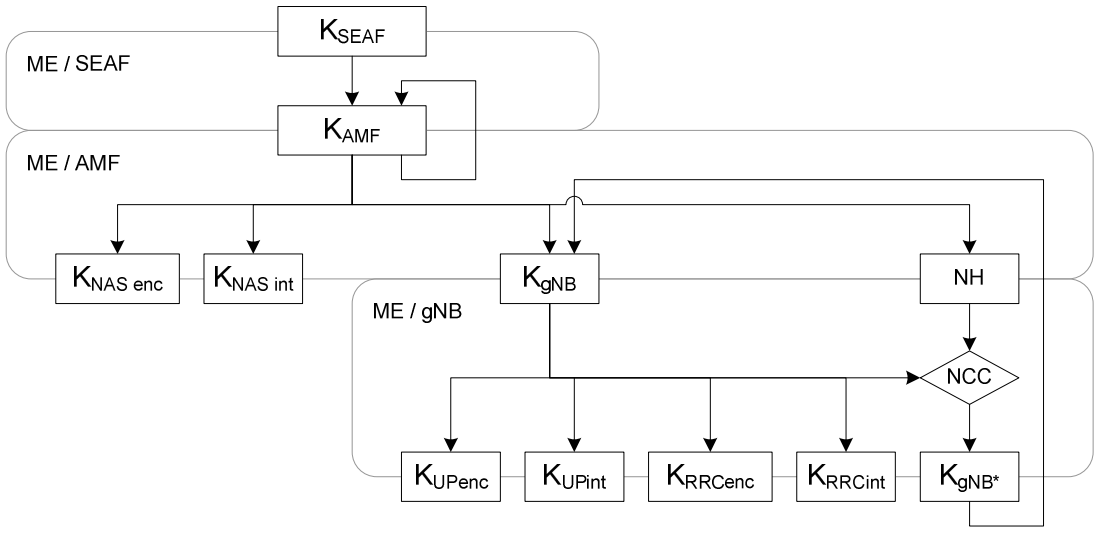


Figure 13.1-1: 5G Key Derivation

With such key derivation, a gNB with knowledge of a K_{gNB}, shared with a UE, is unable to compute any previous K_{gNB} that has been used between the same UE and a previous gNB, therefore providing backward security. Similarly, a gNB with knowledge of a K_{gNB}, shared with a UE, is unable to predict any future K_{gNB} that will be used between the same UE and another gNB after n or more handovers (since NH parameters are only computable by the UE and the AMF).

The AS SMC procedure is for RRC and UP security algorithms negotiation and RRC security activation. When AS security context is to be established in the gNB, the AMF sends the complete UE 5G security capabilities to the gNB

(i.e., all bits for every capability defined in TS 24.501 [28] and received in NAS signalling). At handover (or at UE Context retrieval), the complete UE 5G security capabilities are also sent by the source gNB to the target gNB (or by the last serving gNB to the receiving gNB respectively). The gNB chooses the ciphering algorithm which has the highest priority from its configured list and is also present in the UE 5G security capabilities. The gNB also chooses the integrity algorithm which has the highest priority from its configured list and is also present in the UE 5G security capabilities. The chosen algorithms are indicated to the UE in the AS SMC and this message is integrity protected. RRC downlink ciphering (encryption) at the gNB starts after sending the AS SMC message. RRC uplink deciphering (decryption) at the gNB starts after receiving and successful verification of the integrity protected AS security mode complete message from the UE. The UE verifies the validity of the AS SMC message from the gNB by verifying the integrity of the received message. RRC uplink ciphering (encryption) at the UE starts after sending the AS security mode complete message. RRC downlink deciphering (decryption) at the UE shall start after receiving and successful verification of the AS SMC message. The RRC Connection Reconfiguration procedure used to add DRBs shall be performed only after RRC security has been activated as part of the AS SMC procedure.

A UE connected to 5GC, shall support integrity protected DRBs at any data rate, up to and including the highest data rate supported by the UE for both UL and DL. In case of failed integrity check (i.e. faulty or missing MAC-I), the concerned PDU shall be discarded by the receiving PDCP entity.

Key refresh is possible for K_{gNB}, $K_{RRC\text{-}enc}$, $K_{RRC\text{-}int}$, $K_{UP\text{-}enc}$, and $K_{UP\text{-}int}$ and can be initiated by the gNB when a PDCP COUNTs are about to be re-used with the same Radio Bearer identity and with the same K_{gNB}. Key re-keying is also possible for the K_{gNB}, $K_{RRC\text{-}enc}$, $K_{RRC\text{-}int}$, $K_{UP\text{-}enc}$, and $K_{UP\text{-}int}$ and can be initiated by the AMF when a 5G AS security context different from the currently active one shall be activated.

13.2 Security Termination Points

The table below describes the security termination points.

Table 13.2-1 Security Termination Points

	Ciphering	Integrity Protection
NAS Signalling	AMF	AMF
RRC Signalling	gNB	gNB
User Plane Data	gNB	gNB

13.3 State Transitions and Mobility

As a general principle, on RRC_IDLE to RRC_CONNECTED transitions, RRC protection keys and UP protection keys are generated while keys for NAS protection as well as higher layer keys are assumed to be already available. These higher layer keys may have been established as a result of an AKA run, or as a result of a transfer from another AMF during handover or idle mode mobility see TS 23.502 [22]).

On RRC_CONNECTED to RRC_IDLE transitions, the gNBs deletes the keys it stores for that UE such that state information for idle mode UEs only has to be maintained in AMF. It is also assumed that gNB does no longer store state information about the corresponding UE and deletes the current keys from its memory. In particular, on connected to idle transitions:

- The gNB and UE delete NH, K_{gNB}, K_{RRCint}, K_{RRCenc}, K_{UPint} and K_{UPenc} and related NCC;
- AMF and UE keeps K_{AMF}, K_{NASint} and K_{NASenc} stored.

On mobility with vertical key derivation the NH is further bound to the target PCI and its frequency ARFCN-DL before it is taken into use as the K_{gNB} in the target gNB. On mobility with horizontal key derivation the currently active K_{gNB} is further bound to the target PCI and its frequency ARFCN-DL before it is taken into use as the K_{gNB} in the target gNB (see clause 13.1). In both cases, ARFCN-DL is the absolute frequency of CD-SSB of the target PCell.

It is not required to change the AS security algorithms during intra-gNB-CU handover. If the UE does not receive an indication of new AS security algorithms during an intra-gNB-CU handover, the UE shall continue to use the same algorithms as before the handover (see TS 38.331 [12]).

14 UE Capabilities

The UE capabilities in NR rely on a hierarchical structure where each capability parameter is defined per UE, per duplex mode (FDD/TDD), per frequency range (FR1/FR2), per band, per band combinations, … as the UE may support different functionalities depending on those (see TS 38.306 [11]).

NOTE 1: Some capability parameters are always defined per UE (e.g. SDAP, PDCP and RLC parameters) while some other not always (e.g. MAC and Physical Layer Parameters).

The UE capabilities in NR do not rely on UE categories: UE categories associated to fixed peak data rates are only defined for marketing purposes and not signalled to the network. Instead, the peak data rate for a given set of aggregated carriers in a band or band combination is the sum of the peak data rates of each individual carrier in that band or band combination, where the peak data rate of each individual carrier is computed according to the capabilities supported for that carrier in the corresponding band or band combination.

For each block of contiguous serving cells in a band, the set of features supported thereon is defined in a Feature Set (FS). The UE may indicate several Feature Sets for a band (also known as feature sets per band) to advertise different alternative features for the associated block of contiguous serving cells in that band. The two-dimensional matrix of feature sets for all the bands of a band combination (i.e. all the feature sets per band) is referred to as a feature set combination. In a feature set combination, the number of feature sets per band is equal to the number of band entries in the corresponding band combination, and all feature sets per band have the same number of feature sets. Each band combination is linked to one feature set combination. This is depicted on Figure 14-1 below:

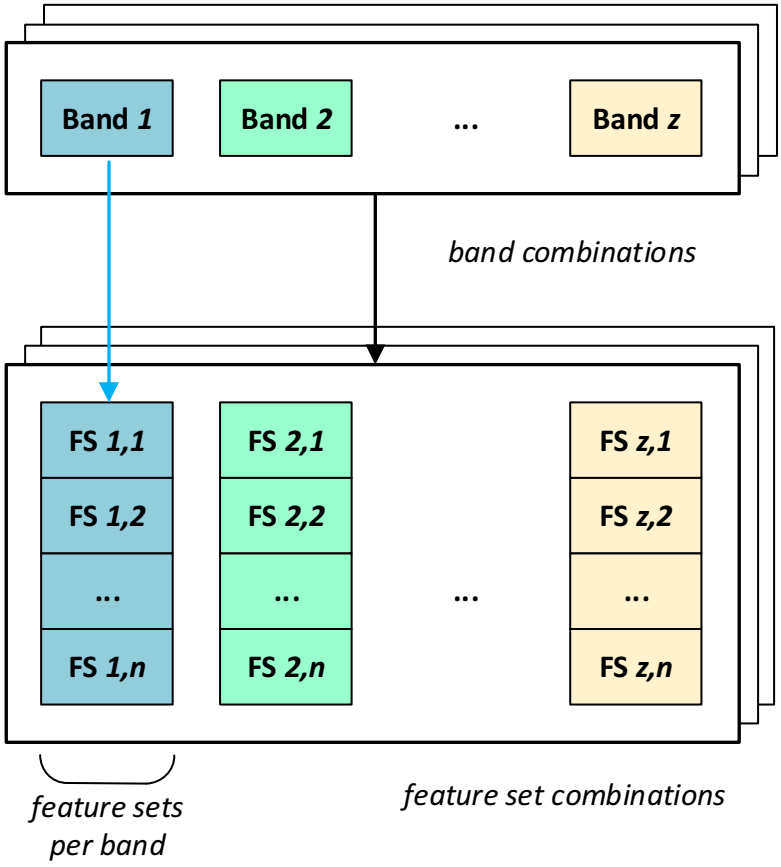


Figure 14-1: Feature Set Combinations

In addition, for some features in intra-band contiguous CA, the UE reports its capabilities individually per carrier. Those capability parameters are sent in feature set per component carrier and they are signalled in the corresponding FSs (per Band) i.e. for the corresponding block of contiguous serving cells in a band. The capability applied to each individual carrier in a block is agnostic to the order in which they are signalled in the corresponding FS.

NOTE 2: For intra-band non-contiguous CA, there are as many feature sets per band signalled as the number of (groups of contiguous) carriers that the UE is able to aggregate non-contiguously in the corresponding band.

To limit signalling overhead, the gNB can request the UE to provide NR capabilities for a restricted set of bands. When responding, the UE can skip a subset of the requested band combinations according to the UE capability fallback behaviour as specified in TS 38.306 [11] and in TS 38.331 [12]. An eRedCap UE may ignore UE capability filtering and send all supported bands in the mirrored UE capability filter with an explicit indication on whether the filter was ignored or not.

If supported by the UE and the network, the UE may provide an ID in NAS signalling that represents its radio capabilities for one or more RATs in order to reduce signalling overhead. The ID may be assigned either by the manufacturer or by the serving PLMN. The manufacturer-assigned ID corresponds to a pre-provisioned set of capabilities. In the case of the PLMN-assigned ID, assignment takes place in NAS signalling.

The AMF stores the UE Radio Capability uploaded by the gNB as specified in TS 23.501 [3].

The gNB can request the UE capabilities for RAT-Types NR, EUTRA, UTRA-FDD. The UTRAN capabilities, i.e. the INTER RAT HANDOVER INFO, include START-CS, START-PS and "predefined configurations", which are "dynamic" IEs. In order to avoid the START values desynchronisation and the key replaying issue, the gNB always requests the UE UTRA-FDD capabilities before handover to UTRA-FDD. The gNB does not upload the UE UTRA-FDD capabilities to the AMF.

15 Self-Configuration and Self-Optimisation

15.1 Definitions

Void.

15.2 Void

15.3 Self-configuration

15.3.1 Dynamic configuration of the NG-C interface

15.3.1.1 Prerequisites

The following prerequisites are assumed:

- An initial remote IP end point to be used for SCTP initialisation is provided to the NG-RAN node for each AMF the NG-RAN node is supposed to connect to.

15.3.1.2 SCTP initialization

NG-RAN establishes the first SCTP (IETF RFC 4960 [23]) using a configured IP address.

NOTE: The NG-RAN node may use different source and/or destination IP end point(s) if the SCTP establishment towards one IP end point fails. How the NG-RAN node gets the remote IP end point(s) and its own IP address are outside the scope of this specification.

15.3.1.3 Application layer initialization

Once SCTP connectivity has been established, the NG-RAN node and the AMF shall exchange application level configuration data over NGAP with the NG Setup procedure, which is needed for these two nodes to interwork correctly on the NG interface:

- The NG-RAN node provides the relevant configuration information to the AMF, which includes list of supported TA(s), etc.;
- The AMF provides the relevant configuration information to the NG-RAN node, which includes PLMN ID, etc.;
- When the application layer initialization is successfully concluded, the dynamic configuration procedure is completed and the NG-C interface is operational.

After the application layer initialization is successfully completed, the AMF may add or update or remove SCTP endpoints to be used for NG-C signalling between the AMF and the NG-RAN node pair as specified in TS 23.501 [3].

The AMF and the NG-RAN node may agree at the NG Setup procedure that UE-related contexts and related signalling connection that have been existing before the NG Setup shall not be affected. The AMF or NG-RAN node or both may trigger an NGAP Reset procedure for any UE-related context and related signalling connection for UEs which could not be kept in CM_CONNECTED mode, or for UEs for which the AMF or the NG-RAN node decided to remove the UE context and related signalling connection. If either the AMF or the NG-RAN node do not agree to keep the UE contexts (if any), then they are removed and all related signalling connections are erased.

15.3.2 Dynamic Configuration of the Xn interface

15.3.2.1 Prerequisites

The following prerequisites are necessary:

- An initial remote IP end point to be used for SCTP initialisation is provided to the NG-RAN node.

15.3.2.2 SCTP initialization

NG-RAN establishes the first SCTP (IETF RFC 4960 [23]) using a configured IP address.

NOTE: The NG-RAN node may use different source and/or destination IP end point(s) if the SCTP establishment towards one IP end point fails.

15.3.2.3 Application layer initialization

Once SCTP connectivity has been established, the NG-RAN node and its candidate peer NG-RAN node are in a position to exchange application level configuration data over XnAP needed for the two nodes to interwork correctly on the Xn interface:

- The NG-RAN node provides the relevant configuration information to the candidate NG-RAN node, which includes served cell information;
- The candidate NG-RAN node provides the relevant configuration information to the initiating NG-RAN node, which includes served cell information;
- When the application layer initialization is successfully concluded, the dynamic configuration procedure is completed and the Xn interface is operational;
- The NG-RAN node shall keep neighbouring NG-RAN nodes updated with the complete list of served cells, or, if requested by the peer NG-RAN node, by a limited list of served cells, while the Xn interface is operational.

15.3.3 Automatic Neighbour Cell Relation Function

15.3.3.1 General

The purpose of ANR function is to relieve the operator from the burden of manually managing NCRs. Figure 15.3.3.1-1 shows ANR and its environment:

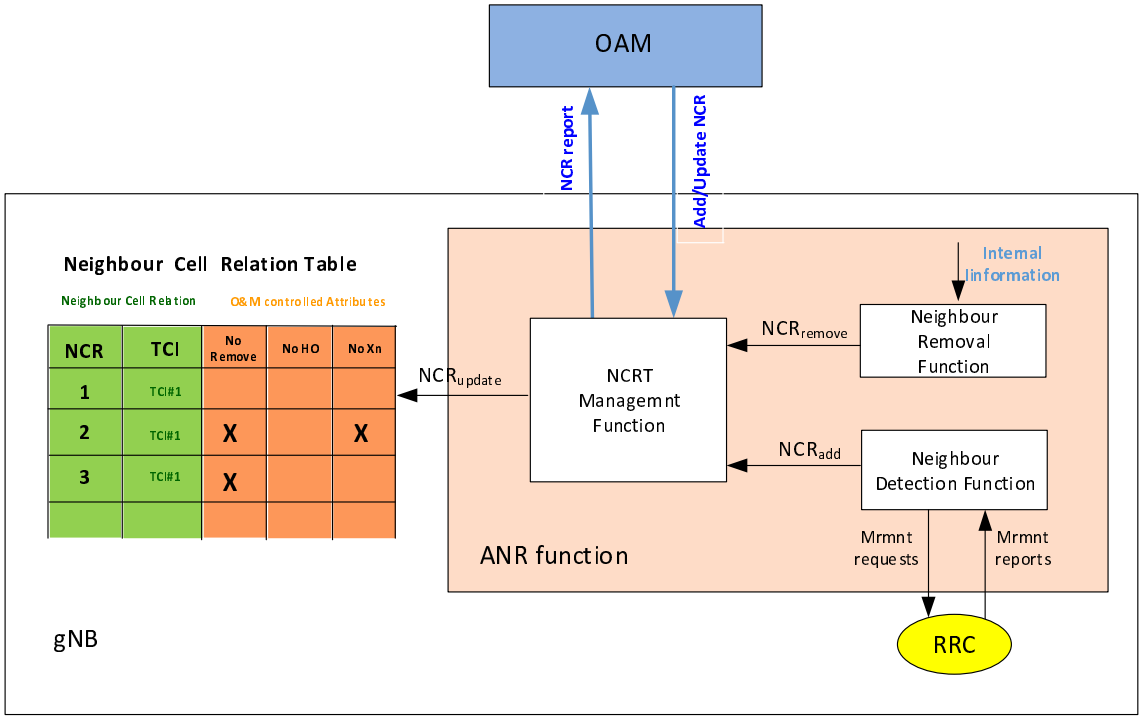


Figure 15.3.3.1-1: Interaction between gNB and OAM due to ANR

The ANR function resides in the gNB and manages the Neighbour Cell Relation Table (NCRT). Located within ANR, the Neighbour Detection Function finds new neighbours and adds them to the NCRT. ANR also contains the Neighbour Removal Function which removes outdated NCRs. The Neighbour Detection Function and the Neighbour Removal Function are implementation specific.

An existing NCR from a source cell to a target cell means that gNB controlling the source cell:

a) Knows the global and physical IDs (e.g. NR CGI/NR PCI, ECGI/PCI) of the target cell; and

b) Has an entry in the NCRT for the source cell identifying the target cell; and

c) Has the attributes in this NCRT entry defined, either by OAM or set to default values.

NCRs are cell-to-cell relations, while an Xn link is set up between two gNBs. Neighbour Cell Relations are unidirectional, while an Xn link is bidirectional.

NOTE: The neighbour information exchange, which occurs during the Xn Setup procedure or in the gNB Configuration Update procedure, may be used for ANR purpose.

The ANR function also allows OAM to manage the NCRT. OAM can add and delete NCRs. It can also change the attributes of the NCRT. The OAM system is informed about changes in the NCRT.

15.3.3.2 Intra-system Automatic Neighbour Cell Relation Function

ANR relies on NCGI (see clause 8.2) and ANR reporting of E-UTRA cells as specified in TS 36.300 [2].

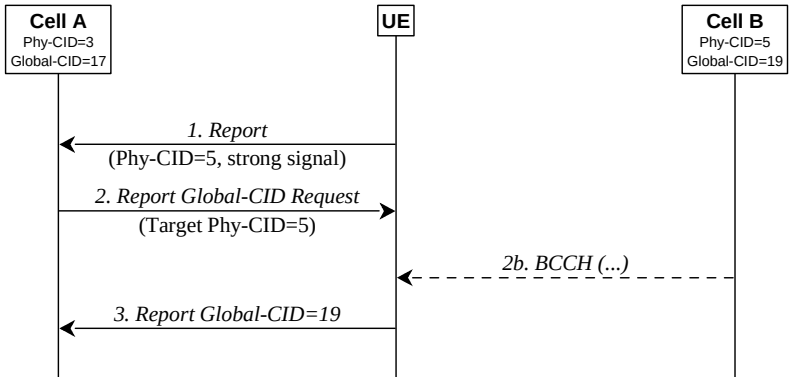


Figure 15.3.3.2-1: Automatic Neighbour Relation Function

Figure 15.3.3.2-1 depicts an example where the NG-RAN node serving cell A has an ANR function. In RRC_CONNECTED, the NG-RAN node instructs each UE to perform measurements on neighbour cells. The NG-RAN node may use different policies for instructing the UE to do measurements, and when to report them to the NG-RAN node. This measurement procedure is as specified in TS 38.331[12] and TS 36.331 [29].

1. The UE sends a measurement report regarding cell B. This report contains Cell B's PCI, but not its NCGI/ECGI.

When the NG-RAN node receives a UE measurement report containing the PCI, the following sequence may be used.

2. The NG-RAN node instructs the UE, using the newly discovered PCI as parameter, to read all the broadcast NCGI(s) /ECGI(s), TAC(s), RANAC(s), PLMN ID(s) and, for neighbour NR cells, NR frequency band(s) and the gNB ID length(s). To do so, the NG-RAN node may need to schedule appropriate idle periods to allow the UE to read the NCGI/ECGI from the broadcast channel of the detected neighbour cell. How the UE reads the NCGI/ECGI is specified in TS 38.331 [12] and TS 36.331 [29].

3. When the UE has found out the new cell's NCGI(s) /ECGI(s), the UE reports all the broadcast NCGI(s)/ECGI(s) to the serving cell NG-RAN node. In addition, the UE reports all the tracking area code(s), RANAC(s), PLMN IDs and, for neighbour NR cells, NR frequency band(s), and the gNB ID length(s) that have been read by the UE. In case the detected NR cell does not broadcast SIB1, the UE may report *noSIB1* indication as specified in TS 38.331 [12].

4. The NG-RAN node decides to add this neighbour relation, and can use PCI and NCGI(s)/ECGI(s) to:

    a. Lookup a transport layer address to the new NG-RAN node;

    b. Update the Neighbour Cell Relation List;

    c. If needed, setup a new Xn interface towards this NG-RAN node.

15.3.3.3 Void

15.3.3.4 Void

15.3.3.5 Inter-system Automatic Neighbour Cell Relation Function

For Inter-system ANR, each cell contains an Inter Frequency Search list. This list contains all frequencies that shall be searched. Figure 15.3.3.5-1 depicts an example where the NG-RAN node serving cell A has an ANR function.

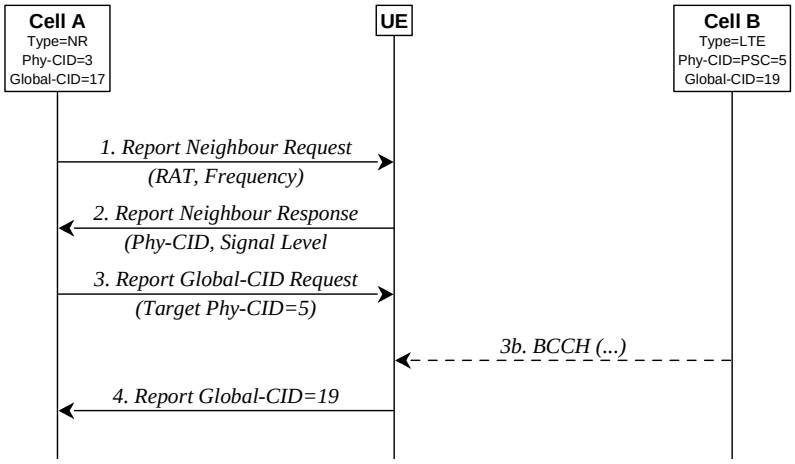


Figure 15.3.3.5-1: Automatic Neighbour Relation Function in case of E-UTRAN detected cell

In RRC_CONNECTED, the NG-RAN node instructs a UE to perform measurements and detect E-UTRA cells connected to EPC.:

1 The NG-RAN node instructs a UE to look for neighbour cells in the target system. To do so the NG-RAN node may need to schedule appropriate idle periods to allow the UE to scan all cells in the target system.

2 The UE reports the PCI and carrier frequency of the detected cells in the target system.

NOTE: The NG-RAN node may use different policies for instructing the UE to do measurements, and when to report them to the NG-RAN node.

When the NG-RAN node receives the UE reports containing PCIs of cell(s), the following sequence may be used:

3 The NG-RAN node instructs the UE, using the newly discovered PCI as parameter, to read the ECGI, the TAC and all available PLMN ID(s) of the newly detected cell in case of E-UTRA detected cells. The UE ignores transmissions from the serving cell while finding the requested information transmitted in the broadcast channel of the detected inter-system/inter-frequency neighbour cell. To do so, the NG-RAN node may need to schedule appropriate idle periods to allow the UE to read the requested information from the broadcast channel of the detected inter-system neighbour cell.

4 After the UE has read the requested information in the new cell, it reports the detected ECGI, TAC, and available PLMN ID(s) to the serving cell NG-RAN node.

5 The NG-RAN node updates its inter-system NCRT.

15.3.4 Xn-C TNL address discovery

If the NG-RAN node is aware of the RAN node ID of the candidate NG-RAN node (e.g. via the ANR function) but not of a TNL address suitable for SCTP connectivity, then the NG-RAN node can utilize the 5GC (an AMF it is connected to) to determine the TNL address as follows:

- The NG-RAN node sends the UPLINK RAN CONFIGURATION TRANSFER message to the AMF to request the TNL address of the candidate NG-RAN node, and includes relevant information such as the source and target RAN node ID;

- The AMF relays the request by sending the DOWNLINK RAN CONFIGURATION TRANSFER message to the candidate NG-RAN node identified by the target RAN node ID;

- The candidate NG-RAN node responds by sending the UPLINK RAN CONFIGURATION TRANSFER message containing one or more TNL addresses to be used for SCTP connectivity with the initiating NG-RAN node, and includes other relevant information such as the source and target RAN node ID;

- The AMF relays the response by sending the DOWNLINK CONFIGURATION TRANSFER message to the initiating NG-RAN node identified by the target RAN node ID.

NOTE: Void.

The NG-RAN node may determine the gNB ID length of the candidate gNB based on, e.g. OAM configuration or UE reporting in ANR function. If the NG-RAN node is not able to make this determination, it may include the NR cell identifier in the UPLINK RAN CONFIGURATION TRANSFER message to the AMF. The AMF may, if supported, determine the target gNB ID by matching the NR cell identifier with a gNB ID of a gNB it connects to.

15.4 Support for Energy Saving

15.4.1 General

The aim of this function is to reduce operational expenses through energy savings.

The function allows, for example in a deployment where capacity boosters can be distinguished from cells providing basic coverage, to optimize energy consumption enabling the possibility for an E-UTRA or NR cell providing additional capacity via single or dual connectivity, to be switched off when its capacity is no longer needed and to be re-activated on a need basis, or to support various adaptation techniques in time, frequency, spatial and power domains.

15.4.2 Solution description

15.4.2.1 Intra-system energy saving

The solution builds upon the possibility for the NG-RAN node owning a capacity booster cell to autonomously decide to switch-off such cell to lower energy consumption (inactive state). The decision is typically based on cell load information, consistently with configured information. The switch-off decision may also be taken by O&M.

The NG-RAN node may initiate handover actions in order to off-load the cell being switched off and may indicate the reason for handover with an appropriate cause value to support the target node in taking subsequent actions, e.g. when selecting the target cell for subsequent handovers.

All neighbour NG-RAN nodes are informed by the NG-RAN node owning the concerned cell about the switch-off actions over the Xn interface, by means of the NG-RAN node Configuration Update procedure.

All informed nodes maintain the cell configuration data, e.g., neighbour relationship configuration, also when a certain cell is inactive. If basic coverage is ensured by NG-RAN node cells, NG-RAN node owning non-capacity boosting cells may request a re-activation over the Xn interface if capacity needs in such cells demand to do so. This is achieved via the Cell Activation procedure. During switch off time period of the boost cell, the NG-RAN node may prevent idle mode UEs from camping on this cell and may prevent incoming handovers to the same cell.

The NG-RAN node receiving a request should act accordingly. The switch-on decision may also be taken by O&M. All peer NG-RAN nodes are informed by the NG-RAN node owning the concerned cell about the re-activation by an indication on the Xn interface.

The solution also builds upon the possibility for the NG-RAN node owning a coverage cell to request neighbouring NG-RAN node(s) owning a capacity booster cell to switch on some SSB beams within the cell which are deactivated. The receiving NG-RAN node should act accordingly.

The solution also builds upon the possibility for an NG-RAN node to page certain UEs (e.g., stationary UEs) in RRC_INACTIVE state on a limited set of beams, instead of paging on all the beams within the cell. It is up to the gNB's implementation to select the UEs in RRC_INACTIVE for which paging in limited set of beams applies. If the paging over the limited set of beams fails, the gNB performs subsequent paging by implementation, e.g., by ensuring the same paging message is repeated in all the transmitted SSB beams.

15.4.2.2 Inter-system energy saving

The solution builds upon the possibility for the NG-RAN node owning a capacity booster cell to autonomously decide to switch-off such cell to dormant state. The decision is typically based on cell load information, consistently with configured information. The switch-off decision may also be taken by O&M. The NG-RAN node indicates the switch-off action to the eNB over NG interface and S1 interface. The NG-RAN node could also indicate the switch-on action to the eNB over NG interface and S1 interface.

The eNB providing basic coverage may request a NG-RAN node's cell re-activation based on its own cell load information or neighbour cell load information, the switch-on decision may also be taken by O&M. The eNB requests a NG-RAN node's cell re-activation and receives the NG-RAN node's cell re-activation reply from the NG-RAN node over the S1 interface and NG interface. Upon reception of the re-activation request, the NG-RAN node's cell should remain switched on at least until expiration of the minimum activation time. The minimum activation time may be configured by O&M or be left to the NG-RAN node's implementation.

15.4.2.3 Cell DTX/DRX

To facilitate reducing gNB downlink transmission/uplink reception active time, UE can be configured with a periodic cell DTX/DRX pattern (i.e. active and non-active periods). The pattern configuration for cell DTX/DRX is common for the UEs configured with this feature in the cell. The cell DTX and cell DRX patterns can be configured and activated separately. A maximum of two cell DTX/DRX patterns can be configured per MAC entity for different serving cells. When cell DTX is configured and activated for the concerned cell, the UE may not monitor PDCCH in selected cases or does not monitor SPS occasions during cell DTX non-active duration. When cell DRX is configured and activated for the concerned cell, the UE does not transmit on CG resources, does not transmit a SR or periodic/semi-persistent SRS during cell DRX non-active duration. SRS for positioning is not impacted by cell DRX operation. This feature is only applicable to UEs in RRC_CONNECTED state and it does not impact Random Access procedure, SSB transmission, paging, and system information broadcasting. Cell DTX/DRX operation is only supported for single TRP scenario. Cell DTX/DRX can be activated/deactivated by RRC signalling or L1 group common signalling. Cell DTX/DRX is characterized by the following:

- **active duration**: duration that the UE waits for to receive PDCCHs or SPS occasions, and transmit SR or CG. In this duration, the gNB transmission/reception of PDCCH, SPS, SR, CG, periodic and semi-persistent CSI report, periodic and semi-persistent SRS are not impacted for the purpose of network energy saving;

- **cycle**: specifies the periodic repetition of the active-duration followed by a period of non-active duration.

Active duration and cycle parameters are common between cell DTX and cell DRX, when both are configured;

Once the gNB recognizes there is an emergency call or public safety related service, the network should ensure that there is no impact to that service (e.g. it may release or deactivate cell DTX/DRX configuration). The network should also ensure that there is at least partial overlapping between UE's connected mode DRX on-duration and cell DTX/DRX active duration, i.e. the UE's connected mode DRX periodicity is a multiple of cell DTX/DRX periodicity or vice versa.

15.4.2.4 Conditional Handover

The same principle as described in 9.2.3.4 applies to conditional handover in case the source cell is using a network energy saving solution (e.g., the cell is activating cell DTX/DRX or turning off), unless hereunder specified. In this case, the following additional triggering conditions are supported, upon which UE may use NES-specific CHO event for executing CHO to a candidate cell, as defined in TS 38.331 [12]:

- The UE may be notified via DCI to enable CHO conditions(s) configured with NES event indication.

15.4.2.5 Camping Restrictions

If a cell is activating or going to activate NES cell DTX/DRX, the cell can allow the access of UEs capable of NES cell DTX/DRX via a single bit in SIB1 but prevent the access of UEs not capable of cell DTX/DRX using barring mechanisms described in clause 7.4.

If a cell provides on-demand SIB1, the cell can allow the access of UEs supporting OD-SIB1 but prevent the access of UEs not supporting OD-SIB1 based on no SIB1 indication in MIB as described in clause 7.3.1.

15.4.2.6 SSB-less SCell

For an intra-band or inter-band CA SCell, a UE may obtain timing reference and AGC source from another serving cell in case the UE is not provided with SSB nor SMTC configuration for this SCell, as described in TS 38.331 [12].

15.4.2.7 Spatial and power domain adaptation

To assist the gNB on muting transceivers and/or adapting transmission power, the UE can be configured to report multiple CSI entries in a CSI report based on two or more sub-configurations, as specified in clause 5.2.1.6 in TS 38.214 [56]. Each sub-configuration corresponds to a spatial domain adaptation pattern (subsets of available spatial elements) and/or a power offset between PDSCH and CSI-RS.

15.4.2.8 On-demand SSB SCell

On-demand SSB-based SCell operations are supported for UEs in RRC_CONNECTED configured with carrier aggregation (CA), applicable to both intra-band and inter-band CA configurations for FR1 and FR2 in non-shared spectrum. The OD-SSB transmission activation command can only be transmitted to a UE configured with an SCell prior to or when receiving the SCell activation command. Both RRC and MAC-CE can be used for signalling the activation/deactivation state of OD-SSB transmissions. Additionally, the same MAC-CE can also update the transmission parameter of an activated OD-SSB after the SCell activation completion. The OD-SSB transmission deactivation can also be achieved implicitly based on the number of OD-SSB bursts to be transmitted configured by RRC. When there is no SSB on the SCell, the OD-SSB transmission is maintained while the SCell is activated. When SSB and OD-SSB have different centre frequencies in the SCell, only a single OD-SSB on a different centre frequency is supported. L3 measurement on OD-SSB is supported as specified in TS 38.331 [12].

15.4.2.9 On-demand SIB1

To facilitate reducing gNB downlink transmissions, instead of always periodically transmitting SIB1, the gNB can provide on-demand SIB1, i.e., upon receiving an OD-SIB1 request from a UE supporting OD-SIB1. OD-SIB1 is supported for UEs in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED when T311 is running. A request for SIB1 triggers a random access procedure, where MSG1 is used for indicating OD-SIB1 request and the gNB acknowledges the request in MSG2. OD-SIB1 request configurations of one or more cells which support OD-SIB1 are included in SIB26, which can be broadcasted in any cell, including cell's own OD-SIB1 request configuration. UE may request SIB1 based on the OD-SIB1 request configuration from SIB26 in order to determine the suitability of a cell during and after cell reselection as specified in TS 38.331 [12].

A gNB may request neighbour gNB(s) over the Xn interface to transmit or stop transmitting the OD-SIB1 configuration for a cell supporting OD-SIB1. The neighbour gNB(s) deciding to stop the OD-SIB1 configuration transmission informs the requesting gNB over Xn. The inter-gNB coordination procedures are defined in TS 38.401 [4].

15.4.2.10 Common signal/channel transmissions adaptation

For adaptation of paging in time domain, the value range for parameter N, which is the number of paging frames in one paging cycle, is extended to make it possible to have increased interval between PFs. The value range for Ns, which is the number of paging occasions within one paging frame, is increased to compensate the decrease in the number of PFs. UEs supporting paging adaption and PEI can monitor PEI according to the additional PEI configuration, if configured.

Adaptation of SSB in time domain is supported for SCells for UEs in RRC_CONNECTED configured with carrier aggregation (CA). SSB adaptation is indicated via DCI. Multiple SMTC configurations can be configured to the UE, and the UE selects one SMTC based on the SSB adaptation indication. SSB adaptation is not applicable to deactivated SCells.

Adaptation of PRACH configurations in time domain is supported for 4-step RACH CBRA. Furthermore, additional PRACH resource 1-bit indication in PDCCH-order applies to both CFRA and CBRA in the serving cell. Additional RACH resources are configured together with the common RACH resources in the same set of RACH resources, and the network can indicate via DCI whether the additional RACH resources are available as specified in section 8.1 of TS 38.213 [38].

15.4.3 O&M requirements

Operators should be able to configure the energy saving function.

The configured information should include:

- The ability of an NG-RAN node to perform autonomous cell switch-off;

- The ability of an NG-RAN node to request the re-activation of a configured list of inactive cells owned by a peer NG-RAN node.

O&M may also configure:

- policies used by the NG-RAN node for cell switch-off decision;
- policies used by peer NG-RAN nodes for requesting the re-activation of an inactive cell;
- The minimum time an NG-RAN node's cell should remain activated upon reception of a re-activation request from an eNB.

15.5 Self-optimisation

15.5.1 Support for Mobility Load Balancing

15.5.1.1 General

The objective of mobility load balancing is to distribute load evenly among cells and among areas of cells, or to transfer part of the traffic from congested cell or from congested areas of cells, or to offload users from one cell, cell area, carrier or RAT to achieve network energy saving. This can be done by means of optimization of cell reselection/handover parameters and handover actions. The automation of such optimisation can provide high quality user experience, while simultaneously improving the system capacity and also to minimize human intervention in the network management and optimization tasks.

Intra-RAT, intra-system inter-RAT and inter-system load balancing scenarios are supported.

In general, support for mobility load balancing consists of one or more of following functions:

- Load reporting for intra-RAT and intra-system inter-RAT load balancing;
- Load balancing action based on handovers;
- Adapting handover and/or reselection configuration;
- Load reporting for inter-system load balancing.

15.5.1.2 Load reporting for intra-RAT and intra-system inter-RAT load balancing

The load reporting function is executed by exchanging load information over the Xn/X2/F1/E1 interfaces.

The following load related information should be supported which consists of:

- Radio resource usage (per-cell and per SSB area PRB usage: DL/UL GBR PRB usage, DL/UL non-GBR PRB usage, DL/UL total PRB usage, and DL/UL scheduling PDCCH CCE usage; PRB usage for slice(s): DL/UL GBR PRB usage, DL/UL non-GBR PRB usage, and DL/UL Total PRB allocation);
- TNL capacity indicator (UL/DL TNL offered capacity and available capacity);
- Cell Capacity Class value (UL/DL relative capacity indicator);
- Capacity value (per cell, per SSB area and per slice: UL/DL available capacity);
- HW capacity indicator (offered throughput and available throughput over E1, percentage utilisation over F1);
- RRC connections (number of RRC connections, and available RRC Connection Capacity);
- Number of active UEs;
- NR-U channel load (DL/UL channel occupancy time percentage, DL/UL energy detection threshold, radio resource usage).

To achieve load reporting function, Resource Status Reporting Initiation & Resource Status Reporting procedures are used.

15.5.1.3 Load balancing action based on handovers

The source cell may initiate handover due to load. The target cell performs admission control for the load balancing handovers. A handover preparation related to a mobility load balancing action is distinguishable from other handovers, so that the target cell is able to apply appropriate admission control.

15.5.1.4 Adapting handover and/or reselection configuration

This function enables requesting of a change of handover and/or reselection parameters at target cell. The source cell that initialized the load balancing estimates if it is needed to change mobility configuration in the source and/or target cell. If the amendment is needed, the source cell initializes mobility negotiation procedure toward the target cell.

The source cell informs the target cell about the new mobility setting and provides cause for the change (e.g. load balancing related request). The proposed change is expressed by the means of the difference (delta) between the current and the new values of the handover trigger. The handover trigger is the cell specific offset that corresponds to the threshold at which a cell initialises the handover preparation procedure. Cell reselection configuration may be amended to reflect changes in the HO setting. The target cell responds to the information from the source cell. The allowed delta range for HO trigger parameter may be carried in the failure response message. The source cell should consider the responses before executing the planned change of its mobility setting.

All automatic changes on the HO and/or reselection parameters must be within the range allowed by OAM.

15.5.1.5 Load reporting for inter-system load balancing

The load reporting function for inter-system load balancing is executed by exchanging load information between NG-RAN and E-UTRAN. Both event-triggered and periodic inter-system load reporting are supported. Event-triggered inter-system load reports are sent when the reporting node detects crossing of cell load thresholds.

The following load related information should be supported:

- Cell Capacity Class value (UL/DL relative capacity indicator);
- Capacity value (per cell: UL/DL available capacity);
- RRC connections (number of RRC connections, and available RRC Connection Capacity);
- Number of active UEs;
- Radio Resource Status (per cell PRB usage: UL/DL GBR PRB usage for MIMO, DL/UL non-GBR PRB usage for MIMO, DL/UL total PRB usage for MIMO).

NGAP procedures used for inter-system load balancing are Uplink RAN Configuration Transfer and Downlink RAN Configuration Transfer.

S1AP procedures used for inter-system load balancing are eNB Configuration Transfer and MME Configuration Transfer.

15.5.2 Support for Mobility Robustness Optimization

15.5.2.1 General

Mobility Robustness Optimisation aims at detecting and enabling correction of following problems:

- Connection failure due to intra-system or inter-system mobility;
- Inter-system Unnecessary HO (too early inter-system HO from NR to E-UTRAN with no radio link failure);
- Inter-system HO ping-pong;
- PSCell change failure;
- Inter-system voice fallback failure;
- Fast MCG recovery failure or a sub-optimal Fast MCG recovery.

MRO provides means to distinguish the above problems from NR coverage related problems and other problems, not related to mobility.

For detection of a sub-optimal successful handovers, MRO additionally enables observability of:

- Successful HO due to intra-NR mobility;
- Successful HO due to inter-RAT mobility.

For detection of a sub-optimal successful PSCell addition/change, MRO additionally enables observability of:

- Successful PSCell addition/change.

15.5.2.2 Connection failure

15.5.2.2.1 General

For analysis of connection failures, the UE makes the RLF Report available to the network.

The UE stores the latest RLF Report, including both LTE and NR RLF report until the RLF report is fetched by the network or for 48 hours after the connection failure is detected.

The UE only indicates RLF report availability and only provides the RLF report to the network if the current RPLMN is a PLMN that was present in the UE's EPLMN List or was the RPLMN at the time the connection failure was detected, or if the current registered SNPN is an SNPN that was present in the UE's equivalent SNPN list or was the registered SNPN at the time the connection failure was detected. In case RLF happens in an E-UTRA cell, the UE makes the LTE RLF Report available to NG-RAN nodes and eNB(s), and in case RLF happens in an NR cell the UE makes the NR RLF Report available to gNB(s).

If the LTE RLF Report is reported to a NG-RAN node, and the last serving node is an E-UTRAN node, the NG-RAN node may transfer it to the E-UTRAN node by triggering the Uplink RAN configuration transfer procedure over NG and the E-UTRAN node can take this into account as defined in TS 36.300 [2].

15.5.2.2.2 Connection failure due to intra-system mobility

One of the functions of Mobility Robustness Optimization is to detect connection failures that occur due to Too Early or Too Late Handovers, or Handover to Wrong Cell. These problems are defined as follows:

- Intra-system Too Late Handover: an RLF occurs after the UE has stayed for a long period of time in the cell; the UE attempts to re-establish the radio link connection in a different cell.
- Intra-system Too Early Handover: an RLF occurs shortly after a successful handover from a source cell to a target cell or a handover failure occurs during the handover procedure; the UE attempts to re-establish the radio link connection in the source cell.
- Intra-system Handover to Wrong Cell: an RLF occurs shortly after a successful handover from a source cell to a target cell or a handover failure occurs during the handover procedure; the UE attempts to re-establish the radio link connection in a cell other than the source cell and the target cell.

In the definition above, the "successful handover" refers to the UE state, namely the successful completion of the RA procedure.

In case of MCG LTM cell switch, the "successful handover" in the definitions above refers to a successful completion of the RA procedure in case of RACH-based LTM or when the UE determines that the network has successfully received its first UL data in case of RACH-less LTM.

In case of CHO, the Too Late Handover, Too Early Handover and Handover to Wrong Cell in the definition above means Too Late CHO Execution, Too Early CHO Execution and CHO Execution to Wrong Cell.

In case of LTM Cell switch, the Too Late Handover, Too Early Handover and Handover to Wrong Cell in the definition above means Too Late LTM cell switch, Too Early LTM cell switch and LTM cell switch to Wrong Cell.

In case of CHO with candidate SCG(s), the Too Late Handover, Too Early Handover and Handover to Wrong Cell in the definition above means Too Late CHO with candidate SCG(s), Too Early CHO with candidate SCG and CHO Execution to Wrong Cell.

Detection mechanism

A failure indication may be initiated after a UE attempts to re-establish the radio link connection at NG-RAN node B after a failure at NG-RAN node A. NG-RAN node B may initiate the Failure Indication procedure towards multiple NG-RAN nodes if they control cells which use the PCI signalled by the UE during the re-establishment procedure. The NG-RAN node receiving this selects the UE context that matches the received Failure Cell ID and C-RNTI, and, if available, uses the shortMAC-I to confirm this identification, by calculating the shortMAC-I and comparing it to the received IE.

A failure indication may also be sent to the node last serving the UE when the NG-RAN node fetches the RLF REPORT from UE by triggering:

- The Failure Indication procedure over Xn;
- The Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

The detailed detection mechanisms for too late handover, too early handover and handover to wrong cell are carried out through the following in the NG-RAN node that served the UE before the reported connection failure:

- Intra-system Too Late Handover: there is no recent handover for the UE prior to the connection failure e.g. the UE reported timer is absent or larger than the configured threshold (e.g. Tstore_UE_cntxt), or if CHO/LTM or CHO with candidate SCG(s) is configured but the CHO/LTM execution is not initiated for the UE prior to the connection failure, e.g. the UE reported timer is absent or larger than the configured threshold (e.g. Tstore_UE_cntxt).
- Intra-system Too Early Handover: there is a recent handover/LTM cell switch for the UE prior to the connection failure e.g. the UE reported timer is smaller than the configured threshold (e.g. Tstore_UE_cntxt), and the first re-establishment attempt cell/the successful re-connect cell/the cell UE attempts LTM recovery is the cell that served the UE at the last handover/LTM initialisation or fall back to the source cell configuration in case of DAPS HO.
- Intra-system Handover to Wrong Cell: there is a recent handover/LTM cell switch for the UE prior to the connection failure e.g. the UE reported timer is smaller than the configured threshold (e.g. Tstore_UE_cntxt), and the first re-establishment attempt cell/ the cell UE attempts to re-connect/the cell UE attempts CHO recovery/the cell UE attempts LTM recovery is neither the cell that served the UE at the last handover/LTM initialisation nor the cell that served the UE where the RLF happened or the cell that the handover/LTM was initialized toward.

The "UE reported timer" above indicates the time elapsed since the last handover initialisation until connection failure or the time elapsed since the CHO/LTM execution until connection failure.

In case of Too Early Handover or Handover to Wrong Cell, the NG-RAN node receiving the failure indication may inform the NG-RAN node controlling the cell where the mobility configuration caused the failure by means of the Handover Report procedure over Xn or the Uplink RAN Configuration Transfer procedure over NG. This may include the RLF report.

In case of Too Late Handover when UE is configured with CHO with candidate SCG(s), the NG-RAN node receiving the failure indication may send a Handover Report over Xn to the candidate NG-RAN node(s) controlling the candidate PSCell(s) whose mobility configuration caused the failure.

For MRO analysis, in case of RLFs or handover failures, the source gNB may take into account the information regarding the LBT failures occurred in UL and DL for a specific UE. For UL, the information may be collected and provided by the UE to the network in the RLF report. For DL, the information may be collected at the source and target gNBs. The target gNB may provide the information to the source gNB via the Access and Mobility Indication procedure over Xn, if requested by the source gNB during the handover preparation.

Retrieval of information needed for problem analysis

In order to retrieve relevant information collected at the network side as part of the UE context, the UE provides C-RNTI used in the last serving cell. If the cause for the failure is identified as a "Too Early HO" or a "HO to Wrong

Cell", the NG-RAN node controlling the last serving cell shall, include in the HANDOVER REPORT message the C-RNTI used in the source cell of the last completed handover before the failure. If the NG RAN node controlling that source cell provided the Mobility Information, it is also included in the HANDOVER REPORT message. If used, the Mobility Information is prepared at the source NG RAN node of a handover and may refer to or identify any handover-related data at this NG RAN node. In the Handover Preparation procedure, the source gNB may request the target gNB to provide information on DL LBT failures at the target gNB and to report it in case of mobility failure of the UE.

Handling multiple reports from a single failure event

In case the RRC re-establishment fails and the RRC connection setup succeeds, MRO evaluation of intra-RAT mobility connection failures may be triggered twice for the same failure event. In this case, only one failure event should be counted.

15.5.2.2.3 Connection failure due to inter-system mobility

One of the functions of Mobility Robustness Optimization is to detect connection failures that occurred due to Too Early or Too Late inter-system handovers or inter-system Mobility Failure for Voice Fallback. These problems are defined as follows:

- Inter-system/ Too Late Handover: an RLF occurs after the UE has stayed in a cell belonging to an NG-RAN node for a long period of time; the UE attempts to re-connect to a cell belonging to an E-UTRAN node.
- Inter-system/ Too Early Handover: an RLF occurs shortly after a successful handover from a cell belonging to an E-UTRAN node to a target cell belonging to an NG-RAN node or a handover failure occurs during the handover procedure; the UE attempts to re-connect to the source cell or to another cell belonging to an E-UTRAN node.
- Inter-system Mobility Failure for Voice Fallback: an RLF occurs shortly after a successful handover triggered due to Voice Fallback, or a failure occurs during an handover triggered due to Voice Fallback, from a cell belonging to an NG-RAN node to a cell belonging to an E-UTRAN node; the UE attempts to re-connect to a cell belonging to an E-UTRAN node, or an NG-RAN node.

Detection mechanism

A failure indication may be sent to the node last serving the UE when the NG-RAN node fetches the RLF REPORT from UE by triggering:

- The Failure Indication procedure over Xn;
- The Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

In case the last serving node is an E-UTRAN node, the detection mechanism proceeds as defined in TS 36.300 [2].

In case the last serving node is an NG-RAN node, the detection mechanisms for Too Late Inter-system Handover, Too Early Inter-system Handover, and Inter-system Mobility Failure for Voice Fallback are carried out through the following:

- Too Late Inter-system Handover: the connection failure occurs while being connected to a NG-RAN node, and there is no recent handover for the UE prior to the connection failure i.e., the UE reported timer is absent or larger than the configured threshold, e.g., *Tstore_UE_cntxt*, and the first node where the UE attempts to re-connect is a E-UTRAN node.
- Too Early Inter-system Handover: the connection failure occurs while being connected to a NG-RAN node, and there is a recent inter-system handover for the UE prior to the connection failure i.e., the UE reported timer is smaller than the configured threshold, e.g., *Tstore_UE_cntxt*, and the first cell where the UE attempts to re-connect and the node that served the UE at the last handover initialisation are both E-UTRAN node.
- Inter-system Mobility Failure for Voice Fallback: in case the connection failure occurs during an inter-system handover for voice fall back from NR, the RLF Report from the UE includes a voice fallback indication, as defined in TS 38.331 [12].

The "UE reported timer" above indicates the time elapsed since the last handover initialisation until connection failure. The UE may make the RLF Report available to an NG-RAN node. The NG-RAN node may forward the information using the FAILURE INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure

and Downlink RAN configuration transfer over NG to the node that served the UE before the reported connection failure.

In case the failure is a Too Early Inter-system Handover, the NG-RAN node receiving the failure indication may inform the E-UTRAN node by means of the Uplink RAN Configuration Transfer procedure over NG. This may include the RLF report.

15.5.2.3 Inter-system Unnecessary HO

One of the purposes of inter-system Mobility Robustness Optimisation is the detection of a non-optimal use of network resources. In particular, in case of inter-system operations and when NR is considered, the case known as Unnecessary HO to another system is identified. The problem is defined as follows:

- UE is handed over from NR to E-UTRAN even though quality of the NR coverage was sufficient for the service used by the UE. The handover may therefore be considered as unnecessary HO to another system (i.e. EPS) (too early inter-system HO without connection failure).

In inter-system HO, if the serving cell threshold (NR cell) is set too high, and cell in another system (i.e. EPS) with good signal strength is available, a handover to another system may be triggered unnecessarily, resulting in an inefficient use of the networks. With a lower threshold the UE could have continued in the source system (5GS).

To be able to detect the Unnecessary HO to another system, a gNB node may choose to put additional coverage and quality condition information into the HANDOVER REQUIRED message in the Handover Preparation procedure when an inter-system HO from gNB to another system occurs. The RAN node in the other system, upon receiving this additional coverage and quality information, may instruct the UE to continue measuring the cell(s) in source system during a period of time, while being connected to another system, and send periodic or single measurement reports to the node in other system. When the period of time indicated by the node in source system expires, the RAN node in the other system, may evaluate the received measurement reports with the coverage/quality condition received during the inter-system HO procedure and decide if an inter-system unnecessary HO report should be sent to the gNB in the source system.

The inter-system unnecessary HO report shall only be sent in cases where, in all UE measurement reports collected during the measurement period, any cells in the source system exceed the radio coverage and/or quality threshold (the radio threshold RSRP, RSRQ or/and SINR and the measurement period are indicated in the additional coverage and quality information in the Handover Preparation procedure). If an inter-system handover towards 5GS is executed from EPS within the indicated measurement period, the measurement period expires. In this case, the eNB in EPS may also send the HO Report. No HO Report shall be sent in case no NR cell could be included, or if the indicated period of time is interrupted by an inter-system handover to a system different than 5GS.

The RAN node in the source system (5GS) upon receiving of the report, can decide if/how its parameters (e.g., threshold to trigger Inter-system HO) should be adjusted.

15.5.2.4 Inter-system Ping-pong

One of the functions of Mobility Robustness Optimization is to detect ping-pongs that occur in inter-system environment. The problem is defined as follows:

- A UE is handed over from a cell in a source system (e.g. 5GS) to a cell in a target system different from the source system (e.g. EPS), then within a predefined limited time the UE is handed over back to a cell in the source system, while the coverage of the source system was sufficient for the service used by the UE. The event may occur more than once.

The solution for the problem may consist of the following steps:

1) Statistics regarding inter-system ping-pong occurrences are collected by the responsible node;

2) Coverage verification is performed to check if the mobility to other system was inevitable.

The statistics regarding ping-pong occurrence may be based on evaluation of the *UE History Information* IE in the HANDOVER REQUIRED message. If the evaluation indicates a potential ping-pong case and the source NG_RAN node of the 1st inter-system handover is different than the target NG-RAN node of the 2nd inter-system handover, the target NG-RAN node may use the HANDOVER REPORT message or the UPLINK RAN CONFIGURATION TRANSFER message to indicate the occurrence of potential ping-pong cases to the source NG-RAN node.

If NG-RAN coverage during the potential ping-pong event needs to be verified for the purpose of determining corrective measures, the Unnecessary HO to another system procedure may be used.

NOTE: Inter-system mobility triggered by Voice Fallback is not considered as inter-system ping-pong.

15.5.2.5 O&M Requirements

All automatic changes of the HO and/or reselection parameters for mobility robustness optimisation shall be within the ranges allowed by OAM and specified below.

The following control parameters shall be provided by OAM to control MRO behaviour:

- Maximum deviation of Handover Trigger: this parameter defines the maximum allowed absolute deviation of the Handover Trigger, from the default point of operation defined by the parameter values assigned by OAM.
- Minimum time between Handover Trigger changes: this parameter defines the minimum allowed time interval between two Handover Trigger change performed by MRO. This is used to control the stability and convergence of the algorithm.

Furthermore, in order to support the solutions for detection of mobility optimisation, the parameter *Tstore_UE_cntxt* shall be configurable by the OAM system.

15.5.2.6 PSCell addition/change failure

For analysis of PSCell addition/change failures, the UE makes the SCG Failure Information available to the MN. If the MN can perform an initial analysis, it transfers the SCG Failure Information together with the analysis results to the relevant SN as defined in TS 37.340 [21].

In case there is an SCG failure when UE is configured with CHO with candidate SCG(s), the serving M-NG-RAN node receiving *SCGFailureInformation* from the UE performs initial analysis. If the SCG failure has been caused by a different M-NG-RAN node, the serving M-NG-RAN node sends SCG FAILURE INDICATION message to the M-NG-RAN node that caused the failure. If it is an SN that caused the failure, the M-NG-RAN node sends SCG FAILURE INFORMATION REPORT message to the SN as defined in TS 37.340 [21].

15.5.2.7 Successful HO

One of the functions of Mobility Robustness Optimization is to detect a sub-optimal successful handover event. The aim is to identify underlying conditions during successful ordinary handovers, successful LTM cell switches, successful DAPS handovers, or successful Conditional handovers.

For analysis of successful handover or LTM cell switch, the UE may collect Successful Handover Report (SHR) based on configuration by network, if stored, and makes the SHR available to the network as specified in TS 38.331 [12]. The UE stores the SHR until it is fetched by the network or for 48 hours after the SHR is recorded.

For SHR collected during intra-NR handover, if the target NR node fetches the SHR from the UE and the trigger of SHR is T310/T312, it may forward the information to the source NR node, i.e. the node handling the cell reported as source cell in this SHR, by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

If the NG-RAN node that fetches the SHR from the UE is neither the source node nor the target node of the handover or LTM cell switch, it forwards the information to the node(s) which configured the SHR trigger causing the SHR to be generated, by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

In case of failure shortly after successful Handover or LTM cell switch, the same mobility event may generate both a SHR and a RLF report. In this case, the node(s), which configured the SHR trigger causing the SHR, may take the duplication into account e.g. ignore the SHR.

Upon retrieval of an SHR, the receiving node may analyse whether its mobility configuration needs adjustment.

The SHR can be used to detect one case of Intra-system Too Late Handover, namely when DAPS HO is configured but an RLF is detected in the source cell during a successful DAPS HO.

The SHR can be collected for intra-NR handover or LTM cell switch, and for handover from NR to E-UTRA.

15.5.2.8 Successful PSCell Addition/Change Report

For the analysis of successful PSCell addition/change, the UE may collect Successful PSCell Addition/Change Report (SPR) based on the configuration by network, if received, and makes the SPR available to the network as specified in TS 38.331 [12].

The UE stores the SPR until the SPR is fetched by the network or for 48 hours after the SPR is recorded.

The UE makes the SPR available to gNB(s).

When a gNB fetches the SPR from UE, it forwards the SPR to the MN that was serving the UE at the time the SPR was generated by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer over NG.

15.5.3 Support for RACH Optimization

RACH optimization is supported by UE reported information made available at the NG RAN node as specified in TS 38.331 [12] and by PRACH parameters exchange between NG RAN nodes.

The contents of the RA Report comprise of the following:

- Contention detection indication per RACH attempt;
- Indexes of the SSBs and number of RACH preambles sent on each tried SSB listed in chronological order of attempts;
- Indication whether the selected SSB is above or below the configured RSRP threshold per RACH attempt;
- 2-step RACH information as specified in clause 5.7.10.4 of TS 38.331 [12];
- Indication of LBT failures detected during the random access.

SN RA Reports

The UE may also support collection of SN RA Reports.

The SN RA report retrieval and forwarding is specified in TS 37.340 [21].

15.5.4 UE History Information

The source NG-RAN node collects and stores the UE History Information for as long as the UE stays in one of its cells.

The UE may report the UE history information when connecting to a cell of the NG-RAN node, consisting of PCell and PSCell mobility history information, as specified in TS 38.331 [12].

When information needs to be discarded because the list is full, such information will be discarded in order of its position in the list, starting with the oldest cell record. If the list is full, and the UE history information from the UE is available, the UE history information from the UE should also be discarded.

The resulting information is then used in subsequent handover preparations by means of the Handover Preparation procedures over the NG and XN interfaces, which provide the target NG-RAN node with a list of previously visited cells and associated (per-cell) information elements. The Handover Preparation procedures also trigger the target NG-RAN node to start collection and storage of UE history Information and thus to propagate the collected information.

In case of CHO, the target NG-RAN node updates the time UE stayed in cell of the latest PCell entry (i.e. the source cell) when the UE successfully accesses a candidate cell of the target NG-RAN node. The updated value of the time UE stayed in the source cell is equal to the value received from the source NG-RAN node during the Handover Preparation plus the time from receiving the Handover Request message from the source NG-RAN node to receiving the RRC Reconfiguration Complete message from the UE. When the target NG-RAN node receives the SCG UHI from the source NG-RAN node via the Handover Request message, the target NG-RAN node also updates the time UE stayed in cell of the latest PSCell entry (i.e. the source PSCell) as specified in TS 37.340 [21]. The target NG-RAN node may also update the SCG Activation Time provided in the Handover Preparation.

15.5.5 Support for Coverage and Capacity Optimisation

15.5.5.1 General

The objective of NR Coverage and Capacity Optimization (CCO) function is to detect and resolve or mitigate CCO issues, e.g. coverage and cell edge interference issues.

15.5.5.2 OAM requirements

Each NG-RAN node may be configured with *alternative coverage configurations* by OAM. The alternative coverage configurations contain relevant radio parameters and may also include a range for how each parameter is allowed to be adjusted.

15.5.5.3 Dynamic coverage configuration changes

An NG-RAN node may autonomously adjust within and switch between coverage configurations. When a change is executed, a NG-RAN node may notify its neighbour NG-RAN nodes using the NG-RAN NODE CONFIGURATION UPDATE message with the list of cells and SSBs with modified coverage included. The list contains the CGI of each modified cell with its coverage state indicator and optionally the SSB index of each modified SSB with its coverage state indicator.

The coverage state indicator may be used at the receiving NG-RAN node to adjust the functions of the Mobility Robustness Optimisation, e.g. by using the coverage state indicator to retrieve a previously stored Mobility Robustness Optimisation state. The coverage state indicator may also be used at the receiving NG-RAN node to adopt coverage configurations matching with neighbouring cells coverage configurations.

If the list includes indication about planned reconfiguration and possibly a list of replacing cells, the receiving NG-RAN node may use this to avoid connection or re-establishment failures during the reconfiguration. Also, if the sending NG-RAN node adds cells in inactive state, the receiving NG-RAN node may use this information to avoid connection or re-establishment failures. The receiving NG-RAN node may also use the notification to reduce the impact on mobility. The receiving NG-RAN node should avoid triggering handovers towards cell(s) that are indicated to be inactive.

15.5.6 Support for PCI Optimisation

The PCI Optimization Function in split gNB case is specified in TS 38.401 [4].

15.5.6.1 Centralized PCI Assignment

For centralized PCI assignment in gNB, the OAM assigns a single PCI for each NR cell in the gNB, and the gNB selects this value as the PCI of the NR cell.

15.5.6.2 Distributed PCI Assignment

For distributed PCI assignment in gNB, the OAM assigns a list of PCIs for each NR cell in the gNB, and the gNB selects a PCI value from the list of PCIs. The gNB may restrict this list by removing some PCIs that are reported by UEs, reported over the Xn interface by neighbouring gNBs, and/or acquired through other methods, e.g. detected over the air using a downlink receiver.

16 Verticals Support

16.1 URLLC

16.1.1 Overview

The support of Ultra-Reliable and Low Latency Communications (URLLC) services is facilitated by the introduction of the mechanisms described in the following clauses. Please note however that those mechanisms need not be limited to

the provision of URLLC services. Furthermore, RRC can associate logical channels with different SR configurations, for instance, to provide more frequent SR opportunities to URLLC services.

16.1.2 LCP Restrictions

With LCP restrictions in MAC, RRC can restrict the mapping of a logical channel to a subset of the configured cells, numerologies, PUSCH transmission durations, configured grant configurations and control whether a logical channel can utilise the resources allocated by a Type 1 Configured Grant (see clause 10.3) or whether a logical channel can utilise dynamic grants indicating a certain physical priority level. With such restrictions, it then becomes possible to reserve, for instance, the numerology with the largest subcarrier spacing and/or shortest PUSCH transmission duration for URLLC services. Furthermore, RRC can associate logical channels with different SR configurations, for instance, to provide more frequent SR opportunities to URLLC services.

16.1.3 Packet Duplication

When duplication is configured for a radio bearer by RRC, at least one secondary RLC entity is added to the radio bearer to handle the duplicated PDCP PDUs as depicted on Figure 16.1.3-1, where the logical channel corresponding to the primary RLC entity is referred to as *the primary logical channel*, and the logical channel corresponding to the secondary RLC entity(ies), the *secondary logical channel(s)*. All RLC entities have the same RLC mode. Duplication at PDCP therefore consists in submitting the same PDCP PDUs multiple times: once to each activated RLC entity for the radio bearer. With multiple independent transmission paths, packet duplication therefore increases reliability and reduces latency and is especially beneficial for URLLC services. Packet duplication can be configured for a MP split bearer with SL indirect path or N3C indirect path (see clause 16.21). In this case, PDCP entity is associated with one or more RLC entities and, either one SRAP entity or the N3C, as defined in TS 38.323 [8].

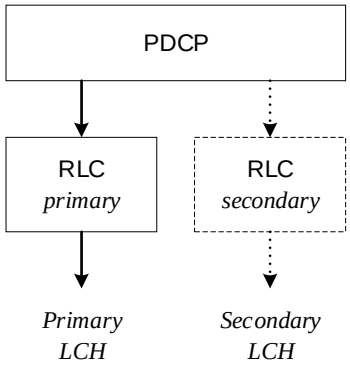


Figure 16.1.3-1: Packet Duplication

NOTE: PDCP control PDUs are not duplicated and always submitted to the primary RLC entity.

When configuring duplication for a DRB, RRC also sets the state of PDCP duplication (either activated or deactivated) at the time of (re-)configuration. After the configuration, the PDCP duplication state can then be dynamically controlled by means of a MAC control element and in DC, the UE applies the MAC CE commands regardless of their origin (MCG or SCG). When duplication is configured for an SRB the state is always active and cannot be dynamically controlled. When configuring duplication for a DRB with more than one secondary RLC entity, RRC also sets the state of each of them (i.e. either activated or deactivated). Subsequently, a MAC CE can be used to dynamically control whether each of the configured secondary RLC entities for a DRB should be activated or deactivated, i.e. which of the RLC entities shall be used for duplicate transmission. Primary RLC entity cannot be deactivated. When duplication is deactivated for a DRB, all secondary RLC entities associated to this DRB are deactivated. When a secondary RLC entity is deactivated, it is not re-established, the HARQ buffers are not flushed, and the transmitting PDCP entity should indicate to the secondary RLC entity to discard all duplicated PDCP PDUs.

When activating duplication for a DRB, NG-RAN should ensure that at least one serving cell is activated for each logical channel associated with an activated RLC entity of the DRB; and when the deactivation of SCells leaves no serving cells activated for a logical channel of the DRB, NG-RAN should ensure that duplication is also deactivated for the RLC entity associated with the logical channel.

When duplication is activated, the original PDCP PDU and the corresponding duplicate(s) shall not be transmitted on the same carrier. The logical channels of a radio bearer configured with duplication can either belong to the same MAC

entity (referred to as CA duplication) or to different ones (referred to as DC duplication). CA duplication can also be configured in either or both of the MAC entities together with DC duplication when duplication over more than two RLC entities is configured for the radio bearer. In CA duplication, logical channel mapping restrictions are used in a MAC entity to ensure that the different logical channels of a radio bearer in the MAC entity are not sent on the same carrier. When CA duplication is configured for an SRB, one of the logical channels associated to the SRB is mapped to SpCell.

When CA duplication is deactivated for a DRB in a MAC entity (i.e. none or only one of RLC entities of the DRB in the MAC entity remains activated), the logical channel mapping restrictions of the logical channels of the DRB are lifted for as long as CA duplication remains deactivated for the DRB in the MAC entity.

When an RLC entity acknowledges the transmission of a PDCP PDU, the PDCP entity shall indicate to the other RLC entity(ies) to discard it. In addition, in case of CA duplication, when an RLC entity restricted to only SCell(s) reaches the maximum number of retransmissions for a PDCP PDU, the UE informs the gNB but does not trigger RLF.

16.1.4 CQI and MCS

For channel state reporting, a CQI table for target block error rate 10^{-5} is introduced.

For scheduling data packets with higher reliability, 64QAM MCS tables containing entries with lower spectral efficiency are introduced for both downlink and uplink. The tables are different for CP-OFDM and DFT-s-OFDM. The MCS tables can be configured semi-statically or dynamically. The dynamic signalling of MCS table is supported by configuring UE with MCS-C-RNTI, where the scrambling of DCI CRC by MCS-C-RNTI indicates the 64QAM MCS tables with entries of lower spectral efficiency.

16.1.5 DCI formats

For PDCCH transmission with higher reliability, two DCI formats are introduced for uplink and downlink scheduling respectively.

16.1.6 Higher layer multi-connectivity

The redundant transmission may be applied on the user plane path between the UE and the network for URLLC service as specified in TS 23.501 [3].

16.1.6.1 Redundant user plane paths based on dual connectivity

UE may initiate two redundant PDU Sessions over the 5G network. The 5GS sets up the user plane paths of the two redundant PDU sessions to be disjoint. When PDU session setup or modification is initiated, the RAN can configure dual connectivity in one NG-RAN node or two NG-RAN nodes for the two redundant PDU sessions to ensure the disjoint user plane paths according to the redundancy information received from the 5GC. The RAN shall ensure that the resources of the data radio bearers for the two redundant PDU sessions are isolated. If the RAN cannot satisfy the disjoint user plane requirement, the redundant PDU sessions may be kept or not kept according to the RAN local configuration. The redundancy information is transferred to the target NG-RAN node in case of handover.

16.1.6.2 Redundant data transmission via single UPF and single RAN node

Two NG-U tunnels are setup between single UPF and single NG-RAN node for redundant transmission of the QoS flows when PDU session setup or modification is initiated. The two NG-U tunnels are transferred via disjointed transport layer paths. The 5GC provides the indicator per QoS flow to the NG-RAN for the redundant transmission. For downlink, the NG-RAN node eliminates the duplicated packets per QoS flow. For uplink, the NG-RAN node replicates the packets and transmits them via the two NG-U tunnels. The indicator per QoS flow for redundant transmission is transferred to the target NG-RAN node in case of handover.

16.1.7 URLLC in Unlicensed Controlled Environment

URLLC services can be supported in shared spectrum where LBT failures are assumed to be not frequent. In this case, a channel access procedure for semi-static channel occupancy can be initiated by the gNB or the UE, or the gNB operates in dynamic channel access mode, as described in TS 37.213 [37]. To handle potential LBT failures on configured grants (CG), the CG retransmission timer can be optionally configured to enable autonomous retransmissions, and it may be

configured simultaneously with enhanced intra-UE overlapping resource prioritization mechanisms. When the CG retransmission timer is configured, the UE shall select the HARQ process for each CG resource by itself. If the enhanced intra-UE overlapping resource prioritization mechanisms is also configured, the UE may be further configured to select the HARQ process for a CG resource based on logical channel priority.

16.1.8 PUCCH cell switching for TDD cells

To reduce the delay for HARQ-ACK feedback for TDD operation with URLLC services, PUCCH cell switching for TDD cells is supported. The UE can be provided in each PUCCH group with a PUCCH switching SCell (PUCCH sSCell) that can be used for PUCCH transmission in addition to PCell / PSCell / PUCCH SCell. The applicable cell for PUCCH transmission to be either on PCell /PSCell / PUCCH SCell or the PUCCH sSCell at a time is either defined by:

- a higher layer configured semi-static time-domain pattern of the applicable cell for PUCCH transmission; or
- dynamic indication of the cell for PUCCH transmission through a PDCCH scheduling a PUCCH transmission.

The PUCCH cell switching is applicable to all UCI types when using the higher layer configured time-domain pattern, but is only applicable to HARQ feedback for the dynamic indication of the cell for PUCCH transmission through a PDCCH scheduling PUCCH.

16.2 IMS Voice

16.2.0 Support for IMS voice

For IMS voice support in NG-RAN, the following is assumed:

- Network ability to support IMS voice sessions, i.e. ability to support QoS flows with 5QI for voice and IMS signalling (see clause 12 and TS 23.501 [3]), or through EPC System fallback;
- UE capability to support "IMS voice over PS", see TS 24.501 [28].

The capabilities indications check is handled at NAS layer. To maintain the voice service in NG-RAN, the UE provides additional capabilities over RRC (see TS 38.331 [12]), that are used to determine accurate NR voice support options.

Further MMTEL IMS voice and video enhancements are facilitated by the mechanisms described in the following clauses.

16.2.1 Support for MMTEL IMS voice and video enhancements

16.2.1.1 RAN-assisted codec adaptation

RAN-assisted codec adaptation provides a means for the gNB to send codec adaptation indication with recommended bit rate to assist the UE to select or adapt to a codec rate for MMTEL voice or MMTEL video. The RAN-assisted codec adaptation mechanism supports the uplink/downlink bit rate increase or decrease. For a bearer associated with configuration of MBR greater than GBR, the recommended uplink/downlink bit rate is within boundaries set by the MBR and GBR of the concerned bearer.

For uplink or downlink bit rate adaptation, gNB may send a recommended bit rate to the UE to inform the UE on the currently recommended transport bit rate on the local uplink or downlink, which the UE may use in combination with other information to adapt the bit rate, e.g. the UE may send a bit rate request to the peer UE via application layer messages as specified in TS 26.114 [24], which the peer UE may use in combination with other information to adapt the codec bit rate. The recommended bit rate is in kbps at the physical layer at the time when the decision is made.

The recommended bit rate for UL and DL is conveyed as a MAC Control Element (CE) from the gNB to the UE as outlined in Figure 16.2.1.1-1.

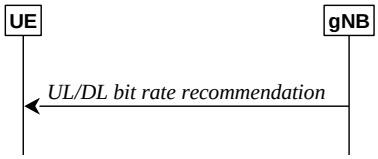


Figure 16.2.1.1-1: UL or DL bit rate recommendation

Based on the recommended bit rate from the gNB, a UE may initiate an end-to-end bit rate adaptation with its peer (UE or MGW). The UE may also send a query message to its local gNB to check if a bit rate recommended by its peer can be provided by the gNB. The UE is not expected to go beyond the recommended bit rate from the gNB.

The recommended bit rate query message is conveyed as a MAC CE from the UE to the gNB as outlined in Figure 16.2.1.1-2.

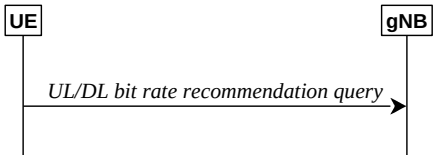


Figure 16.2.1.1-2: UL or DL bit rate recommendation query

A prohibit timer can be configured per logical channel by the network to limit UEs sending frequent query MAC CEs. Independent prohibit timers are used for each direction (uplink and downlink) to prohibit the UE from retransmitting exactly the same query MAC CE to the gNB during the configured time.

16.2.1.2 MMTEL voice quality/coverage enhancements

The air interface delay budget can be relaxed to increase the robustness of the transmission for coverage enhancement. Such relaxation may be achieved when a UE in good coverage indicates a preference to the gNB to reduce the local air interface delay by sending a *DelayBudgetReport* message to decrease the DRX cycle length, so that the E2E delay and jitter can be reduced. When the UE detects changes such as end-to-end MMTEL voice quality or local radio quality, the UE may inform the gNB its new preference by sending *DelayBudgetReport* messages with updated contents.

16.3 Network Slicing

16.3.1 General Principles and Requirements

In this clause, the general principles and requirements related to the realization of network slicing in the NG-RAN for NR connected to 5GC and for E-UTRA connected to 5GC are given.

A network slice always consists of a RAN part and a CN part. The support of network slicing relies on the principle that traffic for different slices is handled by different PDU sessions. Network can realise the different network slices by scheduling and also by providing different L1/L2 configurations.

Each network slice is uniquely identified by a S-NSSAI, as defined in TS 23.501 [3]. NSSAI (Network Slice Selection Assistance Information) includes one or a list of S-NSSAIs (Single NSSAI) where a S-NSSAI is a combination of:

- mandatory SST (Slice/Service Type) field, which identifies the slice type and consists of 8 bits (with range is 0-255);
- optional SD (Slice Differentiator) field, which differentiates among Slices with same SST field and consist of 24 bits.

The list includes at most 8 S-NSSAI(s).

The UE provides NSSAI (Network Slice Selection Assistance Information) for network slice selection in *RRCSetupComplete*, if it has been provided by NAS (see clause 9.2.1.3). While the network can support large number of slices (hundreds), the UE need not support more than 8 slices simultaneously. A BL UE or a NB-IoT UE supports a maximum of 8 slices simultaneously.

Network Slicing is a concept to allow differentiated treatment depending on each customer requirements. With slicing, it is possible for Mobile Network Operators (MNO) to consider customers as belonging to different tenant types with each having different service requirements that govern in terms of what slice types each tenant is eligible to use based on Service Level Agreement (SLA) and subscriptions.

The following key principles apply for support of Network Slicing in NG-RAN:

RAN awareness of slices

- NG-RAN supports a differentiated handling of traffic for different network slices which have been pre-configured. How NG-RAN supports the slice enabling in terms of NG-RAN functions (i.e. the set of network functions that comprise each slice) is implementation dependent.

Selection of RAN part of the network slice

- NG-RAN supports the selection of the RAN part of the network slice, by NSSAI provided by the UE or the 5GC which unambiguously identifies one or more of the pre-configured network slices in the PLMN.

Resource management between slices

- NG-RAN supports policy enforcement between slices as per service level agreements. It should be possible for a single NG-RAN node to support multiple slices. The NG-RAN should be free to apply the best RRM policy for the SLA in place to each supported slice.

Support of QoS

- NG-RAN supports QoS differentiation within a slice, and per Slice-Maximum Bit Rate may be enforced per UE, if feasible. How NG-RAN enables UE-Slice-MBR enforcement and rate limitation (see TS 23.501 [3]) is up to network implementation.

RAN selection of CN entity

- For initial attach, the UE may provide NSSAI to support the selection of an AMF. If available, NG-RAN uses this information for routing the initial NAS to an AMF. If the NG-RAN is unable to select an AMF using this information or the UE does not provide any such information the NG-RAN sends the NAS signalling to one of the default AMFs.

- For subsequent accesses, the UE provides a Temp ID, which is assigned to the UE by the 5GC, to enable the NG-RAN to route the NAS message to the appropriate AMF as long as the Temp ID is valid (NG-RAN is aware of and can reach the AMF which is associated with the Temp ID). Otherwise, the methods for initial attach applies.

Resource isolation between slices

- The NG-RAN supports resource isolation between slices. NG-RAN resource isolation may be achieved by means of RRM policies and protection mechanisms that should avoid that shortage of shared resources in one slice breaks the service level agreement for another slice. It should be possible to fully dedicate NG-RAN resources to a certain slice. Some RACH resources can be associated to specific NSAG(s). Other aspects how NG-RAN supports resource isolation is implementation dependent.

Access control

- By means of the unified access control (see clause 7.4), operator-defined access categories can be used to enable differentiated handling for different slices. NG-RAN may broadcast barring control information (i.e. a list of barring parameters associated with operator-defined access categories) to minimize the impact of congested slices.

Slice Availability and Support

- Some slices may be available only in part of the network. A slice is considered available in a cell if it is supported by the TA comprising the cell and the slice is not configured with zero resources, as specified in TS 23.501 [3]. A slice is supported within a TA if the NG-RAN has been configured to support the S-NSSAI in the TA. All supported slices are included in the slice support list for the TA signalled from the NG-RAN to the AMF. The NG-RAN supported S-NSSAI(s), NSAG(s) and NSAG related information such as NSAG associated Cell Reselection Priority and/or NSAG associated RACH resources are configured by OAM. Awareness in the NG-RAN of the slices supported in the cells of its neighbours may be beneficial for inter-frequency mobility in

connected mode. In order to support the NSAG, the NG-RAN provides the AMF with the NSAG information per TA in the appropriate NG interface management procedures, as specified in TS 38.413 [26]. Awareness in the NG-RAN of the NSAG information supported in the list(s) of neighbour cells may be configured by OAM, or exchanged with neighbour NG-RAN nodes.

- The NG-RAN and the 5GC are responsible to handle a service request for a slice that may or may not be available in a given area. Admission or rejection of access to a slice may depend by factors such as support for the slice, availability of resources, support of the requested service by NG-RAN.

- The NG-RAN may be signalled with the Partially Allowed NSSAI from the AMF as specified in TS 23.501 [3]. The NG-RAN may decide to use the Partially Allowed NSSAI for mobility decision.

- Support for Network Slices with Network Slice Area of Service not matching deployed Tracking Areas is specified in TS 23.501 [3]. NG-RAN cells that are outside the Area of Service may be configured with zero resources for the concerned slice(s). The concerned slice(s) cannot use any dedicated, prioritized nor any shared resources of that cell. Awareness of zero resources configured for a slice in one or more cells may be exchanged with neighbour NG-RAN nodes for mobility reasons.

Support for UE associating with multiple network slices simultaneously

- In case a UE is associated with multiple slices simultaneously, only one signalling connection is maintained and for intra-frequency cell reselection, the UE always tries to camp on the best cell. For inter-frequency cell reselection, dedicated priorities can be used to control the frequency on which the UE camps.

Granularity of slice awareness

- Slice awareness in NG-RAN is introduced at PDU session level, by indicating the S-NSSAI corresponding to the PDU Session, in all signalling containing PDU session resource information.

Validation of the UE rights to access a network slice

- It is the responsibility of the 5GC to validate that the UE has the rights to access a network slice. Prior to receiving the Initial Context Setup Request message, the NG-RAN may be allowed to apply some provisional/local policies, based on awareness of which slice the UE is requesting access to. During the initial context setup, the NG-RAN is informed of the slice for which resources are being requested.

Network slice replacement

- NG-RAN may support network slice replacement for a PDU session as defined in TS 23.501 [3].

NOTE: The resources used to serve the alternative slice may be subject to subsequent O&M adjustments to take into account the additional load generated by remapping of one or more slices into the alternative S-NSSAI, if this alternative slice is not member of the same *RRMPolicyRatio* (see TS 28.541 [49]) as the original slice.

16.3.2 AMF and NW Slice Selection

16.3.2.1 CN-RAN interaction and internal RAN aspects

NG-RAN selects AMF based on a Temp ID or NSSAI provided by the UE over RRC as specified in TS 38.410 [16]. The mechanisms used in the RRC protocol are described in the next clause.

Table 16.3.2.1-1 AMF selection based on Temp ID and NSSAI

Temp ID	NSSAI	AMF Selection by NG-RAN
not available or invalid	not available	One of the default AMFs is selected (NOTE)
not available or invalid	present	Selects AMF which supports UE requested slices
valid	not available, or present	Selects AMF per CN identity information in Temp ID
NOTE: The set of default AMFs is configured in the NG-RAN nodes via OAM.		

16.3.2.2 Radio Interface Aspects

When triggered by the upper layer, the UE conveys the NSSAI over RRC in the format explicitly indicated by the upper layer.

16.3.3 Resource Isolation and Management

16.3.3.1 General

Resource isolation enables specialized customization and avoids one slice affecting another slice.

Hardware/software resource isolation is up to implementation. Each slice may be assigned with either shared, prioritized or dedicated radio resource up to RRM implementation and SLA as in TS 28.541 [49].

To enable differentiated handling of traffic for network slices with different SLA:

- NG-RAN is configured with a set of different configurations for different network slices by OAM;
- To select the appropriate configuration for the traffic for each network slice, NG-RAN receives relevant information indicating which of the configurations applies for this specific network slice.

Slice-based RACH configuration for RA isolation and prioritization can be included in SIB1 messages. The slice-based RACH configurations are associated to specific NSAG(s), and if not provided for a NSAG that UE considers for selecting the RACH configuration, then the UE does not consider the NSAG for selecting the slice-based RACH configuration. The UE determines the NSAG to be considered during RA as specified in TS 23.501 [3]. When the UE AS does not receive any NSAG information from NAS for Random Access, the UE does not apply the slice-based RACH configuration.

16.3.3.2 Handling of Slice Resources

The NG-RAN node may use Multi-Carrier Resource Sharing or Resource Repartitioning to allocate resources to a slice during the procedures described in 16.3.4 to support the slice service continuity in case of slice resources shortage.

In Multi-Carrier Resource Sharing the RAN node can setup the dual connectivity or carrier aggregation with different frequency and overlapping coverage where the same slice is available.

The Resource Repartitioning allows a slice to use resources from the shared pool or/and prioritized pool when its own dedicated or prioritized resources are not available and the use of unused resources in the prioritized pool is as specified in TS 28.541 [49].

Slice RRM policies/restrictions associated with Resource Repartitioning are configured from O&M.

Measurements of RRM policy utilization according to resource types defined in TS 28.541 [49] are reported from RAN nodes to O&M and may lead O&M to update the configuration of the Slice RRM policies/restrictions.

16.3.3a Slice-based cell reselection

Slice-based cell reselection information can be included in SIB16 and in *RRCRelease* messages. The slice-based cell reselection information may include reselection priorities per NSAG per frequency and corresponding list(s) of cells where the slices of the NSAG are supported or not supported. The UE determines the NSAG(s) and their priorities to be considered during cell reselection as specified in TS 23.501 [3], and in TS 38.304 [10].

When a UE supports slice-based cell reselection, and when slice-based cell reselection information is provided to the UE, then the UE uses the slice-based cell reselection information. Valid cell reselection information provided in *RRCRelease* always has a priority over cell reselection information provided in SIB messages. When no slice-based cell reselection information is provided for any NSAG that was determined to be considered during cell reselection (as specified in TS 23.501 [3]), then the UE uses the general cell reselection information, i.e., without considering the NSAG(s) and their priorities.

16.3.4 Signalling Aspects

16.3.4.1 General

In this clause, signalling flows related to the realization of network slicing in the NG-RAN are given.

16.3.4.2 AMF and NW Slice Selection

RAN selects the AMF based on a Temp ID or NSSAI provided by the UE.

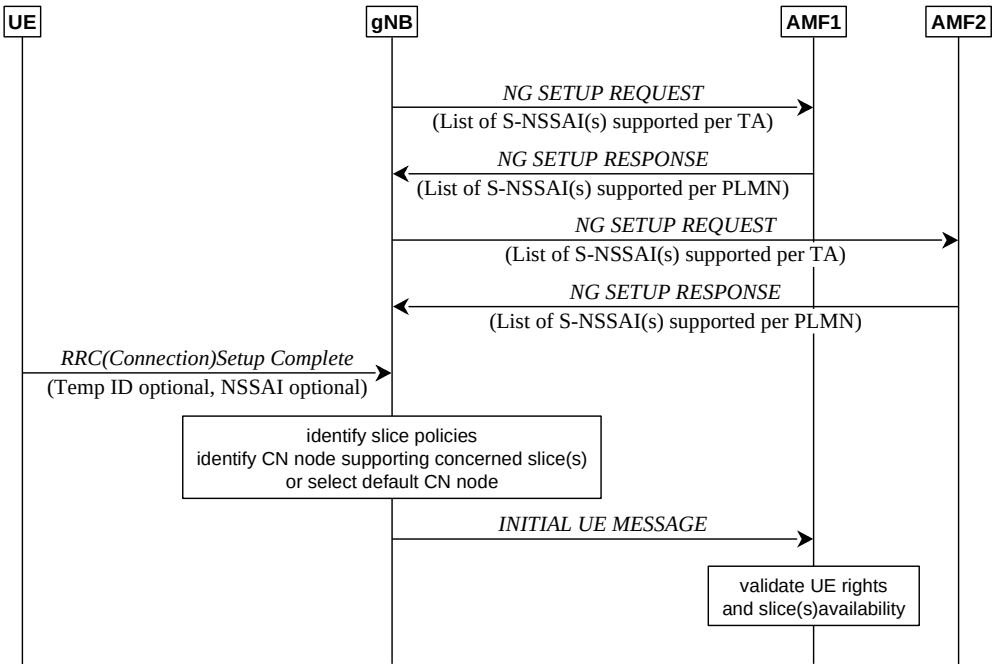


Figure 16.3.4.2-1: AMF selection

In case a Temp ID is not available, the NG-RAN uses the NSSAI provided by the UE at RRC connection establishment to select the appropriate AMF (the information is provided after MSG3 of the random access procedure). If such information is also not available, the NG-RAN routes the UE to one of the configured default AMF(s).

The NG-RAN uses the list of supported S-NSSAI(s) previously received in the NG Setup Response message when selecting the AMF with the NSSAI. This list may be updated via the AMF Configuration Update message.

16.3.4.3 UE Context Handling

Following the initial access, the establishment of the RRC connection and the selection of the correct AMF, the AMF establishes the complete UE context by sending the Initial Context Setup Request message to the NG-RAN over NG-C. The message contains the Allowed NSSAI and additionally contains the S-NSSAI(s) as part of the PDU session(s) resource description when present in the message and may contain Partially Allowed NSSAI. Upon successful establishment of the UE context and allocation of PDU session resources to the relevant network slice(s) when present, the NG-RAN responds with the Initial Context Setup Response message.

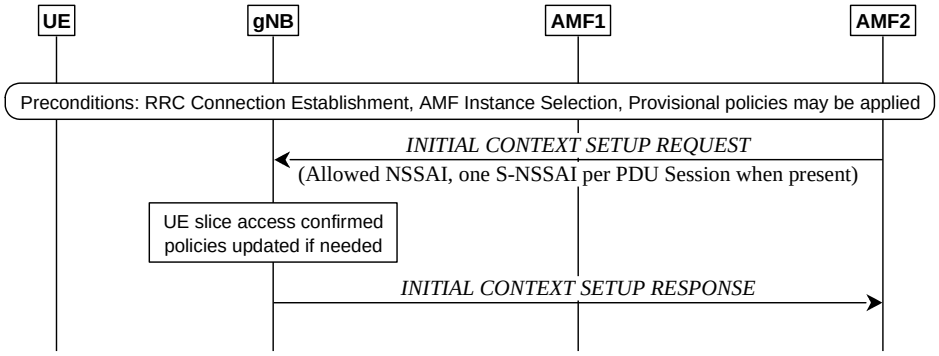


Figure 16.3.4.3-1: Network Slice-aware Initial Context Setup

16.3.4.4 PDU Session Setup Handling

When new PDU sessions need to be established, the 5GC requests the NG-RAN to allocate/ resources relative to the relevant PDU sessions by means of the PDU Session Resource Setup procedures over NG-C. One S-NSSAI is added per PDU session to be established, so NG-RAN is enabled to apply policies at PDU session level according to the SLA represented by the network slice, while still being able to apply (for example) differentiated QoS within the slice.

NG-RAN confirms the establishment of the resources for a PDU session associated to a certain network slice by responding with the PDU Session Resource Setup Response message over the NG-C interface.

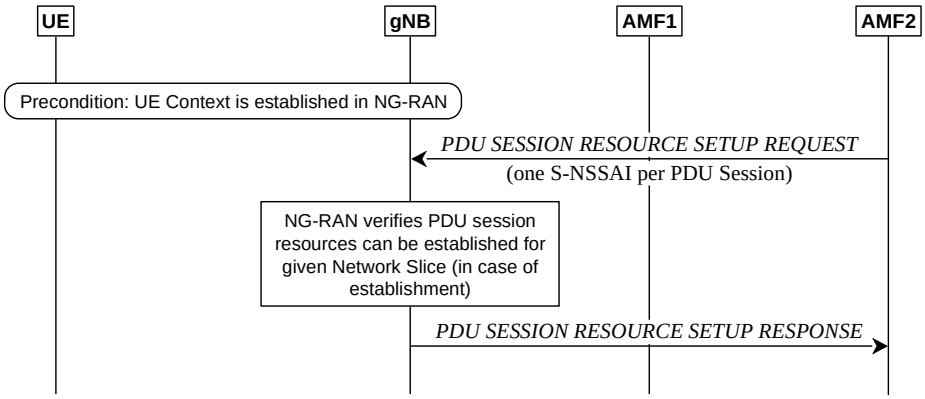


Figure 16.3.4.4-1: Network Slice-aware PDU Session Resource Setup

16.3.4.5 Mobility

To make mobility slice-aware in case of Network Slicing, S-NSSAI is introduced as part of the PDU session information that is transferred during mobility signalling. This enables slice-aware admission and congestion control.

NG handovers are allowed regardless of the slice support of the target NG-RAN node i.e. even if the target NG-RAN node does not support the same slices as the source NG-RAN node. Xn handovers are allowed only when at least one of the slices with active PDU sessions for the UE at the source gNB is supported at the target gNB. The source gNB performs this check as part of the Handover Preparation. An example for the case of connected mode mobility across different Registration Areas is shown in Figure 16.3.4.5-1 for the case of NG based handover and in Figure 16.3.4.5-2 for the case of Xn based handover.

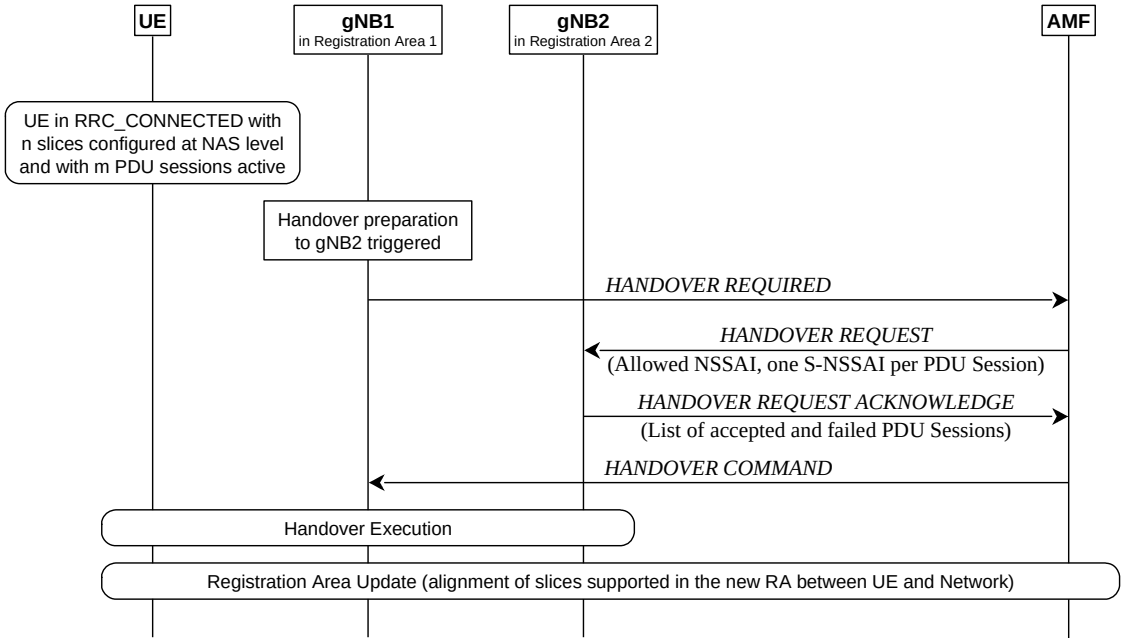


Figure 16.3.4.5-1: NG based mobility across different Registration Areas

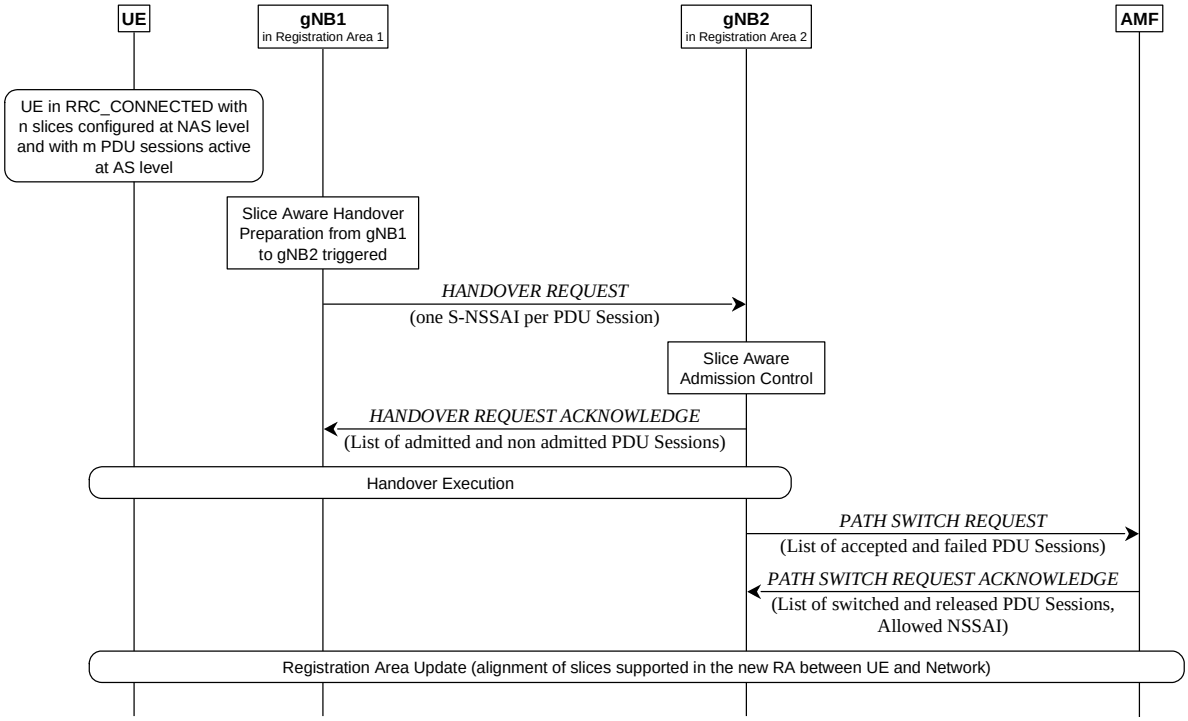


Figure 16.3.4.5-2: Xn based mobility across different Registration Areas

16.4 Public Warning System

NR connected to 5GC provides support for public warning systems (PWS) through means of system information broadcast capability. NR is responsible for scheduling and broadcasting of the warning messages as well as for paging the UE to provide indication that the warning message is being broadcast:

- Earthquake and Tsunami Warning System: ETWS is a public warning system developed to meet the regulatory requirements for warning notifications related to earthquake and/or tsunami events (see TS 22.168 [14]). ETWS

warning notifications can either be a primary notification (short notification) or secondary notification (providing detailed information).

- Commercial Mobile Alert System: CMAS is a public warning system developed for the delivery of multiple, concurrent warning notifications (see TS 22.268 [15]).

Different SIBs are defined for ETWS primary notification, ETWS secondary notification and CMAS notification. Paging is used to inform UEs about ETWS indication and CMAS indication (see clause 9.2.5). UE monitors ETWS/CMAS indication in its own paging occasion for RRC_IDLE and for RRC_INACTIVE while no SDT procedure (see clause 18.0) is ongoing. UE monitors ETWS/CMAS indication in any paging occasion for RRC Connected and during the SDT procedure in RRC_INACTIVE. Paging indicating ETWS/CMAS notification triggers acquisition of system information (without delaying until the next modification period).

Enhancements of public warning system (ePWS) enable broadcast of language-independent content and notifications to UEs with no user interface or with a user interface that is incapable of displaying text, see clause 9 in TS 22.268 [15] and TS 23.041 [54]. ETWS/CMAS notifications with ePWS functionality use the same AS mechanisms as ETWS/CMAS.

KPAS and EU-Alert are public warning systems developed for the delivery of multiple, concurrent warning notifications (see TS 22.268 [15]). KPAS and EU-Alert uses the same AS mechanisms as CMAS. Therefore, the NR procedures defined for CMAS equally apply for KPAS and EU-Alert.

16.5 Emergency Services

16.5.1 Overview

NG-RAN provides support for Emergency Services either directly or through fallback mechanisms towards E-UTRA. The support of Emergency Services is broadcast in system information (see TS 38.331 [12]).

16.5.2 IMS Emergency call

An IMS Emergency call support indication is provided to inform the UE that emergency bearer services are supported. In normal service state the UE is informed if the PLMN supports emergency services through an Emergency Service Support indicator in the Attach and TAU procedures (see TS 23.501 [3]). In limited service state and for emergency services other than eCall over IMS, a UE is informed about if a cell supports emergency services over NG-RAN from a broadcast indication (*ims-EmergencySupport*). The broadcast indicator is set to "support" if any AMF in a non-shared environment or at least one of the PLMN's in a shared environment supports IMS emergency bearer services.

16.5.3 eCall over IMS

NG-RAN broadcast an indication to indicate support of eCall over IMS (*eCallOverIMS-Support*). UEs that are in limited service state need to consider both *eCallOverIMS-Support* and *ims-EmergencySupport* to determine if eCall over IMS is possible. UEs that are not in limited service state need to only consider *eCallOverIMS-Support* to determine if eCall over IMS is possible. The broadcast indicator is set to "support" if the PLMN in a non-shared environment, or all PLMNs in a shared environment, supports eCall over IMS.

16.5.4 Fallback

RAT fallback towards E-UTRA connected to 5GC is performed when NR does not support Emergency Services and System fallback towards E-UTRA connected to EPS is performed when 5GC does not support Emergency Services. Depending on factors such as CN interface availability, network configuration and radio conditions, the fallback procedure results in either CONNECTED state mobility (handover procedure) or IDLE state mobility (redirection) - see TS 23.501 [3] and TS 38.331 [12].

16.5.5 Barring exemption for emergency calls

The network may allow (e)RedCap UEs and 2Rx XR UEs to consider the cell as an acceptable cell to perform emergency calls in the cell, even if the cell would otherwise be considered as barred due to the cell barring indication in

SIB1 for (e)RedCap UEs or 2Rx XR UEs. This is enabled via the *barringExemptEmergencyCall* by the network (see TS 38.304 [10] and TS 38.331 [12]).

16.6 Stand-Alone NPN

16.6.1 General

An SNPN is a network deployed for non-public use which does not rely on network functions provided by a PLMN (see clause 4.8). An SNPN is identified by a PLMN ID and NID (see clause 8.2) broadcast in SIB1.

An SNPN-capable UE supports the SNPN access mode. When the UE is set to operate in SNPN access mode, the UE only selects and registers with SNPNs. When the UE is not set to operate in SNPN access mode, the UE performs normal PLMN selection procedures.

Emergency services and ETWS /CMAS can be supported by SNPNs. An IMS Emergency call support indication is provided per SNPN to inform the UE which SNPN(s) support emergency bearer. In normal service state the indication is provided in the same way as in case of PLMNs (see clause 16.5.2). In limited service state and for emergency services other than eCall over IMS, a UE is informed whether an SNPN of the cell supports emergency services over NG-RAN from a per SNPN broadcast indication (*imsEmergencySupportForSNPN*). The broadcast indicator for an SNPN may be set to "support" if any AMF of the SNPN supports IMS emergency bearer services.

NR-NR Dual Connectivity within a single SNPN or across SNPNs as indicated in the mobility restriction list is supported.

16.6.2 Mobility

16.6.2.1 General

The same principles as described in 9.2 apply to SNPN except for what is described below.

UEs operating in SNPN access mode only (re)select cells within the selected/registered SNPN or within equivalent SNPNs and a cell can only be considered as suitable if the PLMN and NID broadcast by the cell matches the selected/registered SNPN or an equivalent SNPN.

In addition, manual selection of SNPN(s) is supported, for which HRNN(s) can be optionally provided.

The roaming and access restrictions applicable to SNPN are described in clause 9.4.

16.6.2.2 Inactive Mode

The mobility of a UE in inactive mode builds on existing functionality described in clause 9.2.2 and is limited to the SNPN(s) identified within the mobility restrictions received in the UE context.

16.6.2.3 Connected Mode

The NG-RAN node is aware of the SNPN ID(s) supported by neighbour cells.

At the time of handover, cells that do not support the serving SNPN ID or the SNPN ID of an equivalent SNPN within the mobility restrictions received in the UE context are not considered as candidate target cells by the source NG-RAN node.

The target NG-RAN node performs access control. In case it cannot accept the handover for the serving SNPN the target NG-RAN node fails the handover including an appropriate cause value.

16.6.3 Self-Configuration for SNPN

Self-configuration is described in clause 15. In addition, on NG, the NG-RAN node signals the SNPN ID(s) supported per tracking area and the AMF signals the SNPN ID(s) supported per node; on Xn, NG-RAN nodes exchange SNPN ID(s) supported per cell.

16.6.4 Access Control

During the establishment of the UE-associated logical NG-connection towards the 5GC, the AMF checks whether the UE is allowed to access the cell for the signalled SNPN ID as specified in TS 23.501 [3].

If the check is successful, the AMF sets up the UE-associated logical NG-connection and provides the NG-RAN node with the mobility restrictions applicable for the SNPN.

If the check is not successful, the AMF shall reject setting up the UE-associated NG connection and inform the NG-RAN node with an appropriate cause value as specified in TS 23.501 [3].

16.6.5 Access with subscription/credentials owned by a Credentials Holder

An SNPN may allow access to UEs being authorized using credentials or subscription owned by a separate Credentials Holder (CH). The support of this feature is uniform across the SNPN as specified in TS 23.501 [3].

The following information is broadcast to support SNPN access with subscription of a Credentials Holder:

- an indication per SNPN in SIB1 that access using credentials from a Credentials Holder is supported;
- optionally a list of supported GINs in SIB18 (each GIN may be assigned to one or more SNPNs);
- an optional indication per SNPN in SIB1 that the SNPN allows registration attempts from UEs that are not explicitly configured to select the SNPN.

The above listed items are forwarded to the UE NAS layer that uses them for SNPN selection.

16.6.6 Support of UE onboarding and remote provisioning

An SNPN may offer support for restricted 3GPP connectivity for remote provisioning of credentials. The feature is enabled/disabled per cell.

The following information is broadcast to support UE onboarding and remote provisioning:

- an indication per onboarding SNPN in SIB1 that UE onboarding is enabled;
- optionally a list of supported GINs in SIB18 (each GIN may be assigned to one or more onboarding SNPNs).

The above listed items are forwarded to the UE NAS layer that uses them for onboarding SNPN selection. When a UE intends to perform onboarding, it sends the onboarding request indication to the gNB during RRC connection establishment.

The NG-RAN nodes receive information about onboarding support capabilities of the AMF(s). This information is used by the NG-RAN node to select a suitable AMF when receiving the onboarding request indication from the UE.

16.7 Public Network Integrated NPN

16.7.1 General

A PNI-NPN is a network deployed for non-public use which relies on network functions provided by a PLMN (see clause 4.8). In PNI-NPN, a Closed Access Groups (CAG) identifies a group of subscribers who are permitted to access one or more CAG cells associated to the CAG. A CAG is identified by a CAG identifier broadcast in SIB1.

A CAG-capable UE can be configured with the following per PLMN (see clause 5.30.3.3 of TS 23.501 [3]):

- an Allowed CAG list containing the CAG identifiers which the UE is allowed to access; and
- a CAG-only indication if the UE is only allowed to access 5GS via CAG cells.

Dual Connectivity is supported and may involve both PNI-NPN and PLMN cells, according to the mobility restrictions in the UE context as described in TS 37.340 [21].

16.7.2 Mobility

16.7.2.1 General

The same principles as described in 9.2 apply to CAG cells except for what is described below.

Cell selection/reselection to CAG cells may be based on a UE autonomous search function, which determines itself when/where to search, but cannot contradict the dedicated cell reselection priority information if any is stored.

A range of PCI values reserved by the network for use by CAG cells may be broadcast.

A CAG Member Cell for a UE is a cell broadcasting the identity of the selected PLMN, registered PLMN or equivalent PLMN, and for that PLMN, a CAG identifier belonging to the Allowed CAG list of the UE for that PLMN. The UE checks the suitability of CAG cells based on the Allowed CAG list provided by upper layers and a CAG-only cell can only be suitable for its subscribers but can be acceptable for the rest.

NOTE: A non-CAG-capable UE (e.g. Rel-15 UE) considers a CAG-only cell as acceptable cell if the cell is not barred to Rel-15 UEs, and if a PLMN ID without CAG list is broadcast and that PLMN is forbidden (e.g. by use of a PLMN ID for which all registration attempts are rejected such that the PLMN ID becomes forbidden).

When the UE is configured with a CAG-only indication, only CAG Member Cells can be suitable. A non-suitable cell can be acceptable though if the UE is configured with a CAG-only indication for one of the PLMN broadcast by the cell.

In addition, manual selection of CAG cell(s) is supported, for which an HRNN(s) can be optionally provided.

The roaming and access restrictions applicable to PNI-NPN are described in clause 9.4.

16.7.2.2 Inactive Mode

The mobility of a UE in inactive mode builds on existing functionality described in clause 9.2.2 according to the mobility restrictions received in the UE context.

16.7.2.3 Connected Mode

The source NG-RAN node is aware of the list of CAG IDs supported by the candidate target cells which are CAG cells.

At the time of handover, the source NG-RAN node determines a target cell among the candidates which is compatible with the received PNI-NPN restrictions.

At incoming handover, the target NG-RAN node receives the PNI-NPN mobility restrictions and checks that the selected target cell is compatible with the received mobility restrictions.

Mobility between PNI-NPN and PLMN cells is supported according to the mobility restrictions in the UE context.

16.7.3 Self-Configuration for PNI-NPN

Self-configuration is described in clause 15.

In addition, each NG-RAN node informs the connected neighbour NG-RAN nodes of the list of supported CAG ID(s) per CAG cell in the appropriate Xn interface management procedures.

16.7.4 Access Control

During the establishment of the UE-associated logical NG-connection towards the 5GC, the AMF checks whether the UE is allowed to access the cell as specified in TS 23.501 [3].

If the check is successful, the AMF sets up the UE-associated logical NG-connection and provides the NG-RAN node with the list of CAGs allowed for the UE and, whether the UE is allowed to access non-CAG cells. This information is used by the NG-RAN for access control of subsequent mobility.

If the check is not successful, the AMF shall reject setting up the UE-associated NG connection and inform the NG-RAN node with an appropriate cause value as specified in TS 23.501 [3].

16.7.5 Paging

The NG-RAN node may receive a paging message including the list of CAGs allowed for the UE, and whether the UE is allowed to access non-CAG cells. The NG-RAN node may use this information to avoid paging in cells on which the UE is not allowed to camp.

For UEs in RRC_INACTIVE state, the NG-RAN node may page a neighbour NG-RAN node including the list of CAGs allowed for the UE, and whether the UE is allowed to access non-CAG cells. The neighbour NG-RAN node may use this information to avoid paging in cells on which the UE is not allowed to camp.

16.8 Support for Time Sensitive Communications

16.8.1 General

Time Sensitive Communications (TSC), as defined in TS 23.501 [3], is a communication service that supports deterministic communication and/or isochronous communication with high reliability and availability. Examples of such services are the ones in the area of Industrial Internet of Things, e.g. related to cyber-physical control applications as described in TS 22.104 [39].

To support strict synchronization accuracy requirements of TSC applications, the gNB may signal 5G system time reference information to the UE using unicast or broadcast RRC signalling with a granularity of 10 ns. Uncertainty parameter may be included in reference time information to indicate its accuracy. The UE may indicate to the gNB a preference to be provisioned with reference time information using UE Assistance Information procedure. Propagation delay compensation (PDC) mechanisms may be applied based on RTT or TA, and can be performed at the UE or gNB side. When performed at UE side, the PDC mechanisms are controlled via RRC signalling by the gNB.

The RTT-based PDC mechanism is achieved by using Rx-Tx time difference measurements of a single pair of configured TRS/PRS and SRS. The following figure describes the signalling procedures of UE-side RTT-based PDC:

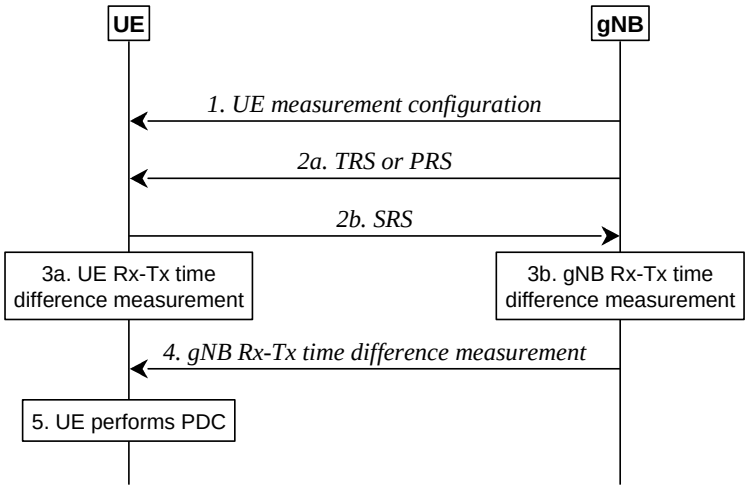


Figure 16.8-1: Signalling Procedure of UE-side RTT-based PDC

1. The gNB provides measurement configurations to the UE;

2a/b. The gNB transmits TRS or PRS to the UE for measurements, and the UE transmits SRS to the gNB for measurement;

3a/b. Both the UE and the gNB perform Rx-Tx time difference measurements;

4. The gNB provides its Rx-Tx time difference measurement to the UE;

5. The UE performs PDC based on Rx-Tx time difference measurements from itself and the gNB.

The following figure describes the signalling procedures of gNB-side RTT-based PDC:

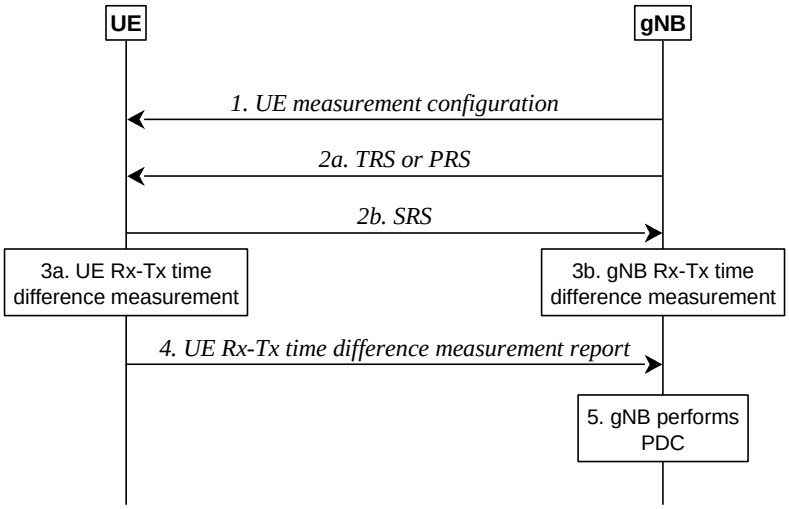


Figure 16.8-2: Signalling Procedure of gNB-side RTT-based PDC

1. The gNB provides measurement configurations to the UE;

2a/b. The gNB transmits TRS or PRS to the UE for measurements, and the UE transmits SRS to the gNB for measurement;

3a/b. Both the UE and the gNB perform Rx-Tx time difference measurements;

4. The UE reports its Rx-Tx time difference measurement to the gNB;

5. The gNB performs PDC based on Rx-Tx time difference measurements from itself and the UE.

The gNB may also receive TSC Assistance Information (TSCAI), see TS 23.501 [3], from the Core Network, e.g. during QoS flow establishment, or from another gNB during handover. TSCAI contains additional information about the traffic flow such as burst arrival time, burst periodicity, and survival time. TSCAI knowledge may be leveraged in the gNB's scheduler to more efficiently schedule periodic, deterministic traffic flows either via Configured Grants, Semi-Persistent Scheduling or with dynamic grants, and/or to improve the associated link reliability to meet the survival time requirement (see TS 22.104 [39]).

To support uplink periodic traffics of services with survival time requirement, configured grant resources can be used such that the mapping relation between the service and the configured grant is known to both gNB and UE, thus allowing the gNB to use configured grant retransmission scheduling (addressed by CS-RNTI) to trigger survival time state entry for the corresponding DRB. Upon survival time state entry, all RLC entities configured for the DRB are activated by the UE for duplication to prevent failure of subsequent messages and hence fulfilling the survival time requirement. If CA or DC duplication for the DRB is already activated, the DRB should enter survival time state when any retransmission grant for any of its active LCHs is received.

16.8.2 Network timing synchronization status monitoring

16.8.2.1 General

While time synchronization service is offered by the 5GS, the network timing synchronization status of the gNB may change. The gNB detects timing synchronization degradation or improvement locally and informs the consumer of the information as specified in TS 23.501 [3] as follows:

- TSCTSF may receive information about timing synchronization status from the gNB via the AMF based on node-level reporting configuration or via OAM;
- UE may receive clock quality information from the gNB based on UE-level clock quality reporting control information.

16.8.2.2 Network timing synchronization status monitoring towards CN

The gNB may receive a request for RAN timing synchronization status (TSS) information from the AMF as specified in TS 23.501 [3]. The RAN TSS information includes one or more of the following attributes: synchronization state, traceable to UTC, traceable to GNSS, frequency stability, clock accuracy, parent time source, as defined in TS 23.501 [3].

The gNB may be pre-configured with a threshold for each RAN TSS attribute it supports. When the gNB detects a primary source event as defined in TS 38.401 [4], a timing synchronisation status report is triggered towards the AMF to provide the current RAN timing synchronisation status information.

16.8.2.3 Network timing synchronization status monitoring towards UE

The gNB may receive clock quality reporting control information for a UE from the AMF, see TS 23.501 [3]. The clock quality reporting control information contains the clock quality detail level (i.e., "metrics" or "acceptable/not acceptable indication") and clock quality acceptance criteria for the UE (if the clock quality detail level equals "acceptable/not acceptable indication"). Based on the clock quality reporting control information, the gNB determines what clock quality information provide to the UE:

- If the clock quality detail level equals "clock quality metrics", the gNB provides clock quality attribute values supported by the gNB to the UE.
- If the clock quality detail level equals "acceptable/not acceptable indication", the gNB indicates "acceptable" to the UE if the gNB's timing synchronization status matches the acceptance criteria received from the AMF; otherwise, the gNB indicates "not acceptable" to the UE.

To provide clock quality information to the UEs:

- For UEs in the RRC CONNECTED state, the gNB uses unicast RRC signalling. The RRC signalling includes Event ID and clock quality information.
- For UEs that are not in the RRC_CONNECTED state, the UE first needs to establish or resume the RRC connection to receive the clock quality information from the gNB via unicast RRC signalling. The gNB broadcasts Event ID in SIB9 to notify its timing synchronization status. Event ID or gNB ID change serves as a notification for the UEs reading the SIB information that the RAN timing synchronization status information has changed.

The following figure describes the signalling procedure of gNB reporting clock quality information to a UE:

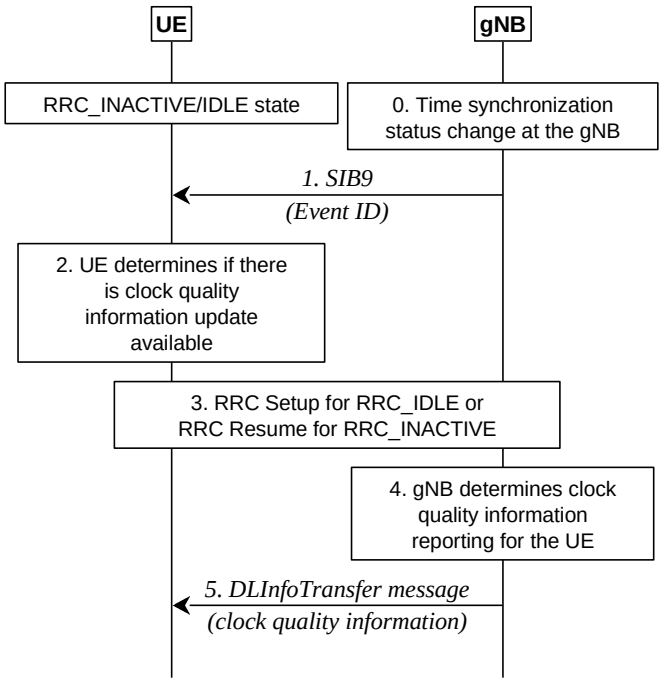


Figure 16.8.2-1: Signalling procedure of gNB reporting clock quality information to a UE

0. The gNB is pre-configured with a threshold for each RAN TSS attribute it supports as described in in TS 23.501 [3]. When there is a primary source event as defined in TS 38.401 [4], the gNB may detect a change on its timing synchronization state (e.g., degradation, failure, recovery).
1. The gNB notifies a change on its timing synchronization operation using Event ID in SIB9. The Event ID scope is local to gNB.
2. The UE in RRC_INACTIVE or RRC_IDLE determines if there is clock quality information update available at the gNB based on SIB9 information. For a UE in RRC_CONNECTED state, steps 2-3 can be skipped.
3. If there is a RAN timing synchronization status update available, the UE's RRC layer indicates this to the NAS layer which may request the RRC layer to initiate RRC Setup or RRC Resume procedure.
4. The gNB determines clock quality information reporting to the UE (e.g., metrics or "acceptable/not acceptable").
5. The gNB sends the clock quality information to the UE via unicast RRC signalling.

16.8.3 RAN feedback for adaptation of Burst Arrival Time and Periodicity

The NG-RAN may support the proactive feedback and reactive feedback mechanisms as specified in TS 23.501 [3]. The NG-RAN can provide the feedback in order to align the arrival of the traffic bursts with the next expected transmission opportunity over the air interface in each direction (i.e. DL or UL) for a QoS flow. The NG-RAN may receive reports of uplink burst arrival time in UE Assistance Information.

16.9 Sidelink

16.9.1 General

In this clause, an overview of NR sidelink communication and how NG-RAN supports NR sidelink communication, V2X sidelink communication and Ranging/Sidelink positioning is given. V2X sidelink communication is specified in TS 36.300 [2]. Ranging/Sidelink positioning is specified in TS 38.305 [42].

The NG-RAN architecture supports the PC5 interface as illustrated in Figure 16.9.1-1. Sidelink transmission and reception over the PC5 interface are supported when the UE is inside NG-RAN coverage, irrespective of which RRC state the UE is in, and when the UE is outside NG-RAN coverage.

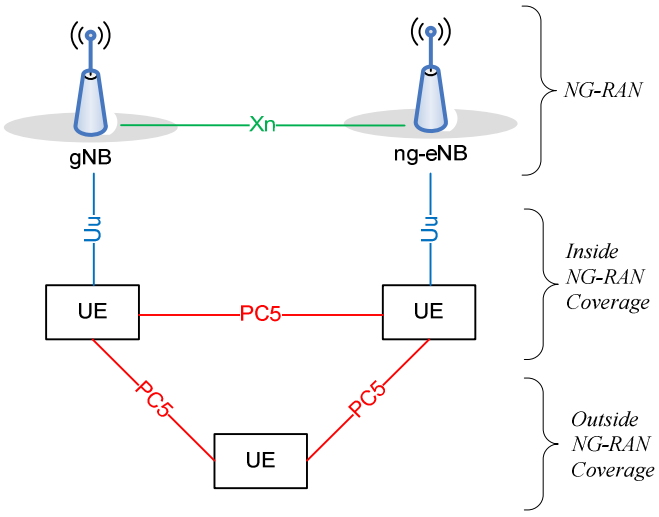


Figure 16.9.1-1: NG-RAN Architecture supporting the PC5 interface

Support of V2X services via the PC5 interface can be provided by NR sidelink communication and/or V2X sidelink communication. NR sidelink communication may be used to support other services than V2X services.

NR sidelink communication can support one of three types of transmission modes for a pair of a Source Layer-2 ID and a Destination Layer-2 ID in the AS:

- **Unicast transmission**, characterized by:
  - Support of one PC5-RRC connection between peer UEs for the pair;
  - Transmission and reception of control information and user traffic between peer UEs in sidelink;
  - Support of sidelink HARQ feedback;
  - Support of sidelink transmit power control;
  - Support of RLC AM;
  - Detection of radio link failure for the PC5-RRC connection.
- **Groupcast transmission**, characterized by:
  - Transmission and reception of user traffic among UEs belonging to a group in sidelink;
  - Support of sidelink HARQ feedback.
- **Broadcast transmission**, characterized by:
  - Transmission and reception of user traffic among UEs in sidelink.

16.9.2 Radio Protocol Architecture for NR sidelink communication

16.9.2.1 Overview

The AS protocol stack for the control plane for SCCH for RRC in the PC5 interface consists of RRC, PDCP, RLC and MAC sublayers, and the physical layer. The protocol stack of control plane for SCCH for RRC is shown in Figure 16.9.2.1-1.

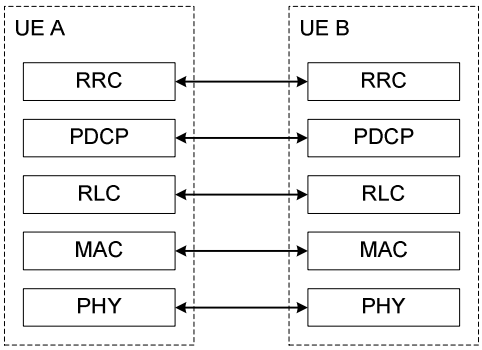


Figure 16.9.2.1-1: Control plane protocol stack for SCCH for RRC.

For support of PC5-S protocol specified in TS 23.287 [40], PC5-S is located on top of PDCP, RLC and MAC sublayers, and the physical layer in the control plane protocol stack for SCCH for PC5-S, as shown in Figure 16.9.2.1-2.

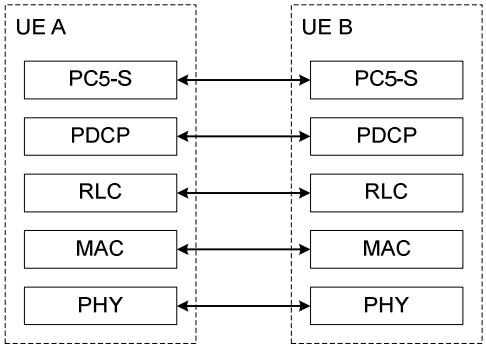


Figure 16.9.2.1-2: Control plane protocol stack for SCCH for PC5-S.

The AS protocol stack for SBCCH in the PC5 interface consists of RRC, RLC, MAC sublayers, and the physical layer as shown below in Figure 16.9.2.1-3.

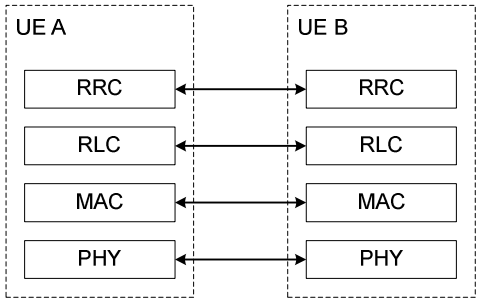


Figure 16.9.2.1-3: Control plane protocol stack for SBCCH.

The AS protocol stack for user plane in the PC5 interface consists of SDAP, PDCP, RLC and MAC sublayers, and the physical layer. The protocol stack of user plane is shown in Figure 16.9.2.1-4.

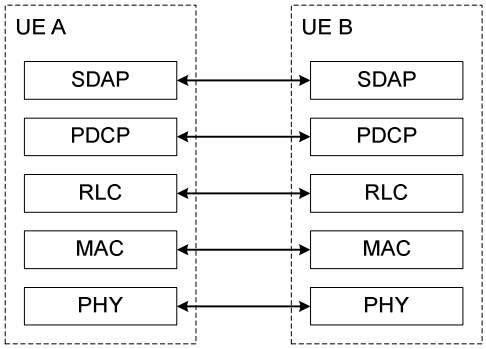


Figure 16.9.2.1-4: User plane protocol stack for STCH.

Sidelink Radio bearers (SLRB) are categorized into two groups: sidelink data radio bearers (SL DRB) for user plane data and sidelink signalling radio bearers (SL SRB) for control plane data. Separate SL SRBs using different SCCHs are configured for PC5-RRC and PC5-S signalling respectively.

16.9.2.2 MAC

The MAC sublayer provides the following services and functions over the PC5 interface in addition to the services and functions specified in clause 6.2.1:

- Radio resource selection;
- Packet filtering;
- Priority handling between uplink and sidelink transmissions for a given UE;

- Sidelink CSI reporting.

With LCP restrictions in MAC, only sidelink logical channels belonging to the same destination can be multiplexed into a MAC PDU for every unicast, groupcast and broadcast transmission which is associated to the destination. NG-RAN can also control whether a sidelink logical channel can utilise the resources allocated to a configured sidelink grant Type 1 (see clause 16.9.3.2). For transmissions to RX UE(s) using SL DRX operation, LCP ensures that a TX UE transmits data in the active time of the RX UE(s).

For packet filtering, a SL-SCH MAC header including portions of both Source Layer-2 ID and a Destination Layer-2 ID is added to each MAC PDU as specified in clause 8.4. LCID included within a MAC subheader uniquely identifies a logical channel within the scope of the Source Layer-2 ID and Destination Layer-2 ID combination.

The following logical channels are used in sidelink:

- Sidelink Control Channel (SCCH): a sidelink channel for transmitting control information (i.e. PC5-RRC and PC5-S messages) and NR sidelink discovery messages from one UE to other UE(s);
- Sidelink Traffic Channel (STCH): a sidelink channel for transmitting user information from one UE to other UE(s);
- Sidelink Broadcast Control Channel (SBCCH): a sidelink channel for broadcasting sidelink system information from one UE to other UE(s).

The following connections between logical channels and transport channels exist:

- SCCH can be mapped to SL-SCH;
- STCH can be mapped to SL-SCH;
- SBCCH can be mapped to SL-BCH.

16.9.2.3 RLC

The services and functions of the RLC sublayer as specified in clause 6.3.2 are supported for sidelink. TM is used for SBCCH. Both UM and AM are used in unicast transmission while only UM is used in groupcast or broadcast transmission. For UM, only unidirectional transmission is supported for groupcast and broadcast.

16.9.2.4 PDCP

The services and functions of the PDCP sublayer as specified in clause 6.4.1 are supported for sidelink with some restrictions:

- Out-of-order delivery is supported only for unicast transmission.

16.9.2.5 SDAP

The SDAP sublayer provides the following service and function over the PC5 interface:

- Mapping between a QoS flow and a sidelink data radio bearer.

There is one SDAP entity per destination for one of unicast, groupcast and broadcast which is associated to the destination. Reflective QoS is not supported over the PC5 interface.

16.9.2.6 RRC

The RRC sublayer provides the following services and functions over the PC5 interface:

- Transfer of a PC5-RRC message between peer UEs;
- Maintenance and release of a PC5-RRC connection between two UEs;
- Detection of sidelink radio link failure for a PC5-RRC connection;
- Measurement configuration and reporting related to sidelink.

A PC5-RRC connection is a logical connection between two UEs for a pair of Source and Destination Layer-2 IDs which is considered to be established after a corresponding PC5 unicast link is established as specified in TS 23.287 [40]. There is one-to-one correspondence between the PC5-RRC connection and the PC5 unicast link. A UE may have multiple PC5-RRC connections with one or more UEs for different pairs of Source and Destination Layer-2 IDs.

Separate PC5-RRC procedures and messages are used for a UE to transfer UE capability and sidelink configuration to the peer UE, as specified in TS 38.331 [12]. Both peer UEs can exchange their own UE capability and sidelink configuration using separate bi-directional procedures in both sidelink directions.

If it is not interested in sidelink transmission, if sidelink RLF on the PC5-RRC connection is declared, or if the Layer-2 link release procedure is completed as specified in TS 23.287 [40], UE releases the PC5-RRC connection.

16.9.3 Radio Resource Allocation

16.9.3.1 General

For NR sidelink communication, the UE can operate in two modes as specified in 5.7.2 for resource allocation in sidelink:

- Scheduled resource allocation, characterized by:
  - The UE needs to be RRC_CONNECTED in order to transmit data;
  - NG-RAN schedules transmission resources.
- UE autonomous resource selection, characterized by:
  - The UE can transmit data when inside NG-RAN coverage, irrespective of which RRC state the UE is in, and when outside NG-RAN coverage;
  - The UE autonomously selects transmission resources from resource pool(s).

For NR sidelink communication, the UE performs sidelink transmissions only on a single carrier.

16.9.3.2 Scheduled Resource Allocation

NG-RAN can dynamically allocate resources to the UE via the SL-RNTI on PDCCH(s) for NR sidelink communication.

In addition, NG-RAN can allocate sidelink resources to a UE with two types of configured sidelink grants:

- With type 1, RRC directly provides the configured sidelink grant only for NR sidelink communication;
- With type 2, RRC defines the periodicity of the configured sidelink grant while PDCCH can either signal and activate the configured sidelink grant, or deactivate it. The PDCCH is addressed to SL-CS-RNTI for NR sidelink communication.

Besides, NG-RAN can also semi-persistently allocate sidelink resources to the UE via the SL Semi-Persistent Scheduling V-RNTI on PDCCH(s) for V2X sidelink communication.

For the UE performing NR sidelink communication, there can be more than one configured sidelink grant activated at a time on the carrier configured for sidelink transmission.

When beam failure or physical layer problem occurs on MCG, the UE can continue using the configured sidelink grant Type 1 until initiation of the RRC connection re-establishment procedure as specified in TS 38.331 [12]. During handover, the UE can be provided with configured sidelink grants via handover command, regardless of the type. If provided, the UE activates the configured sidelink grant Type 1 upon reception of the handover command or execution of CHO.

The UE can send sidelink buffer status report to support scheduler operation in NG-RAN. For NR sidelink communication, the sidelink buffer status reports refer to the data that is buffered in for a group of logical channels (LCG) per destination in the UE. Eight LCGs are used for reporting of the sidelink buffer status reports. Two formats, which are SL BSR and truncated SL BSR, are used.

16.9.3.3 UE Autonomous Resource Selection

The UE autonomously selects sidelink resource(s) from resource pool(s) provided by broadcast system information or dedicated signalling while inside NG-RAN coverage or by pre-configuration while outside NG-RAN coverage.

For NR sidelink communication, the resource pool(s) can be provided for a given validity area where the UE does not need to acquire a new pool of resources while moving within the validity area, at least when this pool is provided by SIB. The NR SIB area scope mechanism as specified in TS 38.331 [12] is reused to enable validity area for SL resource pool configured via broadcasted system information.

The UE is allowed to temporarily use UE autonomous resource selection with random selection for sidelink transmission based on configuration of the exceptional transmission resource pool as specified in TS 38.331 [12].

16.9.3.4 LTE and NR Sidelink co-channel coexistence

NR sidelink supports co-channel coexistence with LTE sidelink, allowing NR sidelink transmissions to share co-channel resources with LTE sidelink transmissions. Dynamic co-channel coexistence is used, in which a resource pool for NR sidelink transmissions is overlapping with a resource pool for LTE sidelink transmissions. Sidelink relay is not supported in a resource pool that uses dynamic co-channel coexistence. Dynamic co-channel coexistence is further specified in TS 38.321 [6], TS 38.213 [38] and TS 38.214 [56].

16.9.4 Uu Control

16.9.4.1 General

When a UE is inside NG-RAN coverage, NR sidelink communication and/or V2X sidelink communication can be configured and controlled by NG-RAN via dedicated signalling or system information:

- The UE should support and be authorized to perform NR sidelink communication and/or V2X sidelink communication in NG-RAN;
- If configured, the UE performs V2X sidelink communication as specified in TS 36.300 [2] unless otherwise specified, with the restriction that the dynamic scheduling for V2X sidelink communication (i.e. based on SL-V-RNTI) is not supported;
- NG-RAN can provide the UE with intra-carrier sidelink configuration, inter-carrier sidelink configuration and anchor carrier(s) which provide sidelink configuration via a Uu carrier for NR sidelink communication and/or V2X sidelink communication;
- When the UE cannot simultaneously perform both NR sidelink transmission and NR uplink transmission in time domain, prioritization between both transmissions is done based on their priorities and thresholds configured by the NG-RAN or pre-configured. When the UE cannot simultaneously perform both V2X sidelink transmission and NR uplink transmission in time domain, prioritization between both transmissions is done based on the priorities (i.e. PPPP) of V2X sidelink communication and a threshold configured by the NG-RAN or pre-configured.

When a UE is outside NG-RAN coverage, SL DRB configuration(s) are preconfigured to the UE for NR sidelink communication. If UE changes the RRC state but has not received the SL DRB configuration(s) for the new RRC state, UE continues using the configuration obtained in the previous RRC state to perform sidelink data transmissions and receptions until the configuration for the new RRC state is received.

16.9.4.2 Control of connected UEs

The UE in RRC_CONNECTED performs NR sidelink communication and/or V2X sidelink communication, as configured by the upper layers. The UE sends Sidelink UE Information to NG-RAN in order to request or release sidelink resources and report QoS information for each destination.

NG-RAN provides *RRCReconfiguration* to the UE in order to provide the UE with dedicated sidelink configuration. The *RRCReconfiguration* may include SL DRB configuration(s) for NR sidelink communication as well as mode 1 resource configuration and/or mode 2 resource configuration. If UE has received SL DRB configuration via system information, UE should continue using the configuration to perform sidelink data transmissions and receptions until a new configuration is received via the *RRCReconfiguration*.

NG-RAN may also configure measurement and reporting of CBR for NR sidelink communication and V2X sidelink communication, and reporting of location information for V2X sidelink communication to the UE via *RRCReconfiguration*.

During handover, the UE performs sidelink transmission and reception based on configuration of the exceptional transmission resource pool or configured sidelink grant Type 1 and reception resource pool of the target cell as provided in the handover command.

16.9.4.3 Control of idle/inactive UEs

The UE in RRC_IDLE or RRC_INACTIVE performs NR sidelink communication and/or V2X sidelink communication, as configured by the upper layers. NG-RAN may provide common sidelink configuration to the UE in RRC_IDLE or RRC_INACTIVE via system information for NR sidelink communication and/or V2X sidelink communication. UE receives resource pool configuration and SL DRB configuration via *SIB12* for NR sidelink communication as specified in TS 38.331 [12], and/or resource pool configuration via *SIB13* and *SIB14* for V2X sidelink communication as specified in TS 38.331 [12].

When the UE performs cell reselection, the UE interested in V2X service(s) considers at least whether NR sidelink communication and/or V2X sidelink communication are supported by the cell. The UE may consider the following carrier frequency as the highest priority frequency, except for the carrier only providing the anchor carrier:

- the frequency providing both NR sidelink communication configuration and V2X sidelink communication configuration, if configured to perform both NR sidelink communication and V2X sidelink communication;
- the frequency providing NR sidelink communication configuration, if configured to perform only NR sidelink communication.
- the frequency providing V2X sidelink communication configuration, if configured to perform only V2X sidelink communication.

When the UE performs cell reselection, the UE interested in ProSe service(s) considers at least whether NR sidelink communication/discovery is supported by the cell. The UE may consider the carrier frequency providing NR sidelink communication/discovery configuration as the highest priority frequency, except for the carrier only providing the anchor carrier.

16.9.5 Sidelink Discovery

The UE may perform NR sidelink discovery while in-coverage or out-of-coverage for non-relay operation.

The Relay discovery mechanism described in clause 16.12.3 (except the U2N Relay specific threshold based discovery message transmission and U2N Relay specific resource allocation mode restriction) is also applied to sidelink discovery.

16.9.6 SL DRX

16.9.6.1 General

Sidelink supports SL DRX for unicast, groupcast, and broadcast. Similar parameters as defined in clause 11 for Uu (on-duration, inactivity-timer, retransmission-timer, cycle) are defined for SL to determine the SL active time for SL DRX. During the SL active time, the UE performs SCI monitoring for data reception (i.e., PSCCH and 2nd stage SCI on PSSCH). The UE may skip monitoring of SCI for data reception during SL DRX inactive time.

The actual parameters supported for each cast type (unicast, groupcast, broadcast) are specified in the following clauses.

The SL active time of the RX UE includes the time in which any of its applicable SL on-duration timer(s), SL inactivity-timer(s) or SL HARQ retransmission timer(s) (for any of unicast, groupcast, or broadcast) are running. In addition, the slots associated with announced periodic transmissions by the TX UE and the time in which a UE is expecting CSI report following a CSI request (for unicast) are considered as SL active time of the RX UE. The time for the unicast link establishment procedure and the time for the PC5 RRC reconfiguration with initial SL DRX configuration procedure as specified in clause 5.28.2 of TS 38.321 [6] are considered as SL active time of the RX UE.

The TX UE maintains a set of timers corresponding to the SL DRX timers in the RX UE(s) for each pair of source/destination L2 ID for unicast or destination L2 ID for groupcast/broadcast. When data is available for transmission to one or more RX UE(s) configured with SL DRX, the TX UE selects resources taking into account the active time of the RX UE(s).

The UE can determine from SIB12 whether the gNB supports SL DRX or not.

16.9.6.2 Unicast

For unicast, SL DRX is configured per pair of source L2 ID and destination L2 ID.

The UE maintains a set of SL DRX timers for each direction per pair of source L2 ID and destination L2 ID. The SL DRX configuration for a pair of source/destination L2 IDs for a direction may be negotiated between the UEs in the AS layer. For SL DRX configuration of each direction, where one UE is the TX UE and the other is the RX UE:

- RX UE may send assistance information, which includes its desired SL on-duration timer, SL DRX start offset, SL DRX slot offset, and SL DRX cycle, to the TX UE and the TX UE using mode 2 resource allocation may use it to determine the SL DRX configuration for the RX UE;
- Regardless of whether assistance information is provided or not, the TX UE in RRC_IDLE/RRC_INACTIVE/OOC, or in RRC_CONNECTED and using mode 2 resource allocation, determines the SL DRX Configuration for the RX UE. For a TX UE in RRC_CONNECTED and using mode 1 resource allocation, the SL DRX configuration for the RX UE is determined by the serving gNB of the TX UE;
- TX UE sends the SL DRX configuration to be used by the RX UE to the RX UE;
- The RX UE may accept or reject the SL DRX configuration.

When the TX UE is in RRC_CONNECTED and using mode 1 resource allocation, the TX UE may report the received assistance information or the received SL DRX configuration reject information to its serving gNB supporting SL DRX and sends the SL DRX configuration to the RX UE upon receiving the SL DRX configuration in dedicated RRC signalling from the gNB. When the RX UE is in RRC_CONNECTED and using mode 1 resource allocation, the RX UE can report the received SL DRX configuration to its serving gNB supporting SL DRX, e.g. for alignment of the Uu and SL DRX configurations.

SL on-duration timer, SL inactivity-timer, SL HARQ RTT timer, and SL HARQ retransmission timer are supported in unicast. SL HARQ RTT timer and SL HARQ retransmission timer are maintained per SL process at the RX UE. In addition to (pre)configured values for each of these timers, SL HARQ RTT timer value can be derived from the retransmission resource timing when SCI indicates more than one transmission resource. SL HARQ RTT timer can be set to different values to support both HARQ enabled and HARQ disabled transmissions.

SL DRX MAC CE is introduced for SL DRX operation in unicast only.

16.9.6.3 Groupcast/Broadcast

For groupcast/broadcast, SL DRX is configured commonly among multiple UEs based on QoS profile and Destination L2 ID. Multiple SL DRX configurations can be supported for each of groupcast/broadcast.

SL on-duration timer, SL inactivity-timer, SL HARQ RTT and SL HARQ retransmission timers are supported for groupcast. Only SL on-duration timer is supported for broadcast. SL DRX cycle, SL on-duration, and SL inactivity timer (only for groupcast) are configured per QoS profile. The starting offset and slot offset of the SL DRX cycle is determined based on the destination L2 ID. The SL HARQ RTT timer (only for groupcast) and SL HARQ retransmission timer (only for groupcast) are not configured per QoS profile or per destination L2 ID. For groupcast, the RX UE maintains a SL inactivity timer for each destination L2 ID, and selects the largest SL inactivity timer value if multiple SL inactivity timer values associated with different QoS profiles are configured for that L2 ID. For groupcast and broadcast, the RX UE maintains a single SL DRX cycle (selected as the smallest SL DRX cycle of any QoS profile of that L2 ID) and single SL on-duration (selected as the largest SL on-duration of any QoS profile of that L2 ID) for each destination L2 ID when multiple QoS profiles are configured for that L2 ID.

For groupcast, SL HARQ RTT timer and SL HARQ retransmission timer are maintained per SL process at the RX UE. SL HARQ RTT timer can be set to different values to support both HARQ enabled and HARQ disabled transmissions.

A default SL DRX configuration, common between groupcast and broadcast, can be used for a QoS profile which is not mapped onto any non-default SL DRX configuration(s). The default SL DRX configuration for groupcast and broadcast

can also be used for discovery message in sidelink discovery in clause 16.9.5 and relay discovery messages in clause 16.12.3, for ProSe Direct Link Establishment Request message as specified in TS 24.554 [55], and for Direct Link Establishment Request message as specified in TS 24.587 [53].

In-coverage TX and RX UEs in RRC_IDLE/RRC_INACTIVE obtain their SL DRX configuration from SIB. UEs (TX or RX) in RRC_CONNECTED can obtain the SL DRX configuration from SIB, or from dedicated RRC signalling during handover. For the out of coverage case, the SL DRX configuration is obtained from pre-configuration.

For groupcast, the TX UE restarts its timer corresponding to the SL inactivity timer for the destination L2 ID (used for determining the allowable transmission time) upon reception of new data with the same destination L2 ID.

TX profile is introduced to ensure compatibility for groupcast and broadcast communication between UEs supporting/not-supporting SL DRX functionality. A TX profile is provided by upper layers to AS layer and identifies one or more sidelink feature group(s). Multiple TX profiles with the support of SL DRX and without the support of SL DRX can be associated to a destination L2 ID. For a given destination L2 ID, all TX and RX UEs should be configured with the same set of TX profile(s). A UE only assumes SL DRX for the given destination L2 ID when all the associated TX profiles correspond to support of SL DRX. A UE assumes no SL DRX for the given destination L2 ID if there is no associated TX profile. An RX UE determines that SL DRX is used if all destination L2 IDs of interest are assumed to support SL DRX. For groupcast, when the UE is in RRC_CONNECTED and using mode 1 resource allocation, the UE reports each destination L2 ID and associated SL DRX on/off indication to the gNB supporting SL DRX.

16.9.6.4 Alignment between Uu DRX and SL DRX

Alignment of Uu DRX and SL DRX for a UE in RRC_CONNECTED is supported for unicast, groupcast, and broadcast. Alignment of Uu DRX and SL DRX at the same UE is supported. In addition, for mode 1 resource allocation, the alignment of Uu DRX of the TX UE and SL DRX of the RX UE is supported.

Alignment may comprise of either full overlap or partial overlap in time between Uu DRX and SL DRX. For SL RX UEs in RRC_CONNECTED, alignment is achieved by the gNB.

16.9.7 Power Savings Resource Allocation

The SL UE in Mode 2 can support partial sensing-based resource allocation and random resource selection as power saving resource allocation methods. A SL mode 2 TX resource pool can be (pre)configured to allow full sensing only, partial sensing only, random selection only, or any combination(s) thereof. A UE decides which resource allocation scheme(s) can be used in the AS based on its capability (for a UE in RRC_IDLE/RRC_INACTIVE/OOC) and the allowed resource schemes in the resource pool configuration.

Random resource selection is applicable to both periodic and aperiodic traffic.

A UE capable for partial sensing can perform periodic-based partial sensing and/or contiguous partial sensing for resource (re)selection. Periodic-based partial sensing can only be performed if periodic resource reservation is configured in the resource pool. In periodic-based partial sensing, the UE monitors slots in periodic sensing occasion(s) for a given resource reservation periodicity. Contiguous partial sensing is performed by a UE capable of partial sensing when resource (re)selection is triggered by a UE in a TX pool configured with partial sensing. In contiguous partial sensing, the UE monitors slots in a contiguous sensing window which occur prior to the selected transmission resource.

16.9.8 Inter-UE Coordination (IUC)

The SL UE can support inter-UE coordination (IUC) in Mode 2, whereby a UE sends information about resources to a peer UE, which the peer UE then uses for resource (re)selection. The following schemes of inter-UE coordination are supported:

- IUC scheme 1, where the IUC information sent from a UE to a peer UE is the preferred or non-preferred resources for the peer UE's transmission, and

- IUC scheme 2, where the IUC information sent from a UE to a peer UE is the presence of expected/potential resource conflict on the resources indicated by the peer UE's SCI.

In scheme 1, the transmission of IUC information from a UE can be triggered by a condition at this UE, or by an explicit request from a peer UE. The UE determines the set of resources reserved by other UEs or slots where the UE, when it is the intended receiver of the peer UE, does not expect to perform SL reception from the peer UE due to half-

duplex operation. The UE uses these resources as the set of non-preferred resources, or excludes these resources to determine a set of preferred resources and sends the preferred/non-preferred resources to the peer UE. Regarding the IUC information received from the UE, the peer UE's resources for resource (re)selection can be based on both the peer UE's sensing results (if available) and the IUC information, or it can be based only on the IUC information. For scheme 1, MAC CE and second-stage SCI or MAC CE only can be used to send IUC information. For IUC information transmission triggered by an explicit request, both the explicit request and the IUC information are transmitted in unicast manner. For IUC information transmission triggered by a condition other than the explicit request, the IUC information indicating preferred resource set is transmitted in unicast manner, and the IUC information indicating non-preferred resource set is transmitted in unicast, groupcast or broadcast manner.

In scheme 2, a UE determines the expected/potential resource conflict within the resources indicated by a peer UE's SCI as either resources reserved by other UEs and identified by the UE as fully/partially overlapping with the resources indicated by the peer UE's SCI, or as slots where the UE is the intended receiver of the peer UE and does not expect to perform SL reception on those slots due to half-duplex operation. The peer UE uses the conflicting resources to determine the resources to be reselected and exclude the conflicting resources from the reselected resources. For scheme 2, PSFCH is used to send IUC information.

16.9.9 Sidelink in Shared Spectrum (SL-U)

16.9.9.1 Overview

Sidelink supports operation in shared spectrum for both mode 1 and mode 2 for ProSe use case only. Sidelink positioning in shared spectrum is not supported. Type1 and Type2 (2A/2B/2C) channel access procedures specified in TS 37.213 [37] are used for NR sidelink operation in a shared channel.

16.9.9.2 Channel Access Priority Classes for Sidelink (SL-CAPC)

The SL-CAPC of SL radio bearers and SL MAC CEs are either fixed or (pre)configurable as follows:

- Fixed to the highest priority for all SL-SRBs and SL MAC CEs
- (Pre)configurable per DRB for all SL-DRBs

When choosing the SL-CAPC for a SL-DRB the network takes into account the PQIs of all QoS flows mapped to that SL DRB. Table 16.9.9-1 below shows which SL-CAPC should be used for which standardized PQI(s), i.e., which SL-CAPC to use for a given QoS flow. For a UE in RRC_IDLE/RRC_INACTIVE or OOC, the UE uses the SL-CAPC configured in SIB/Pre-configuration when the QoS flow can be mapped to a non-default SLRB, or when the default SLRB is used for the QoS flow and the SL-CAPC of the default SLRB is configured.

When the default SLRB is used for the QoS flow and the SL-CAPC of the default SLRB is not configured:

- if the QoS flow is associated with standardized PQI, the UE derives SL-CAPC for the flow directly from the table below
- if the QoS flow is associated with non-standardized PQI, the UE may select the SL-CAPC of the standardized PQI having the closest PDB.

The UE then selects the lowest SL-CAPC priority level (highest SL-CAPC value) among the QoS flows to determine the SL-CAPC for the default SLRB.

Table 16.9.9-1: Mapping between Channel Access Priority Classes for SL-U and PQI

SL-CAPC	PQI
1	21, 22, 23, 24, 26, 33, 55, 56, 57, 58, 60, 71, 90, 91, 92, 93
2	25, 70
3	32, 34, 59, 61
4	-
NOTE: lower SL-CAPC value means higher priority	

When performing Type 1 LBT for the transmission of a sidelink TB, the SL UE shall select the SL-CAPC as follows:

- If only SL MAC CE(s) are included in the SL TB, the highest priority SL-CAPC is used; or
- If SCCH SDU(s) are included in the SL TB, the highest priority SL-CAPC is used; or
- The lowest priority SL-CAPC of the SL logical channel(s) with MAC SDU(s) multiplexed in the TB is used otherwise.

The highest priority SL-CAPC is used for SBCCH SDU transmissions and PSFCH transmissions.

16.9.9.3 Sidelink Specific Consistent LBT Failure

SL-specific consistent LBT failure detection and recovery procedure is supported for SL-U. When the UE detects SL-specific consistent LBT failure, it performs the actions as specified in TS 38.321 [6]. SL-specific consistent LBT failure detection is per RB-set.

A SL UE in RRC_CONNECTED can indicate SL-specific consistent LBT failure to the gNB using a SL MAC CE that indicates the RB set(s) where SL-specific consistent LBT failure was detected. A SL UE using mode 2 resource allocation triggers resource reselection and/or resource pool reselection upon SL-specific consistent LBT failure. In such case, resources in failed RB set(s) are excluded from resource (re)selection until consistent LBT failure on the RB set(s) is cancelled based on conditions in TS 38.321 [6]. The UE triggers SL RLF for all PC5-RRC connections when the UE has triggered SL-specific consistent LBT failure in all RB sets.

16.9.9.4 COT Sharing

UE to UE COT sharing is supported in NR sidelink operation for SL-U. When performing SL-SSB transmission(s), a responding UE can utilize a COT shared by a COT initiating UE when the responding UE intends to transmit SL-SSB in the shared COT. When performing PSFCH transmissions, a responding UE can utilize a COT shared by a COT initiating UE when at least one of the responding UE's PSFCH transmissions is intended for the COT initiating UE.

When performing PSSCH/PSCCH transmissions, a responding UE can utilize a COT shared by a COT initiating UE when the responding UE's transmission(s) is intended for the COT initiating UE. In unicast, the destination/source ID of the responding UE's transmission should match the source/destination ID of the initiator UE's transmission for the same unicast link. In groupcast/broadcast, destination ID of the responding UE's transmission should match the initiator's destination ID. In addition, a COT initiating UE may transmit an additional pair of source/destination ID in either unicast, groupcast, or broadcast. In this case, the responding UE can utilize a COT shared by a COT initiating UE if the destination/source (for unicast) or destination (for groupcast/broadcast) of the responding UE transmission match what is carried in the additional ID(s). In all cases, a UE's transmissions in a shared COT should have SL-CAPC value that is equal to or smaller than the SL-CAPC value indicated in the COT sharing information. In order to satisfy the COT sharing requirements, a responding UE may perform an enhanced LCP procedure as specified in 38.321 [6]. When receiving multiple COT sharing indications from different COT initiators, it is up to UE implementation which shared COT is used.

16.9.9.5 Resource Allocation

A UE using mode 2 resource allocation may support resource selection enhancements to avoid LBT blocking and increase COT resource utilization. If transmission in slot(s) before a reserved resource is able to share its initiated COT to the reservation, the UE may be (pre)configured to prioritize/select resource(s) in the slot(s) for transmission. To avoid blocking, a UE may avoid selection of a number of consecutive resources (up to UE implementation) before a reserved resource. Furthermore, a UE may avoid selection of a number of consecutive resources (up to UE implementation) after a reserved resource.

A UE using mode 2 resource allocation operating in a resource pool of resources without PSFCH configured can support resource selection for multiple consecutive slot transmission (MCSt). Mode 2 resource allocation operating in a resource pool of resources with PSFCH configured can be used for Multi-TB MCSt with single slot candidate resources. A UE autonomously determines whether to use MCSt, and the number of consecutive slots in an MCSt up to the maximum COT duration for a specific SL-CAPC as defined in TS 37.213 [37]. MCSt can be used for transmission of a single TB or multiple TBs. For each TB transmitted in an MCSt, the UE triggers resource (re)selection only when LBT failure is detected on the resources for the initial transmission and all retransmissions of the TB.

16.9.10 Sidelink CA

Carrier aggregation (CA) in sidelink is supported for mode 2 and in V2X case only. It applies to both in coverage UEs and out of coverage UEs. Each resource pool (pre)configured for sidelink is associated to a single carrier. A UE using mode 2 resource allocation performs carrier (re)selection and may select one or more carriers used for sidelink.

The carrier(s) that can be used for transmitting data are provided by the V2X layer per QoS flow, and LCP ensures that data from a SLRB is transmitted on a carrier for which all mapped QoS flows are allowed to use the carrier.

For groupcast and broadcast, when the V2X layer provides multiple carriers in QoS flow to carrier mapping information to the AS, TX profile is used to indicate whether the transmission corresponding to the QoS flow is backward compatible or not. When backward compatibility is needed, the TX UE uses only the legacy carrier without PDCP duplication, or uses PDCP duplication with at least the legacy carrier. A UE assumes backward compatibility is needed for the QoS flow if there is no associated TX profile.

For groupcast and broadcast, carrier selection is performed at MAC layer, depending on the CBR of the configured carriers and logical channel priority. In order to avoid frequent switching across different carriers, the UE may keep using a carrier already selected for transmission, if the measured CBR on this carrier is lower than a (pre)configured threshold. For a UE using mode 2 resource allocation, logical channel prioritization is performed for a sidelink resource on a carrier depending on the CBR measured on the carrier and the logical channel priority, as specified in TS 38.321 [6]. For unicast, SL CA related capability is exchanged between the TX UE and RX UE, and the TX UE delivers the carrier configuration to the RX UE in PC5-RRC. For unicast, carrier selection and logical channel prioritization is performed similar to groupcast and broadcast among the carriers configured in the carrier configuration. SL CA for unicast is not applied until the carrier configuration signalling is complete. When the TX UE detects carrier failure on a specific carrier, carrier (re)selection is performed by excluding the failed carrier, as specified in TS 38.321 [6] and a new carrier configuration is sent to the RX UE as specified in TS 38.331 [12].

Sidelink packet duplication is supported for sidelink CA and is performed at PDCP layer. For sidelink packet duplication for transmission, a PDCP PDU is duplicated at the PDCP entity. The duplicated PDCP PDUs of the same PDCP entity are submitted to two different RLC entities and associated to two different sidelink logical channels respectively. The duplicated PDCP PDUs of the same PDCP entity are only allowed to be transmitted on different sidelink carriers. For a SL DRB, sidelink packet duplication is either (pre)configured in the bearer configuration if the TX profile indicates backward compatibility is not needed, or is decided by the TX UE if the TX profile indicates backward compatibility is needed. For applicable SL SRBs, whether to use duplication is decided by the TX UE. In unicast, the TX UE sends the duplication configuration to the RX UE in PC5-RRC.

There are specified logical channel identities which apply to the sidelink logical channel used for sidelink packet duplication exclusively as specified in TS 38.321 [6].

16.10 Multicast and Broadcast Services

16.10.1 General

NR system enables resource efficient delivery of multicast/broadcast services (MBS).

For broadcast communication service, the same service and the same specific content data are provided simultaneously to all UEs in a geographical area (i.e., all UEs in the broadcast service area as defined in TS 23.247 [45] are authorized to receive the data). A broadcast communication service is delivered to the UEs using a broadcast session. A UE can receive a broadcast communication service in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED state.

For multicast communication service, the same service and the same specific content data are provided simultaneously to a dedicated set of UEs (i.e., not all UEs in the MBS service area as defined in TS 23.247 [45] are authorized to receive the data). A multicast communication service is delivered to the UEs using a multicast session. A UE can receive a multicast communication service in RRC_CONNECTED state with mechanisms such as PTP and/or PTM delivery and/or in RRC_INACTIVE state with PTM delivery, as defined in clause 16.10.5.4. HARQ feedback/retransmission can be applied to both PTP and PTM transmission in RRC_CONNECTED state.

16.10.2 Network Architecture

The overall NG-RAN architecture specified in clause 4 applies for NR MBS. MBS multicast can only be supported in MCG side in NE-DC and NR-DC scenarios, i.e., only for MN-terminated MCG MRB. The configuration of MBS broadcast on SCG is not supported for the UE.

The QoS model for NR MBS can be found in TS 23.247 [45].

16.10.3 Protocol Architecture

Figures 16.10.3-1 and 16.10.3-2 depict the downlink Layer 2 architecture for multicast session and broadcast session respectively, where MBS protocol stack comprises the same layer 2 sublayers as described in clause 6 with the following differences:

- SDAP sublayer provides only the following functionalities:
  - Mapping between an MBS QoS flow and an MRB;
  - Transfer of user plane data.
- PDCP sublayer provides only the following functionalities:
  - Transfer of user plane data;
  - Maintenance of PDCP SNs;
  - Header compression and decompression using the ROHC protocol or EHC protocol;
  - Reordering and in-order delivery;
  - Duplicate discarding.
- For a multicast session, gNB provides one or more of the following multicast MRB configuration(s) to the UE in RRC_CONNECTED state via dedicated RRC signalling:
  - Multicast MRB with DL only RLC-UM or bidirectional RLC-UM configuration for PTP transmission;
  - Multicast MRB with RLC-AM entity configuration for PTP transmission;
  - Multicast MRB with DL only RLC-UM entity for PTM transmission;
  - Multicast MRB with two RLC-UM entities, one DL only RLC-UM entity for PTP transmission and the other DL only RLC-UM entity for PTM transmission;
  - Multicast MRB with three RLC-UM entities, one DL RLC-UM entity and one UL RLC-UM entity for PTP transmission and the other DL only RLC-UM entity for PTM transmission;
  - Multicast MRB with two RLC entities, one RLC-AM entity for PTP transmission and the other DL only RLC-UM entity for PTM transmission.
- For a multicast session, gNB may change the MRB type for the UE in RRC_CONNECTED state using RRC signalling.
- For a multicast session, gNB provides the following multicast MRB configuration to the UE in RRC_INACTIVE state via broadcast RRC signalling and/or dedicated RRC signalling:
  - Multicast MRB with DL only RLC-UM entity for PTM transmission.

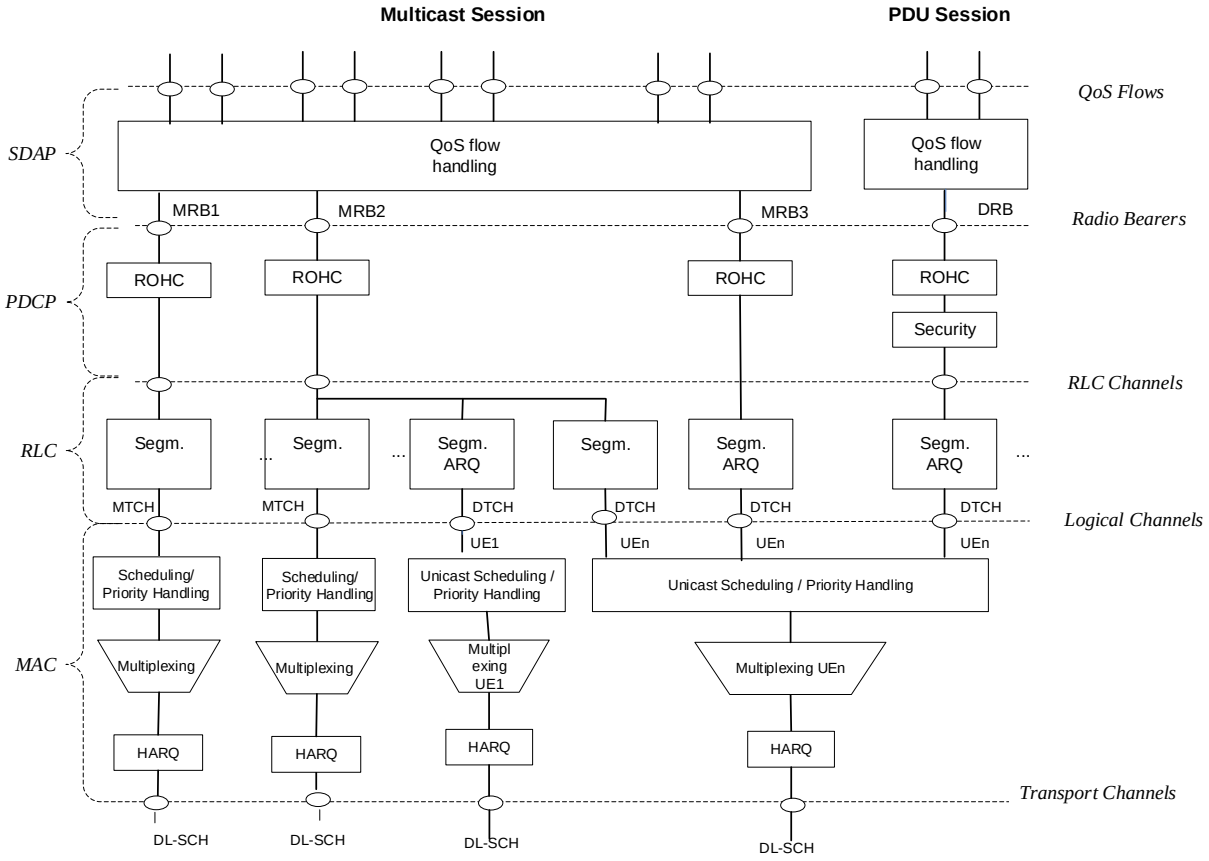


Figure 16.10.3-1: Downlink Layer 2 Architecture for Multicast Session

- For broadcast session, gNB provides the following broadcast MRB configuration to the UE using broadcast RRC signalling:
  - Broadcast MRB with one DL only RLC-UM entity for PTM transmission.

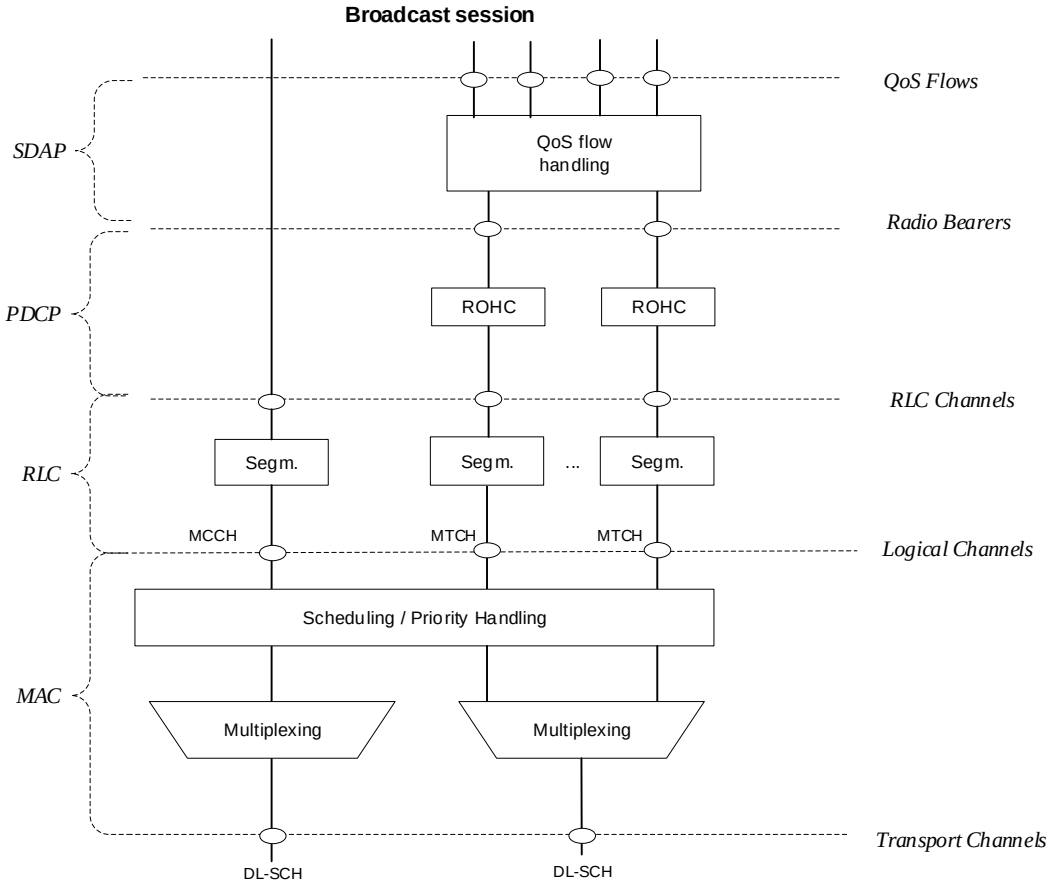


Figure 16.10.3-2: Downlink Layer 2 Architecture for Broadcast Session

16.10.4 Group Scheduling

The following logical channels are used for MBS delivery:

- MTCH: A PTM downlink channel for transmitting MBS data of either multicast session or broadcast session from the network to the UE;
- DTCH: A PTP channel defined in clause 6.2.2 for transmitting MBS data of a multicast session from the network to the UE;
- MCCH: A PTM downlink channel used for transmitting MBS broadcast or MBS multicast control information associated to one or several MTCH(s) from the network to the UE. Broadcast MCCH and multicast MCCH are independent channels. The multicast MCCH is used only for multicast reception in RRC_INACTIVE state.

The following connections between logical channels and transport channels for PTM transmission exist:

- MCCH can be mapped to DL-SCH;
- MTCH can be mapped to DL-SCH.

The following depicts the usage of RNTI for PTM transmission:

- A UE can receive different services using same or different G-RNTIs;
- A UE can receive different services using same or different G-CS-RNTIs.

16.10.5 Multicast Handling

16.10.5.1 Session Management

There are two delivery modes as specified in TS 23.247 [45]:

- 5GC Shared MBS traffic delivery;
- 5GC Individual MBS traffic delivery.

As specified in TS 23.247 [45], if the gNB supports MBS, the network shall use the 5GC Shared MBS traffic delivery in which case an MBS Session Resource context for a multicast session is setup in the gNB when the first UE joins the multicast session.

For 5GC Shared MBS traffic delivery mode, shared NG-U resources are used to provide MBS user data to the gNB. The gNB initiates the Multicast Distribution Setup procedure towards the 5GC, to allocate shared NG-U resources for a multicast session. In case multiple MBS session areas as specified in TS 23.247 [45] are associated with the same multicast session for location dependent MBS services, multiple NG-U shared resources are established for the same multicast session per MBS Area Session ID served by the gNB. If the 5GC detects shared NG-U path failure, it may notify the gNB and the gNB may allocate new shared NG-U resources to replace old ones as specified in TS 23.527 [69].

A shared NG-U resource applies one of the following transport options:

- unicast transport;
- multicast transport.

For 5GC Shared MBS traffic delivery an MBS Session Resource comprises one or several MRBs. If minimisation of data loss is applied for a given MRB, synchronisation of allocation of PDCP COUNT values is applied by either or a combination of the following methods:

- derivation of the PDCP COUNT values by means of a DL MBS QFI Sequence Number provided on NG-U. Synchronisation in terms of MBS QoS flow to MRB mapping and PDCP SN size of the corresponding MRB among gNBs are achieved by means of network implementation.
- deployment of a Shared NG-U Termination at NG-RAN, shared among gNBs, which comprises a common entity for assignment of PDCP COUNT values. Synchronisation in terms of MBS QoS flow to MRB mapping and PDCP SN size of the corresponding MRB among gNBs may be achieved by means of network implementation.

If PDCP COUNT values are derived from a DL MBS QFI Sequence Number provided on NG-U and only one QoS Flow is mapped to an MRB, the gNB shall set the PDCP COUNT value of PDCP PDU to the value of the DL MBS QFI Sequence Number provided with the received packet over NG-U. If PDCP COUNT values are derived from a DL MBS QFI Sequence Number provided on NG-U and multiple QoS Flows are mapped to an MRB, the gNB may derive the PDCP COUNT value of the PDCP PDU from the sum of the DL MBS QFI Sequence Numbers of the QoS Flows mapped to this MRB.

NOTE: Synchronisation of PDCP COUNT values in case user data for MBS QoS flows mapped to the same MRB arrive over NG-U at different gNBs in different order or in case of loss of data over NG-U, and related handling of minimisation of data loss is left to implementation.

As specified in TS 23.247 [45], the gNB may receive from the 5GC MBS Assistance Information associated with a multicast MBS session for a UE, which assists the gNB in configuring the UE properly. The MBS Assistance Information indicates that the UE is expected to require dedicated resources very frequently. Based on this information, the gNB may decide the RRC state of the UE. The QoS requirements of the multicast session apply regardless of the RRC state within which the UE receives multicast session data.

16.10.5.2 Configuration

A UE can be configured to receive data of MBS multicast session only in RRC_CONNECTED state or RRC_INACTIVE state. To receive the multicast service, the UE needs to perform MBS Session Join procedure as specified in TS 23.247 [45]. It is up to gNB to decide whether the UE receives data of MBS multicast session in

RRC_CONNECTED state or RRC_ INACTIVE state. The gNB moves the UE from RRC_CONNECTED state to RRC_INACTIVE state via *RRCRelease* message, and moves the UE from RRC_INACTIVE state to RRC_CONNECTED state via group notification or UE-specific paging.

If the UE which joined a multicast session is in RRC_CONNECTED state and when the multicast session is activated, the gNB may send *RRCReconfiguration* message with relevant MBS configuration for the multicast session to the UE.

If the gNB configures the UE to receive the MBS multicast session in RRC_INACTIVE state, the gNB may provide the PTM configuration via *RRCRelease* message for the MBS multicast session as well as information about which multicast service(s) can be continued to be received in RRC_INACTIVE state. The UE does not suspend MRBs of the multicast session indicated to be continued to be received in RRC_INACTIVE state. Multicast MCCH is used in case a cell supports updating PTM configuration or providing PTM configuration to UEs in RRC_INACTIVE state moved from other cells. Otherwise, multicast MCCH can be optionally present.

A notification mechanism is used to announce the change of the multicast MCCH contents due to multicast session modification or session deactivation or due to neighbouring cell information modification. The scheduling information for multicast MCCH reception is provided via *SIB24* and optionally via *RRCRelease* message.

When there is temporarily no data to be sent to the UEs for a multicast session that is active, the gNB may move the UE to RRC_INACTIVE state. When an MBS multicast session is deactivated, the gNB may move the UE in RRC_CONNECTED state to RRC_IDLE or RRC_INACTIVE state. For UEs receiving data of MBS multicast session in RRC_INACTIVE state, the gNB notifies the UE to stop monitoring PDCCH addressed by corresponding G-RNTI via *RRCRelease message* or multicast MCCH when there is temporarily no data to be sent or when the session is deactivated. gNBs supporting MBS use a group notification mechanism to notify the UEs in RRC_IDLE or RRC_INACTIVE state when a multicast session has been activated by the CN. gNBs supporting MBS use a group notification mechanism to notify the UEs in RRC_INACTIVE state when the session is already activated and the gNB has multicast session data to deliver. If the UE receiving data of MBS multicast session in RRC_INACTIVE state in a cell is notified to stop monitoring PDCCH addressed by G-RNTI for all the joined multicast sessions, the UE does not monitor PDCCH addressed by Multicast MCCH-RNTI until the group notification is received. Upon reception of the group notification that does not indicate multicast reception in RRC_INACTIVE state, the UEs reconnect to the network or resume the connection and transition to RRC_CONNECTED state from either RRC_IDLE state or RRC_INACTIVE state. Upon reception of the group notification that indicates to allow the multicast reception in RRC_INACTIVE state, the UE stays in RRC_INACTIVE state and behaves as specified in TS 38.331 [12]. If the UE is notified by both group notification and the UE-specific paging, the UE follows the UE-specific paging and goes to RRC_CONNECTED state.

The group notification is addressed with P-RNTI on PDCCH, and the paging channels are monitored by the UE as described in clause 9.2.5. Paging message for group notification contains MBS session ID which is utilized to page all UEs in RRC_IDLE and RRC_INACTIVE states that joined the associated MBS multicast session, i.e., UEs are not paged individually. The UE stops monitoring for group notifications related to a specific multicast session, i.e., stops checking for the MBS session ID in the Paging message, when the UE enters RRC_CONNECTED state. The UE does not monitor for group notifications for these cases, i.e., once this UE leaves this multicast session or the network requests the UE to leave, or the network releases the multicast session.

NOTE: The gNB's decision to keep a UE in RRC_CONNECTED state (e.g., to meet latency requirements for mission critical service) or move the UE to RRC_INACTIVE or RRC_IDLE state (e.g., when there is temporarily no data to be sent to the UE or to address congestion in the cell) may consider 5QI value(s) or other QoS parameters for mission critical and non-mission critical UEs.

If the UE in RRC_IDLE state that joined an MBS multicast session is camping on the gNB not supporting MBS, the UE may be notified by CN-initiated paging where CN pages each UE individually due to session activation or data availability, as described in clause 9.2.5. If the UE in RRC_INACTIVE state that joined MBS multicast session is camping on the gNB not supporting MBS, the UE may be notified individually by RAN-initiated paging due to session activation or data availability, as described in clause 9.2.5.

16.10.5.3 Service Continuity

16.10.5.3.1 General

Mobility principles build on existing functionality including functions described in clause 9.2.

16.10.5.3.2 Handover between Multicast supporting cells

Mobility procedures for multicast reception allow the UE to continue receiving multicast service(s) via PTM or PTP in a new cell after handover.

During handover preparation phase, the source gNB transfers to the target gNB about the MBS multicast sessions the UE has joined in the UE context information. To support provision of local multicast service with location dependent content as specified in TS 23.247 [45], for each active multicast session, service area information per Area Session ID may be provided to the target gNB.

The source gNB may propose data forwarding for some MRBs to minimize data loss and may exchange the corresponding MRB PDCP Sequence Number with the target gNB during the handover preparation:

- The lossless handover for multicast service is supported for the handover between MBS supporting cells if the UE is configured with PTP RLC AM entity in target cell MRB of a UE, regardless of whether the UE is configured with PTP RLC AM entity in the source cell or not.

- In order to support lossless handover for multicast service, the network has to ensure DL PDCP COUNT value synchronization and continuity between the source cell and the target cell. Furthermore, data forwarding from the source gNB to the target gNB and/or PDCP status report provided by a UE for an MRB for multicast session can be used during lossless handover.

For each multicast session with ongoing user data transmission for which no MBS Session Resources exist at the target gNB, the target gNB triggers the setup of MBS user plane resources towards the 5GC using the NGAP Distribution Setup procedure. If unicast transport is used, the target gNB provides the DL tunnel endpoint to be used to the MB-SMF. If multicast transport is used, the target gNB receives the IP multicast address from the MB-SMF.

During handover execution, the MBS configuration decided at target gNB is sent to the UE via the source gNB within an RRC container as specified in TS 38.331 [12]. The PDCP entities for multicast MRBs in the UE can either be re-established or remain as it is. When the UE connects to the target gNB, the target gNB sends an indication that it is an MBS-supporting node to the SMF in the Path Switch Request message (Xn handover) or Handover Request Acknowledge message (NG handover).

Upon successful handover completion, the source gNB may trigger the release of the MBS user plane resources towards the 5GC using the NGAP Distribution Release procedure for any multicast session for which there is no remaining joined UE in the gNB.

16.10.5.3.3 Handover between Multicast-supporting cell and Multicast non-supporting cell

During an MBS multicast session, at mobility from an MBS-supporting cell to an MBS non-supporting cell, the target gNB sets up PDU Session Resources mapped to the MBS multicast session. The 5GC infers from the absence of an "MBS-support" indication from gNB in the Path Switch Request message (Xn handover) or Handover Request Acknowledge message (NG handover) that MBS multicast data packets delivery has to be switched to 5GC individual MBS traffic delivery as specified in TS 23.247 [45]. If data forwarding is applied, the source gNB infers from the handover preparation response message that the target gNB does not support MBS and changes the QFI(s) in the forwarded packets to the associated PDU Session QFI(s) if respective mapping information is available. The source gNB may be aware that the target gNB is non-MBS supporting already before Handover Preparation.

For mobility from MBS non-supporting cell to MBS-supporting cell, the existing Xn/NG handover procedures apply. The 5GC infers from the presence of the "MBS-support" indicator from gNB in the Path Switch Request message (Xn handover) or in the Handover Request Acknowledge message (NG handover) that MBS multicast data packets delivery can be switched from 5GC Individual MBS traffic delivery to 5GC Shared MBS traffic delivery. After Xn handover, the SMF triggers switching MBS multicast data packets delivery from 5GC Individual to 5GC Shared MBS traffic delivery by providing MBS Session IDs joined by the UE to the target gNB by means of the PDU Session Resource Modification procedure. For NG handover, the SMF provides the MBS Session IDs joined by the UE to the target gNB by means of NGAP Handover Request. Minimization of data loss and duplication avoidance may be applied by means of identical MBS QFI SNs received over the shared NG-U tunnel against those received over unicast NG-U tunnels or forwarding tunnels.

Mobility from a multicast-supporting cell to a multicast non-supporting cell can be achieved by switching the MRB to a DRB in the source gNB before a handover.

NOTE: A UE may be handed over to a target gNB not supporting MBS without prior reconfiguration from MRB to the DRB in the source gNB. In this case, the AS configuration may not be comprehended by the target gNB causing full configuration.

16.10.5.3.4 MRB reconfiguration

The gNB may use *RRCReconfiguration* message to configure or reconfigure a multicast MRB, e.g., add/release/modify the MRB's RLC entities as described in clause 16.10.3. In order to minimize the data loss due to MRB reconfiguration, gNB may configure UE to send a PDCP status report during reconfiguration for MRB type change.

16.10.5.3.5 Service Continuity in RRC_INACTIVE

Mobility procedures for multicast reception allow the UE in RRC_INACTIVE state to continue receiving MBS service(s) when changing cells without resuming RRC connection if the PTM configuration of the new cell can be acquired by the UE from the multicast MCCH after cell reselection. During an active MBS multicast session, the UE is required to resume RRC connection to get the PTM configuration if the PTM configuration or multicast MCCH is not provided in the new cell. Even if the UE in RRC_INACTIVE state has received an indication to stop monitoring PDCCH addressed by G-RNTI for an MBS multicast session in the source cell, the UE acquires multicast MCCH in the reselected cell after cell reselection.

The gNB may indicate in the multicast MCCH the list of neighbour cells providing the same MBS multicast service(s) for UEs in RRC_INACTIVE state as provided in the serving cell. This allows the UE, e.g., to resume RRC connection without reading *SIB24* and multicast MCCH of the neighbour cell, if the interested service which is activated is not available to the UE in RRC_INACTIVE state.

The gNB may provide an indication on cell PDCP COUNT synchronization for an MBS session with PTM configuration in *RRCRelease* message. If indicated by the gNB, all cells within the RNA are synchronized in terms of PDCP COUNT value to the MRBs of the corresponding MBS service, and the order of MRBs within the list of multicast MRB configuration for the same MBS multicast session in the multicast MCCH message of the last serving cell and (re)selected cell within the RNA should be consistent. Upon reselection to a cell indicated as synchronized in terms of PDCP COUNT value, the UE does not initialize the PDCP state variables. Otherwise, the UE initializes the PDCP state variables as defined in TS 38.323 [8].

The UE may be configured with dedicated frequency priorities in *RRCRelease* message which the UE applies during cell reselection while receiving data of MBS multicast session in RRC_INACTIVE state.

The UE receiving multicast session(s) in RRC_INACTIVE state triggers RRC connection resumption if the latest measured RSRP or RSRQ of the serving cell becomes lower than the threshold configured by the network. The threshold can be configured per MBS session via *RRCRelease* message or multicast MCCH.

16.10.5.4 Reception of MBS Multicast data

For multicast service, gNB may deliver MBS multicast data packets using the following methods:

- PTP Transmission: gNB individually delivers separate copies of MBS data packets to each UEs independently, i.e., gNB uses UE-specific PDCCH with CRC scrambled by UE-specific RNTI (e.g., C-RNTI) to schedule UE-specific PDSCH which is scrambled with the same UE-specific RNTI.

- PTM Transmission: gNB delivers a single copy of MBS data packets to a set of UEs, e.g., gNB uses group-common PDCCH with CRC scrambled by group-common RNTI to schedule group-common PDSCH which is scrambled with the same group-common RNTI.

If a UE is configured with both PTM and PTP transmissions, a gNB dynamically decides whether to deliver multicast data by PTM leg and/or PTP leg for a given UE based on the protocol stack defined in clause 16.10.3, based on information such as MBS Session QoS requirements, number of joined UEs, UE individual feedback on reception quality, and other criteria. The same QoS requirements apply regardless of the decision.

PTP transmission is not supported for MBS multicast session data reception for UEs in RRC_INACTIVE state.

SPS is not supported for MBS multicast session data reception for UEs in RRC_INACTIVE state.

16.10.5.5 Support of CA

UE can be configured to receive MBS multicast data either from a PCell or a single SCell at a time.

16.10.5.6 DRX

The following DRX configurations for PTM/PTP transmission by RRC_CONNECTED UEs are possible:

- For PTM transmission, multicast DRX is configured per G-RNTI/G-CS-RNTI which is independent of UE-specific DRX;
- For PTP transmission, UE-specific DRX is reused, i.e., UE-specific DRX is used for both unicast transmission and PTP transmission of MBS multicast. For PTM retransmission via PTP, UE monitors PDCCH scrambled by C-RNTI/CS-RNTI during UE-specific DRX's Active Time.

The following DRX configuration for PTM transmission by RRC_INACTIVE UEs is possible:

- For PTM transmission, multicast DRX is configured per G-RNTI.

16.10.5.7 Physical Layer

A CFR configured by *RRCReconfiguration* message is defined for multicast scheduling as an 'MBS frequency region' with a number of contiguous PRBs confined within and with the same numerology as the DL BWP, and multicast scheduling may have specific characteristics (e.g., PDCCH, PDSCH and SPS configurations). The CFR for the multicast reception in RRC_INACTIVE state and the CFR for broadcast can be configured differently. If one CFR is not completely contained within the other CFR, the UE in RRC_INACTIVE state is not required to receive both broadcast and multicast simultaneously.

Slot-level repetition is optionally supported for multicast MTCH reception in RRC_INACTIVE state. The maximum number of MIMO layers is one for MBS multicast scheduling for UEs in the RRC_INACTIVE state.

Two HARQ-ACK reporting modes are defined for MBS:

- For the first HARQ-ACK reporting mode, the UE generates HARQ-ACK information with ACK value when a UE correctly decodes a transport block or detects a DCI format indicating an SPS PDSCH release; otherwise, the UE generates HARQ-ACK information with NACK value.
- For the second HARQ-ACK reporting mode, the UE does not transmit a PUCCH that would include only HARQ-ACK information with ACK values.

HARQ-ACK feedback for multicast can be enabled or disabled by higher layer configuration per G-RNTI or per G-CS-RNTI and/or indication in the DCI scheduling multicast transmission.

HARQ feedback is not supported for MBS multicast session data reception for UEs in RRC_INACTIVE state.

16.10.6 Broadcast Handling

16.10.6.1 Session Management

For delivery of location dependent contents of a broadcast session, Area Session ID is included in the NGAP broadcast session resource setup procedure associated with MBS service area information and per Area Session ID NG-U tunnels are established.

If the 5GC detects shared NG-U path failure, it may notify the gNB and the gNB may allocate new shared NG-U resources to replace old ones as specified in TS 23.527 [69].

The 5GC may also provide information to the NG-RAN node whether the broadcast session is intended to be received by only (e)RedCap UEs, only UEs that are neither RedCap UEs nor eRedCap UEs or any kind of UEs. The NG-RAN may take this into account when configuring MBS session resources.

16.10.6.2 Configuration

MBS broadcast can be received by UEs in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED state. A UE can receive the MBS configuration for broadcast session (e.g., parameters needed for MTCH reception) via MCCH in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED state. The parameters needed for the reception of MCCH are provided via System Information.

The following principles govern the MCCH structure:

- MCCH provides the list of all broadcast services with ongoing sessions transmitted on MTCH(s) and the associated information for broadcast session includes MBS session ID, associated G-RNTI scheduling information and information about neighbouring cells providing certain service on MTCH(s). MCCH content is transmitted within periodically occurring time domain windows, referred to as MCCH transmission window defined by MCCH repetition period, MCCH window duration and radio frame/slot offset;

- MCCH uses a modification period and MCCH contents are only allowed to be modified at each modification period boundary; a notification mechanism is used to announce the change of MCCH contents due to broadcast session start, modification or stop and due to neighbouring cell information modification;

NOTE: It is up to UE implementation to use the start and stop times in the USD to determine when to start monitoring the MCCH for the session the UE is interested in.

- When the UE receives an MCCH change notification, it acquires the updated MCCH in the same MCCH modification period where the change notification is sent.

16.10.6.3 Support of CA

UE can be configured to receive MBS broadcast data and MCCH either from a PCell or a single SCell at a time. Meanwhile, dedicated RRC signalling is used for providing SIB20 of the SCell i.e., while in RRC_CONNECTED state, UEs need not acquire broadcast SIB20 directly from the SCells.

NOTE: Void.

16.10.6.4 DRX

Via MCCH, the UE can be configured with a PTM DRX configuration for G-RNTI reception. One PTM DRX configuration can be mapped to more than one G-RNTI.

16.10.6.5 Service Continuity

16.10.6.5.0 General

Mobility principles build on existing functionality including functions described in clause 9.2.

NR MBS supports MBS frequency layer prioritization for MBS broadcast sessions. The gNBs may be configured with the MBS FSA ID(s) supported by each of their cells. The gNBs may exchange this information with their neighbours within Xn Setup messages and subsequent Xn Configuration Update messages to help with frequency layer prioritization. The MBS FSA ID is described in TS 23.247 [45].

16.10.6.5.1 Service Continuity in RRC_IDLE or RRC_INACTIVE

Mobility procedures for MBS reception allow the UE to start or continue receiving MBS service(s) when changing cells. The gNB may indicate in the MCCH the list of neighbour cells providing the same MBS broadcast service(s) as provided in the serving cell. This allows the UE, e.g., to request unicast reception of the service before moving to a cell not providing the MBS broadcast service(s) using PTM transmission. To avoid the need to read MBS broadcast related system information and potentially MCCH on neighbour frequencies, the UE is made aware of which frequency is providing which MBS broadcast services via PTM, through *User Service Description*, as defined in TS 26.517 [46], or the combination of the following:

- *User Service Description* (USD);

- SIB21, as defined in clause 7.3.1.

NOTE: UE can request unicast reception of the service after moving to a cell not providing the MBS broadcast service(s) using PTM transmission.

In RRC_IDLE and RRC_INACTIVE, the UE applies the normal cell reselection rules with the following modifications:

- the UE which is receiving or interested to receive MBS broadcast service(s) via PTM and can only receive these MBS broadcast service(s) via PTM while camping on the frequency providing these MBS broadcast service(s) is allowed to make this frequency highest priority when the conditions described in TS 38.304 [10] are met;
- when the MBS broadcast service(s) which the UE is interested in are no longer available (after the end of the session) or the UE is no longer interested in receiving the service(s), the UE no longer prioritises the frequency providing these MBS broadcast service(s).

16.10.6.5.2 Service Continuity in RRC_CONNECTED

To ensure service continuity of MBS broadcast, the UE in RRC_CONNECTED state may send MBS Interest Indication to the gNB, consisting of the following information:

- List of MBS frequencies UE is receiving or interested to receive, sorted in decreasing order of interest;
- Priority between the reception of all listed MBS frequencies and the reception of any unicast bearer and multicast MRB;
- List of MBS broadcast services the UE is receiving or interested to receive, in case SIB20 is provided for PCell or SCell.

MBS Interest Indication information reporting can be implicitly enabled/disabled by the presence of SIB21.

The gNB may use this information, together with the information about the UE's capabilities (e.g., supported band combinations), when providing an RRC configuration and/or downlink assignments to the UE or to add/release DRBs/multicast MRBs, to allow the UE to receive the MBS services the UE is interested in. MBS Interest Indication information can be exchanged between source gNB and target gNB during handover.

16.10.6.5A Reception of MBS Broadcast data

For broadcast service, gNB may deliver Broadcast MBS data packets using the following method:

- PTM Transmission: gNB delivers a single copy of MBS data packets to a set of UEs, e.g., gNB uses group-common PDCCH with CRC scrambled by group-common RNTI to schedule group-common PDSCH which is scrambled with the same group-common RNTI.

16.10.6.6 Physical Layer

A CFR configured by SIB is defined for broadcast scheduling as an 'MBS frequency region' with a number of contiguous PRBs with a bandwidth equal to or larger than CORESET0, with the same numerology as CORESET0, and broadcast scheduling may have specific characteristics (e.g., PDCCH and PDSCH configurations). The NG-RAN node may configure an additional RedCap CFR when the bandwidth of the configured default CFR exceeds the (e)RedCap UE capability. A UE only monitors one CFR at a time. An (e)RedCap UE monitors the RedCap CFR, if configured, otherwise the (e)RedCap UE monitors the default CFR, if the bandwidth of the default CFR is within the UE capability. The NG-RAN node ensures that a UE does not receive two DCIs simultaneously (i.e., one associated with the RedCap CFR and another associated with the default CFR) with the same G-RNTI or the same MCCH-RNTI.

The maximum number of MIMO layers is one for MBS broadcast scheduling. RB-level rate matching, and RE-level rate matching around LTE-CRS configured by higher layer signalling are supported for MCCH and MTCH. Slot-level repetition is supported for MTCH.

HARQ-ACK feedback is not supported for MBS broadcast.

Only dynamic scheduling is supported for MBS broadcast.

16.10.6.7 Shared processing for MBS broadcast and unicast reception

If the UE in RRC_CONNECTED state is receiving or interested to receive an MBS broadcast service from a non-serving cell as described in TS 38.306 [11] , the UE may use MBS Interest Indication message to inform the serving gNB about the parameters used for the non-serving cell broadcast reception as described in TS 38.331 [12]. The gNB may enable the sending of the MBS Interest Indication by including an indication in SIB1. The UE may indicate to the serving cell the UE capability for receiving MBS broadcast service from a non-serving cell. It is up to gNB implementation to consider the MBS Interest Indication and the UE capability for receiving MBS broadcast service from a non-serving cell, if indicated, when scheduling the UE.

In case the UE only reports the frequency for broadcast service reception from the non-serving cell in MBS Interest Indication due to some parameters (e.g., SCS, bandwidth) not being available, the UE may transmit updated MBS Interest Indication once the parameters are available to the UE. It is up to network implementation on how to enable the UE to acquire these parameters from the non-serving cell.

16.10.6.8 Support of Resource Sharing across multiple Broadcast MBS sessions in RAN Sharing Scenario

NGAP supports resource sharing efficient scheme for broadcast delivery in RAN sharing. Such scheme enables the gNB to identify broadcast MBS sessions from different PLMNs providing identical content. The identification is based on information provided by the involved 5GCs in the Associated Session ID as specified in TS 23.247 [45].

If in the MBS Broadcast Setup Request message an Associated Session ID is received from a 5GC participating in RAN sharing, the gNB uses it to determine whether MBS Session resources can be shared with a broadcast MBS session(s) associated with the same Associated Session ID requested from another 5GC participating in RAN sharing.

The identification of MBS Broadcast Sessions providing identical content may also be based on implementation specific configuration as specified in TS 23.247 [45].

The gNB applying this resource efficiency scheme:

- may decide whether NG-U resources are established towards all involved 5GCs or only some of them;
- resolves different QoS requirements or different S-NSSAIs received from the participating 5GCs in an implementation specific way.

The gNB may also trigger the NGAP Broadcast Session Transport procedure towards one 5GC participating in RAN sharing to set up NG-U resources to maintain NG-U connectivity as specified in TS 23.247 [45].

16.11 Minimization of Service Interruption

In case of a disaster, a radio access network can experience outage, which can result in that UEs belonging to the network experience service interruptions. For this scenario, another network not affected by the disaster, which during non-disaster situations is considered by the UEs as a forbidden network, can allow roaming of the UEs belonging to the network experiencing such disaster service interruptions. Such roaming is referred to as disaster roaming. This is further described in clause 5.40 of TS 23.501 [3] and 3.10 of TS 23.122 [47].

To allow such disaster roaming, a cell can broadcast a list of PLMNs with disaster conditions for which disaster roaming is offered. Disaster roaming service is provided only for the area that covers the area with disaster condition.

Further, to be able to control the load that disaster roaming UEs put on a cell, the cell can broadcast access control parameters applicable specifically for disaster roaming UEs. Access attempts of disaster roaming UEs are based on Access Identity 3. The network can for example set the access control parameters for Access Identity 3 so that access attempts of disaster roaming UEs are more likely to be barred compared to non-disaster roaming UEs.

16.12 Sidelink Relay

16.12.1 General

Sidelink relay supports 5G ProSe UE-to-Network Relay (U2N Relay) function (specified in TS 23.304 [48]) to provide single/multi-hop connectivity to the network for U2N Remote UE(s). Both L2 and L3 U2N Relay architectures are supported. The L3 U2N Relay architecture is transparent to the serving NG-RAN of the U2N Relay UE, except for controlling sidelink resources. The detailed architecture and procedures for L3 U2N Relay can be found in TS 23.304 [48].

A U2N Relay UE shall be in RRC_CONNECTED to perform relaying of unicast data.

For L2 U2N Relay operation, the following RRC state combinations are supported:

- Both L2 U2N Relay UE and L2 U2N Remote UE shall be in RRC_CONNECTED to perform transmission/reception of relayed unicast data; and
- The L2 U2N Relay UE can be in RRC_IDLE, RRC_INACTIVE or RRC_CONNECTED as long as all the L2 U2N Remote UE(s) that are connected to the L2 U2N Relay UE are either in RRC_INACTIVE or in RRC_IDLE.

A single unicast link is established between one L2 U2N Relay UE and one L2 U2N Remote UE and, in case of multi-hop L2 U2N relay, between L2 U2N Relay UEs. The traffic to the NG-RAN of L2 U2N Remote UE via a given L2 U2N Relay UE and the traffic of the L2 U2N Relay UE shall be separated in different Uu RLC channels.

In multi-hop U2N Relay, U2N Remote UE refers to both the actual U2N Remote UE and the intermediate U2N Relay UE that also functions as a U2N Remote UE. The intermediate U2N Relay UE can have its own traffic acting as a U2N Remote UE simultaneously.

For L2 U2N Relay, the L2 U2N Remote UE can only be configured to use resource allocation mode 2 (as specified in 5.7.2 and 16.9.3.1) for data to be relayed.

Sidelink relay additionally supports 5G ProSe UE-to-UE Relay (U2U Relay) function (specified in TS 23.304 [48]) to provide connectivity between U2U Remote UEs. Both L2 and L3 U2U Relay architectures are supported. The L3 U2U Relay architecture is transparent to the AS layer of the U2U Relay UE. The detailed architecture and procedures for L3 U2U Relay can be found in TS 23.304 [48].

A U2U Relay UE is used to provide coverage extension of the sidelink transmissions between two U2U Remote UEs. For the coverage extension, the U2U Remote UE can communicate with a peer U2U Remote UE(s), which are not reachable within the sidelink coverage, via the U2U Relay UE.

The U2U Relay UE and U2U Remote UE can be in any RRC state. The U2U Relay UE and the U2U Remote UEs can be in the coverage of the same or different cells or out-of-coverage. Both sidelink resource allocation modes, i.e., mode 1 and mode 2 are supported for the U2U Relay UE and U2U Remote UEs. For U2U Relay, a single PC5 unicast link is established between U2U Relay UE and each of the U2U Remote UEs. After PC5 unicast link establishment between U2U Relay UE and U2U Remote UEs, end-to-end PC5 unicast link connection establishment is performed between U2U Remote UEs. Only unicast is supported between U2U Relay UE and U2U Remote UEs.

16.12.2 Protocol Architecture

16.12.2.1 L2 UE-to-Network Relay

The protocol stacks for the user plane and control plane of single-hop L2 U2N Relay architecture are illustrated in Figure 16.12.2.1-1 and Figure 16.12.2.1-2. The protocol stacks for the user plane and control plane of multi-hop L2 U2N Relay architecture are illustrated in Figure 16.12.2.1-3 and Figure 16.12.2.1-4. The SRAP sublayer is placed above the RLC sublayer for both CP and UP at both PC5 interface and Uu interface. The Uu SDAP, PDCP and RRC are terminated between L2 U2N Remote UE and gNB, while SRAP, RLC, MAC and PHY are terminated in each hop (i.e., the link between L2 U2N Remote UE and the L2 U2N Relay UE, the link between L2 U2N Relay UEs, and the link between L2 U2N Relay UE and the gNB).

For L2 U2N Relay, the SRAP sublayer over PC5 hop is only for the purpose of bearer mapping. The SRAP sublayer is not present over PC5 hop for relaying the L2 U2N Remote UE's message on BCCH and PCCH. For L2 U2N Remote

UE's message on SRB0, the SRAP header is not present over PC5 hop between the U2N Remote UE and the directly connected U2N Relay UE, but the SRAP header is present over Uu hop or PC5 hop between U2N Relay UEs for both DL and UL.

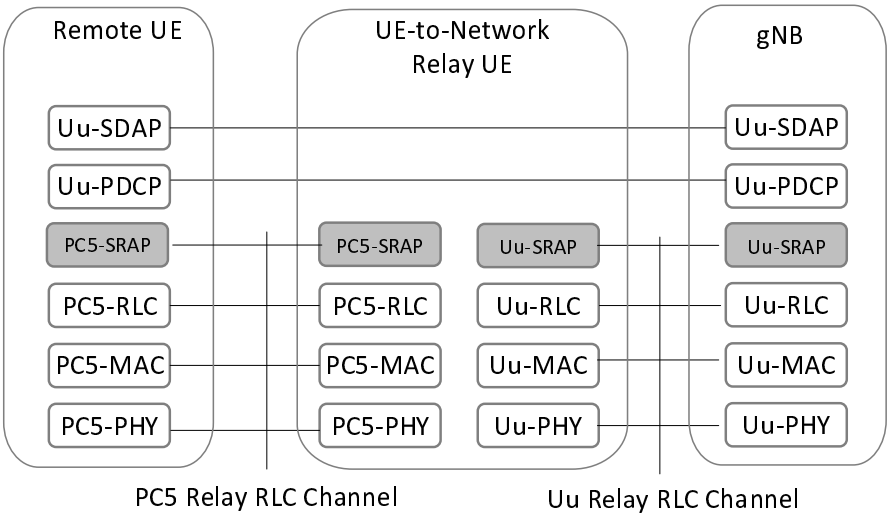


Figure 16.12.2.1-1: User plane protocol stack for single-hop L2 UE-to-Network Relay

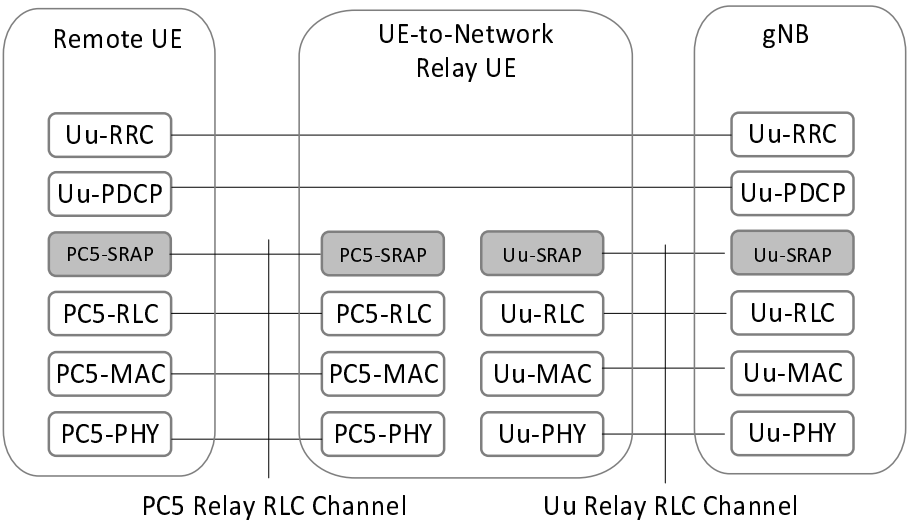


Figure 16.12.2.1-2: Control plane protocol stack for single-hop L2 UE-to-Network Relay

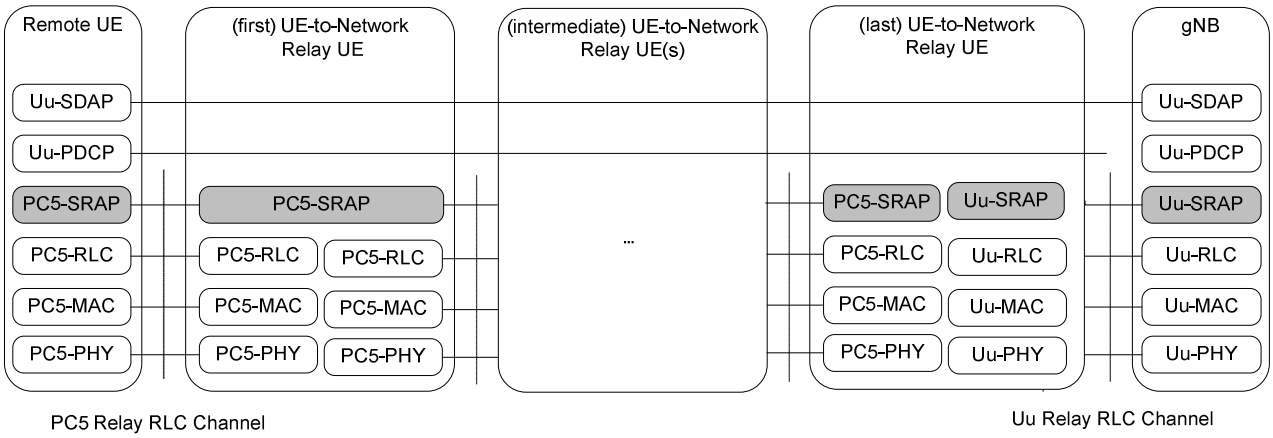


Figure 16.12.2.1-3: User plane protocol stack for multi-hop L2 UE-to-Network Relay

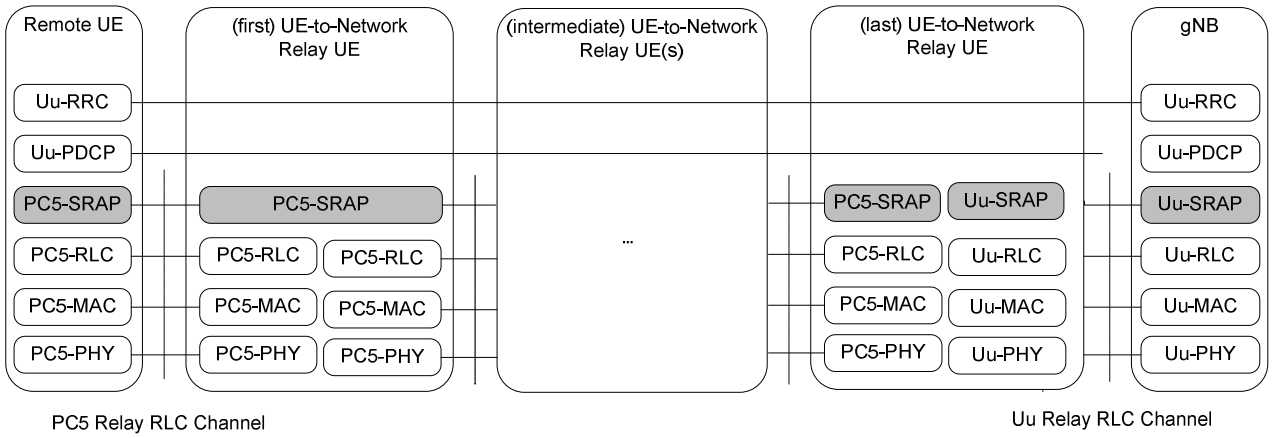


Figure 16.12.2.1-4: Control plane protocol stack for multi-hop L2 UE-to-Network Relay

For L2 U2N Relay, for uplink:

- The Uu/PC5 SRAP sublayer at the U2N Relay UE performs UL bearer mapping between end-to-end Uu Radio Bearers of L2 U2N remote UE (identified for the purposes of this mapping by the local Remote UE ID and an associated bearer ID) and egress Uu/PC5 Relay RLC channels over the L2 U2N Relay UE Uu/PC5 interface. For uplink relaying traffic, the different end-to-end Uu Radio Bearers (SRBs or DRBs) of the same L2 U2N Remote UE and/or different L2 U2N Remote UEs can be multiplexed over the same egress Uu/PC5 Relay RLC channel;

- The Uu/PC5 SRAP sublayer at the U2N Relay UE supports L2 U2N Remote UE identification for the UL traffic. The identity information of L2 U2N Remote UE end-to-end Uu Radio Bearer and a local Remote UE ID are included in the Uu SRAP header at UL in order for gNB to correlate the received packets for the specific PDCP entity associated with the right end-to-end Uu Radio Bearer of the L2 U2N Remote UE;

- The PC5 SRAP sublayer at the L2 U2N Remote UE supports UL bearer mapping between L2 U2N Remote UE end-to-end Uu Radio Bearers and egress PC5 Relay RLC channels.

For L2 U2N Relay, for downlink:

- The Uu SRAP sublayer performs DL bearer mapping at gNB to map end-to-end Uu Radio Bearer (SRB, DRB) of L2 U2N Remote UE (identified for the purposes of this mapping by the local Remote UE ID and an associated bearer ID) into Uu Relay RLC channel. The Uu/PC5 SRAP sublayer at the U2N Relay UE performs DL bearer mapping and data multiplexing between multiple end-to-end Radio Bearers (SRBs or DRBs) of a L2 U2N Remote UE and/or different L2 U2N Remote UEs and one Uu Relay RLC channel over the L2 U2N Relay UE Uu/PC5 interface;

- The Uu/PC5 SRAP sublayer at the U2N Relay UE supports L2 U2N Remote UE identification for DL traffic. The identity information of L2 U2N Remote UE end-to-end Uu Radio Bearer and a local Remote UE ID are

included into the Uu SRAP header by the gNB at DL for the L2 U2N Relay UE to identify the corresponding end-to-end Uu Radio Bearer(s) of L2 U2N Remote UE;

- The PC5 SRAP sublayer at the L2 U2N Relay UE performs DL bearer mapping between end-to-end Uu Radio Bearers of L2 U2N remote UE and egress PC5 Relay RLC channels;

- The PC5 SRAP sublayer at the L2 U2N Remote UE correlates the received packets with the right PDCP entity associated with the given end-to-end Uu Radio Bearer of the L2 U2N Remote UE based on the identity information included in the PC5 SRAP header.

A local Remote UE ID is included in both PC5 SRAP header and Uu SRAP header. L2 U2N Relay UE is configured by the gNB with the local Remote UE ID(s) to be used in SRAP header. L2 U2N Remote UE obtains the local Remote ID from the gNB via Uu RRC messages including *RRCSetup*, *RRCReconfiguration*, *RRCResume* and *RRCReestablishment*.

The end-to-end DRB(s) or end-to-end SRB(s), except SRB0, of L2 U2N Remote UE can be multiplexed to the PC5 Relay RLC channels and Uu Relay RLC channels in both PC5 hop and Uu hop, but an end-to-end DRB and an end-to-end SRB can neither be mapped into the same PC5 Relay RLC channel nor be mapped into the same Uu Relay RLC channel.

It is the gNB responsibility to avoid collision on the usage of local Remote UE ID. The gNB can update the local Remote UE ID by sending the updated local Remote UE ID via *RRCReconfiguration* message. The serving gNB can perform local Remote UE ID update independent of the PC5 unicast link L2 ID update procedure.

16.12.2.2 L2 UE-to-UE Relay

The protocol stacks for the user plane and the control plane of the L2 U2U Relay architecture are illustrated in Figure 16.12.2.2-1 and Figure 16.12.2.2-2. The SRAP sublayer is placed above the RLC sublayer for both CP and UP at both PC5 interfaces. The sidelink SDAP, PDCP and RRC are terminated between two L2 U2U Remote UEs (i.e., end-to-end), while SRAP, RLC, MAC and PHY are terminated in each hop of PC5 link.

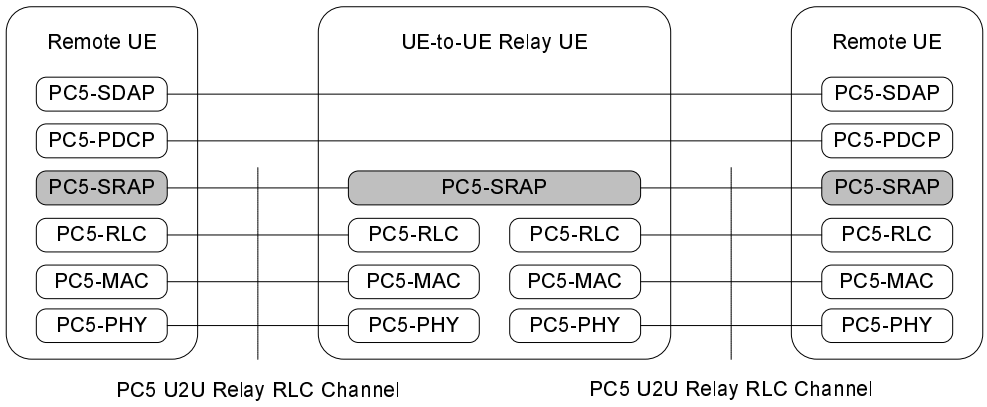


Figure 16.12.2.2-1: User plane protocol stack for L2 UE-to-UE Relay

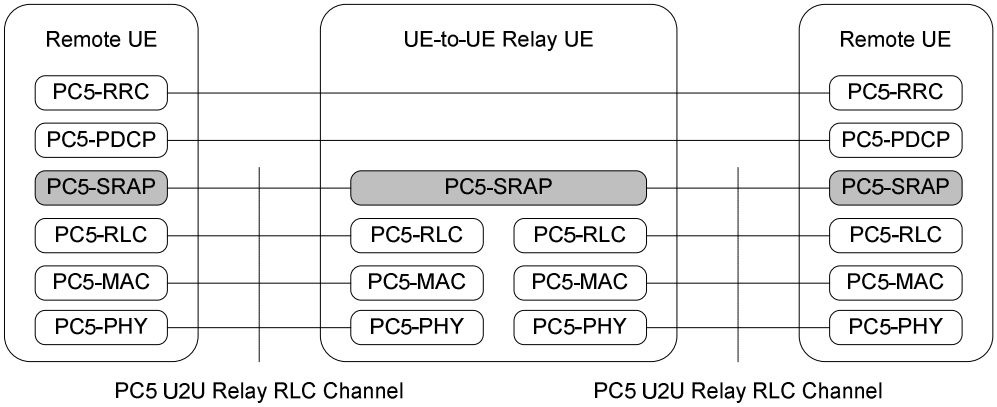


Figure 16.12.2.2-2: Control plane protocol stack for L2 UE-to-UE Relay

For L2 UE-to-UE Relay, the SRAP sublayer at L2 U2U Remote UE:

- The SRAP sublayer at L2 U2U Remote UE performs bearer mapping between end-to-end PC5 Radio Bearers (SL-SRBs or SL-DRBs) of the L2 U2U Remote UE and PC5 Relay RLC Channels between the L2 U2U Remote UE and the L2 U2U Relay UE.

- For the traffic transmitted from an L2 U2U Remote UE to an L2 U2U Relay UE, the different end-to-end PC5 Radio Bearers (SL-SRBs or SL-DRBs) towards the same peer L2 U2U Remote UE and/or different peer L2 U2U Remote UEs can be multiplexed to the same PC5 Relay RLC channel between the L2 U2U Remote UE(s) and the L2 U2U Relay UE. An end-to-end SL-DRB and an end-to-end SL-SRB cannot be multiplexed to the same PC5 Relay RLC channel.

- For the traffic received at L2 U2U Remote UE, the same PC5 Relay RLC channel from one L2 U2U Relay UE can be de-multiplexed to the different end-to-end PC5 Radio Bearers (SL-SRBs or SL-DRBs) of the same peer L2 U2U Remote UE and/or different peer L2 U2U Remote UEs.

- The SRAP sublayer at L2 U2U Remote UE supports identification of the peer L2 U2U Remote UE and itself. The local IDs are assigned by L2 U2U Relay UE to both L2 U2U Remote UEs for identification. For the two local IDs, one of them identifies L2 U2U Remote UE and the other identifies the peer L2 U2U Remote UE. The local ID of the peer L2 U2U Remote UE and the local ID of L2 U2U Remote UE are delivered by L2 U2U Relay UE to the L2 U2U Remote UEs along with the corresponding L2 ID of the peer L2 U2U Remote UE. The SRAP header includes the identity information of the end-to-end PC5 Radio Bearer and two local IDs. The peer L2 U2U Remote UE matches the received packets with the specific sidelink PDCP entity with the correct end-to-end PC5 Radio Bearer of the L2 U2U Remote UEs.

For L2 UE-to-UE Relay, the SRAP sublayer at L2 U2U Relay UE:

- The SRAP sublayer at L2 U2U Relay UE determines the egress PC5 Relay RLC Channel based on the mapping of the end-to-end PC5 Radio Bearer and egress PC5 Relay RLC Channel for a particular pair of L2 U2U Remote UE and the peer L2 U2U Remote UE.

- For the ingress traffic received from an/multiple L2 U2U Remote UE(s) at L2 U2U Relay UE, the different end-to-end PC5 Radio Bearers (SL-SRBs or SL-DRBs) of the same L2 U2U Remote UE and/or the same/different end-to-end PC5 Radio Bearers (SL-SRBs or SL-DRBs) of L2 U2U Remote UEs can be multiplexed to the same egress PC5 Relay RLC channel in between the L2 U2U Relay UE and the peer L2 U2U Remote UE. An end-to-end SL-DRB and an end-to-end SL-SRB cannot be multiplexed to the same PC5 Relay RLC channel.

16.12.3 Relay Discovery

Model A and Model B discovery models as defined in TS 23.304 [48] are supported for U2N/U2U Relay discovery. The protocol stack used for discovery is illustrated in Figure 16.12.3-1.

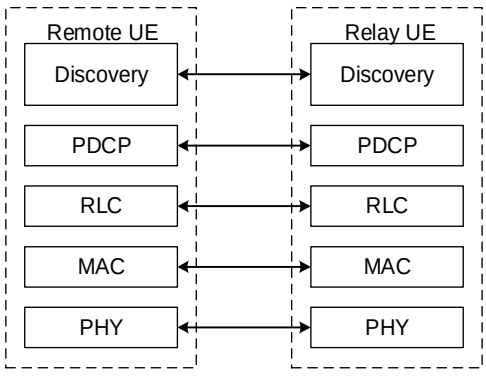


Figure 16.12.3-1: Protocol Stack of Discovery Message for UE-to-Network/UE-to-UE Relay

The U2N Remote UE can perform Relay discovery message (i.e., as specified in TS 23.304 [48]) transmission and may monitor the sidelink for Relay discovery message while in RRC_IDLE, RRC_INACTIVE or RRC_CONNECTED. The network may broadcast or configure via dedicated RRC signalling a Uu RSRP threshold, which is used by the U2N Remote UE to determine if it can transmit Relay discovery messages to U2N Relay UE(s).

The U2N Relay UE can perform Relay discovery message (i.e., as specified in TS 23.304 [48]) transmission and may monitor the sidelink for Relay discovery message while in RRC_IDLE, RRC_INACTIVE or RRC_CONNECTED. The network may broadcast or configure via dedicated RRC signalling a maximum Uu RSRP threshold, a minimum Uu RSRP threshold, or both, which are used by the U2N Relay UE to determine if it can transmit Relay discovery messages to U2N Remote UE(s).

In multi-hop U2N relay, one U2N Relay UE establishes a PC5 connection with each of its child UE(s). One intermediate U2N Relay UE or U2N Remote UE maintains a single PC5 connection with its parent UE.

The U2U Remote UE and U2U Relay UE can perform Relay discovery message transmission or DCR/DCA message with integrated discovery transmission and may monitor for Relay discovery message or DCR/DCA message with integrated discovery while in coverage (i.e. RRC_IDLE, RRC_INACTIVE, or RRC_CONNECTED) or out-of-coverage.

The network may provide the Relay discovery configuration using broadcast or dedicated signalling. In addition, the U2N/U2U Remote UE, L3 U2N Relay UE and U2U Relay UE may use pre-configuration for Relay discovery. If the candidate intermediate U2N Relay UE is out of coverage without a PC5 connection to a parent UE, it can forward discovery messages based on pre-configuration. If the candidate intermediate U2N Relay UE is in coverage without a PC5 connection to a parent UE or out of coverage with a PC5 connection to a parent UE, it can forward discovery message based on SIB12 or dedicated configuration.

The resource pool(s) used for NR sidelink communication can be used for Relay discovery or the network may configure resource pool(s) dedicated for Relay discovery. Resource pool(s) dedicated for Relay discovery can be configured simultaneously with resource pool(s) for NR sidelink communication in system information, dedicated signalling and/or pre-configuration. Whether dedicated resource pool(s) for Relay discovery are configured is based on network implementation. If resource pool(s) dedicated for Relay discovery are configured, only those resource pool(s) dedicated for Relay discovery shall be used for Relay discovery. If only resource pool(s) for NR sidelink communication are configured, all the configured resource pool(s) can be used for Relay discovery and NR sidelink communication. Only the resource pool for NR sidelink communication is used for the DCR/DCA message with integrated discovery.

For U2N Remote UE (including both in-coverage and out of coverage cases) that has been connected to the network via single/multi-hop U2N Relay UE(s), only resource allocation mode 2 is used for Relay discovery message transmission.

For in-coverage U2N Relay UE, and for both in-coverage and out of coverage U2N Remote UEs, NR sidelink resource allocation principles are applied for Relay discovery message transmission.

For U2U Remote UE and U2U Relay UE, NR sidelink resource allocation principles, both mode 1 and mode 2, can be applied for Relay discovery message transmission.

The sidelink power control for the transmission of Relay discovery messages is same as for NR sidelink communication.

No ciphering or integrity protection in PDCP layer is applied for the Relay discovery messages.

The U2N/U2U Remote UE and U2N/U2U Relay UE can determine from SIB12 whether the gNB supports Relay discovery, or Non-Relay discovery, or both.

16.12.4 Relay Selection/Reselection

The U2N Remote UE performs radio measurements at PC5 interface and uses them for U2N Relay selection and reselection along with higher layer criteria, as specified in TS 23.304 [48]. When there is no unicast PC5 connection between the U2N Relay UE and the U2N Remote UE, the U2N Remote UE uses SD-RSRP measurements to evaluate whether PC5 link quality towards a candidate parent U2N Relay UE satisfies relay selection criterion.

For relay reselection, U2N Remote UE uses SL-RSRP measurements towards the serving U2N Relay UE for relay reselection trigger evaluation when there is data transmission from U2N Relay UE to U2N Remote UE, and it is left to UE implementation whether to use SL-RSRP or SD-RSRP for relay reselection trigger evaluation in case of no data transmission from U2N Relay UE to U2N Remote UE.

A U2N Relay UE is considered suitable by a U2N Remote UE in terms of radio criteria if the PC5 link quality measured by U2N Remote UE towards the U2N Relay UE exceeds configured threshold (pre-configured or provided by gNB). The U2N Remote UE searches for suitable U2N Relay UE candidates that meet all AS layer and higher layer criteria (see TS 23.304 [48]). If there are multiple such suitable U2N Relay UEs, it is up to U2N Remote UE

implementation to choose one U2N Relay UE among them. For L2 U2N Relay (re)selection, the PLMN ID, NID, CAG ID and cell ID can be used as additional AS criteria.

The U2N Remote UE triggers U2N Relay selection in following cases:

- Direct Uu signal strength of current serving cell of the U2N Remote UE is below a configured signal strength threshold;
- Indicated by upper layer of the U2N Remote UE.

The U2N Remote UE may trigger U2N Relay reselection in following cases:

- PC5 signal strength of current U2N Relay UE is below a (pre)configured signal strength threshold;
- Cell reselection, handover, Uu RLF, or Uu RRC connection establishment/resume failure has been indicated by U2N Relay UE via PC5-RRC signalling;
- When U2N Remote UE receives a PC5-S link release message from U2N Relay UE;
- When U2N Remote UE detects PC5 RLF;
- Indicated by upper layer.

For L2 U2N Remote UEs in RRC_IDLE or RRC_INACTIVE and L3 U2N Remote UEs, the cell (re)selection procedure and relay (re)selection procedure run independently. If both suitable cells and suitable U2N Relay UEs are available, it is up to the U2N Remote UE implementation to select either a cell or a U2N Relay UE. A L3 U2N Remote UE may select a cell and a L3 U2N Relay UE simultaneously and this is up to implementation of L3 U2N Remote UE.

For both L2 and L3 U2N Relay UE in RRC_IDLE or RRC_INACTIVE, the PC5-RRC message is used to inform their connected U2N Remote UE(s) or child UE(s) when U2N Relay UE selects a new cell. If the PC5-RRC message for informing is triggered by Uu/PC5 RLF, the intermediate U2N Relay UE in RRC_IDLE or RRC_INACTIVE can send the PC5-RRC message after it performs a recovery action successfully. If the recovery action is failed, it is the intermediate U2N Relay UE implementation whether to release or send the PC5-RRC message to the U2N Remote UE(s) or child UE(s). The intermediate U2N Relay UE may omit sending the PC5-RRC message if the relay reselection or cell selection does not cause the change of the serving cell. The PC5-RRC message(s) are also used to inform their connected L2 or L3 child UE(s) when L2 or L3 U2N Relay UE performs handover, detects Uu/PC5 RLF, detects its Uu RRC connection establishment/resume fails, or is released PC5 unicast link with its parent UE. Upon reception of the PC5 RRC message for notification, it is up to U2N Remote UE/intermediate U2N Relay UE implementation whether to release or keep the unicast PC5 link with its parent UE. Upon reception of the PC5 RRC message for notification, it is up to intermediate U2N Relay UE implementation whether to release or send the notification message to the child Relay UE(s). If U2N Remote UE/intermediate U2N Relay UE decides to release the unicast PC5 link, it triggers the PC5 release procedure and may perform cell or relay reselection.

For the discovery model A, the intermediate U2N Relay UE should send the discovery announcement message after PC5 connection establishes with its parent UE. There are no additional SD/SL-RSRP threshold criteria when forwarding discovery messages.

For the discovery model B, if the intermediate U2N Relay UE already has been established a PC5 connection with its parent UE, the intermediate U2N Relay UE may send a response message without forwarding the received discovery solicitation message to the parent UE. Otherwise, the intermediate Relay UE should forward the received discovery solicitation message to the candidate parent UE only when the PC5 RSRP between the child UE and itself is above a SD-RSRP threshold. Upon receiving the discovery solicitation message, a last U2N Relay UE without having a PC5 link between itself and an intermediate U2N Relay UE sends the discovery response message only when the PC5 RSRP between itself and child UE is above the SD-RSRP threshold. Upon receiving the discovery response message, the intermediate U2N Relay UE does not check the PC5 AS condition to forward the response message towards the U2N Remote UE since it assumed that the PC5 links have already been checked when the solicitation messages were forwarded. Upon receiveing the discovery response message, the U2N Remote UE considers an intermediate Relay UE(s) as a candidate first U2N Relay UE(s) along the path to the last U2N Relay UE if the PC5 RSRP towards the first U2N Relay UE is above a SD-RSRP threshold.

The U2U Remote UE performs radio measurements (i.e., SD-RSRP and/or SL-RSRP) at PC5 interface and uses them for U2U Relay selection and reselection along with higher layer criteria, as specified in TS 23.304 [48].

For relay selection, U2U Remote UE uses SL-RSRP measurements towards the peer U2U Remote UE for relay selection trigger evaluation when valid SL-RSRP measurements are available. For relay reselection, U2U Remote UE

uses SL-RSRP measurement towards the U2U Relay UE for relay reselection trigger evaluation when there is data transmission from U2U Relay UE to U2U Remote UE. It is left to U2U Remote UE implementation whether to use SL-RSRP or SD-RSRP for relay selection or reselection trigger evaluation in case of no data transmission. The thresholds for SD-RSRP and SL-RSRP can be configured separately for the trigger evaluation of U2U relay selection or reselection. The same value(s) of the SD-RSRP and SL-RSRP thresholds, which is used for relay selection or reselection, are applied for all the discovery models including DCR with integrated discovery.

The U2U Remote UE may trigger U2U Relay selection in the following cases:

- When the SL-RSRP or SD-RSRP between U2U Remote UEs is below a (pre)configured signal strength threshold;
- When U2U Remote UE receives an indication to trigger U2U relay selection from the upper layer of the UE.

The U2U Remote UE may trigger U2U Relay reselection in the following cases:

- When the SL-RSRP or SD-RSRP of the current U2U Relay UE is below a (pre)configured signal strength threshold;
- When U2U Remote UE receives an indication from the upper layer due to detecting PC5 RLF;
- When L2 U2U Remote UE receives an indication from the upper layer due to receiving the PC5 RLF indication from the L2 U2U Relay UE;
- When U2U Remote UE receives a PC5-S link release message from U2U Relay UE;
- When U2U Remote UE receives an indication to trigger U2U relay reselection from the upper layer of the UE.

For the discovery model A, the U2U Relay UE should announce via discovery announcement message only the neighbour U2U Remote UE(s) for which the SD-RSRP/SL-RSRP between the U2U Relay and the neighbour U2U Remote UE(s) is above a configured threshold. Upon discovery message reception, U2U Remote UE considers a U2U Relay UE as a candidate U2U Relay UE if the SD-RSRP towards the U2U Relay UE is above a configured threshold and the upper layer criteria are met.

For the discovery model B, when the U2U Relay UE receives the discovery solicitation message from U2U Remote UE, the U2U Relay UE forwards the discovery solicitation message only if the SD-RSRP between the U2U Relay UE and the U2U Remote UE is above a threshold. After the peer U2U remote UE receives a discovery solicitation message from the U2U Relay UE, the peer U2U Remote UE transmits the discovery response message only if the SD-RSRP between the peer U2U Remote UE and the U2U Relay UE is above a configured threshold. Upon discovery response message reception forwarded by the U2U Relay UE, the U2U Remote UE considers a U2U Relay UE as a candidate U2U Relay UE if the SD-RSRP towards the U2U Relay UE is above a configured threshold and the upper layer criteria are met.

For the DCR message with integrated discovery, when the U2U Relay UE receives the DCR message with integrated discovery from U2U Remote UE, the U2U Relay UE forwards the DCR message with integrated discovery only if the SL-RSRP between the U2U Relay UE and the U2U Remote UE is above a configured SD-RSRP threshold (not the SL-RSRP, as broadcast is used). Upon receiving DCR message with integrated discovery from one or multiple U2U Relay UEs, the peer U2U Remote UE should consider to which received DCR message to respond amongst candidate U2U Relay UEs towards which the SL-RSRP is above a configured SD-RSRP threshold (not the SL-RSRP, as broadcast is used) and that satisfy upper-layer criteria, and select a U2U Relay UE among them.

16.12.5 Control plane procedures for L2 U2N Relay

16.12.5.1 RRC Connection Management

The L2 U2N Remote UE needs to establish its own PDU sessions/DRBs with the network before user plane data transmission.

The NR sidelink PC5 unicast link establishment procedures can be used to setup a secure unicast link between L2 U2N Remote UE and L2 U2N Relay UE before L2 U2N Remote UE establishes a Uu RRC connection with the network via L2 U2N Relay UE.

The establishment of Uu SRB1/SRB2 and DRB of the L2 U2N Remote UE is subject to Uu configuration procedures for L2 UE-to-Network Relay.

The following high level connection establishment procedure in Figure 16.12.5.1-1 applies to a L2 U2N Relay and L2 U2N Remote UE:

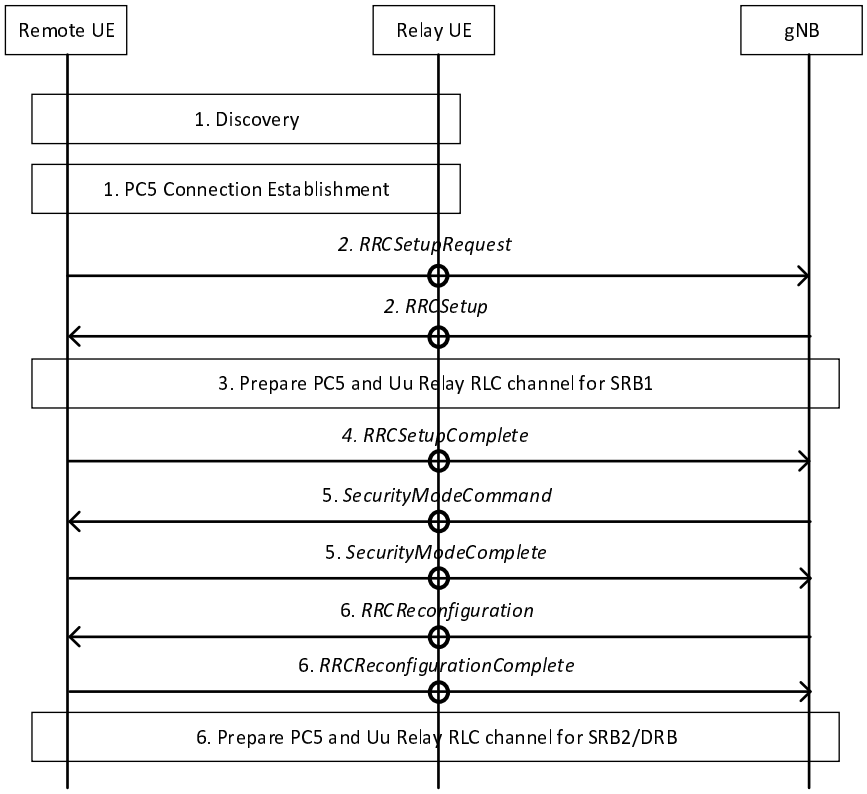


Figure 16.12.5.1-1: Procedure for L2 U2N Remote UE connection establishment

1. The L2 U2N Remote and L2 U2N Relay UE perform discovery procedure, and establish a PC5-RRC connection using the NR sidelink PC5 unicast link establishment procedure.

2. The L2 U2N Remote UE sends the first RRC message (i.e., *RRCSetupRequest*) for its connection establishment with gNB via the L2 U2N Relay UE, using a specified PC5 Relay RLC channel configuration. The L2 U2N Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the relay operation for the L2 U2N Remote UE. If the L2 U2N Relay UE is not in RRC_CONNECTED, it needs to do its own Uu RRC connection establishment upon reception of a message on the specified PC5 Relay RLC channel. After L2 U2N Relay UE's RRC connection establishment procedure and sending the *SidelinkUEInformationNR* message, gNB configures SRB0 relaying Uu Relay RLC channel to the U2N Relay UE. The gNB responds with an *RRCSetup* message to L2 U2N Remote UE. The *RRCSetup* message is sent to the L2 U2N Remote UE using SRB0 relaying Uu Relay RLC channel over Uu and a specified PC5 Relay RLC channel over PC5.

NOTE 1: Void.

3. The gNB and L2 U2N Relay UE perform relaying channel setup procedure over Uu. According to the configuration from gNB, the L2 U2N Relay/Remote UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the L2 U2N Remote/Relay UE over PC5.

4. The *RRCSetupComplete* message is sent by the L2 U2N Remote UE to the gNB via the L2 U2N Relay UE using SRB1 relaying channel over PC5 and SRB1 relaying channel configured to the L2 U2N Relay UE over Uu. Then the L2 U2N Remote UE is as in RRC_CONNECTED with the gNB.

5. The L2 U2N Remote UE and gNB establish security following the Uu security mode procedure and the security messages are forwarded through the L2 U2N Relay UE.

6. The gNB sends an *RRCReconfiguration* message to the L2 U2N Remote UE via the L2 U2N Relay UE, to setup the end-to-end SRB2/DRBs of the L2 U2N Remote UE. The L2 U2N Remote UE sends an *RRCReconfigurationComplete* message to the gNB via the L2 U2N Relay UE as a response. In addition, the

gNB may configure additional Uu Relay RLC channels between the gNB and L2 U2N Relay UE, and PC5 Relay RLC channels between L2 U2N Relay UE and L2 U2N Remote UE for the relaying traffic.

The following high level connection establishment procedure in Figure 16.12.5.1-2 applies to a multi-hop L2 U2N Relay(s) and L2 U2N Remote UE:

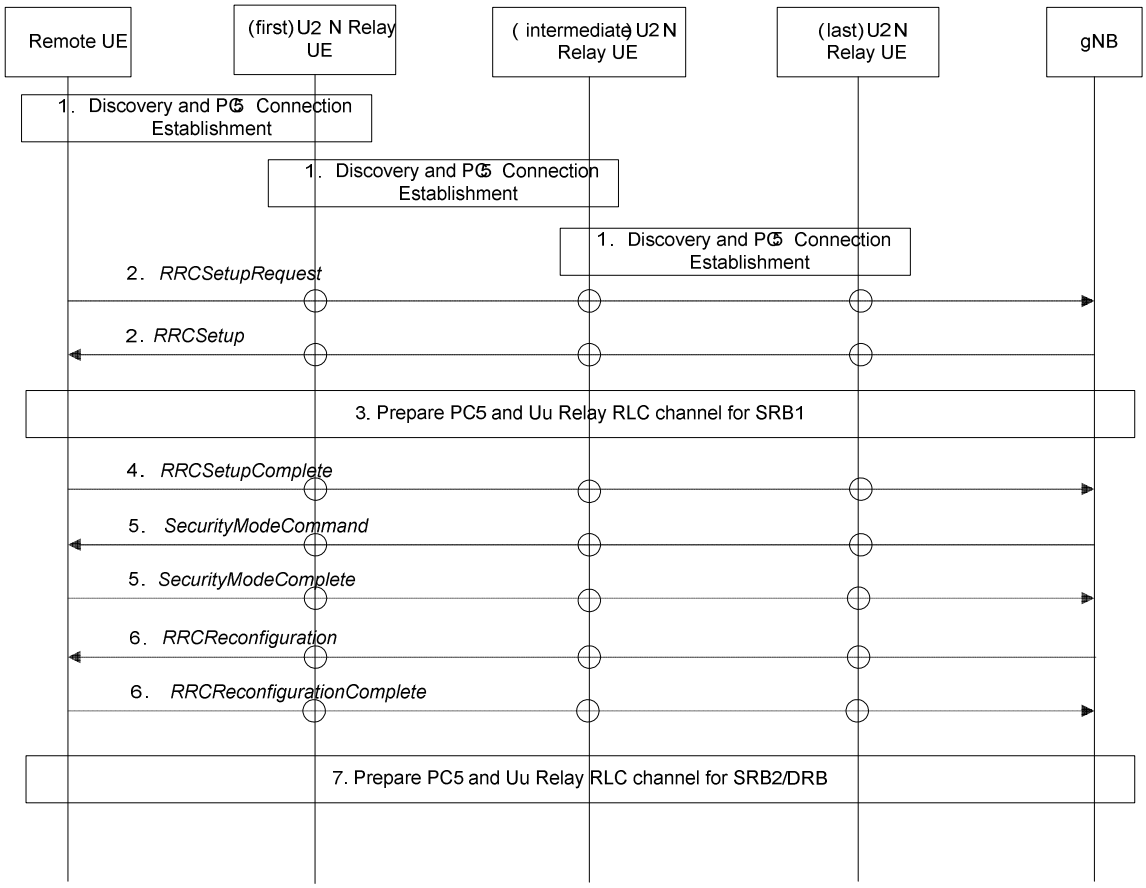


Figure 16.12.5.1-2: Procedure for multi-hop L2 U2N Remote UE connection establishment

1. The L2 U2N Remote and the first L2 U2N Relay UE, and between L2 U2N Relay UEs, perform a discovery procedure and establish a PC5-RRC connection using the NR sidelink PC5 unicast link establishment procedure.

2. The L2 U2N Remote UE sends the first RRC message (i.e., *RRCSetupRequest*) for its connection establishment with gNB via the first L2 U2N Relay UE, using a specified PC5 Relay RLC channel configuration. The first L2 U2N Relay UE sends the *SidelinkUEInformationNR* message to request for the dedicated configurations required to support the relay operation for the L2 U2N Remote UE. If the first L2 U2N Relay UE is not in RRC_CONNECTED, it performs its connection establishment procedure with the gNB. In this case, the first L2 U2N Relay UE acts as a L2 U2N Remote UE to establish its own relay connection. The first L2 U2N Relay UE stores the first RRC message received from the L2 U2N Remote UE and sends its own first RRC message (i.e., *RRCSetupRequest*) via the parent UE, using a specified PC5 Relay RLC channel configuration. If the parent UE is not the last L2 U2N Relay UE and not in RRC_CONNECTED, the same connection establishment procedure as the first L2 U2N Relay UE is performed. If the parent UE is the last L2 U2N Relay UE and not in RRC_CONNECTED, the same connection establishment procedure as the L2 U2N Relay UE in the single-hop is performed. After the first L2 U2N Relay UE's RRC connection establishment procedure and sending the *SidelinkUEInformationNR* message, gNB configures SRB0 relaying PC5 Relay RLC channel to the first L2 U2N Relay UE. The first L2 U2N Relay UE sends the stored first RRC message of the L2 U2N Remote UE to the gNB via the parent UE. The gNB responds with an *RRCSetup* message to L2 U2N Remote UE. The *RRCSetup* message is delivered toward the L2 U2N Remote UE using SRB0 relaying Uu Relay RLC channel over Uu or PC5 Relay RLC channel over PC5 through multiple U2N Relay UEs. The *RRCSetup* message for the L2 U2N Remote UE is delivered via a specified PC5 Relay RLC channel over PC5 from the first L2 U2N Relay UE to the L2 U2N Remote UE.

3. The gNB and the last L2 U2N Relay UE perform relaying channel setup procedure over Uu. The gNB and the intermediate L2 U2N Relay UE(s) perform relaying channel setup procedure over PC5. According to the

configuration from gNB, the L2 U2N Relay UEs/Remote UE establishes a PC5 Relay RLC channel for relaying of SRB1 towards the L2 U2N Remote UE/Relay UEs over PC5.

4. The *RRCSetupComplete* message is sent by the L2 U2N Remote UE to the gNB via intermediate L2 U2N Relay UE(s) using SRB1 relaying channel over PC5 and SRB1 relaying channel configured to the last L2 U2N Relay UE over Uu. Then the L2 U2N Remote UE is as in RRC_CONNECTED with the gNB.

5. The L2 U2N Remote UE and gNB establish security following the Uu security mode procedure and the security messages are forwarded through the multiple L2 U2N Relay UEs.

6. The gNB sends an *RRCReconfiguration* message to the L2 U2N Remote UE via multiple L2 U2N Relay UEs, to setup the end-to-end SRB2/DRBs of the L2 U2N Remote UE. The L2 U2N Remote UE sends an *RRCReconfigurationComplete* message to the gNB via multiple L2 U2N Relay UEs as a response. In addition, the gNB may configure additional Uu Relay RLC channels between the gNB and the last L2 U2N Relay UE, and PC5 Relay RLC channels between L2 U2N Relay UEs, and between the first L2 U2N Relay UE and L2 U2N Remote UE for the relaying traffic.

16.12.5.2 Radio Link Failure

The L2 U2N Remote UE in RRC_CONNECTED suspends Uu RLM (as described in clause 9.2.7) when connected to the gNB via a L2 U2N Relay UE.

The L2 U2N Relay UE declares Uu/PC5 Radio Link Failure (RLF) following the same criteria as described in clause 9.2.7.

After Uu/PC5 RLF is declared, the L2 U2N Relay UE takes the following action on top of the actions described in clause 9.2.7:

- a PC5-RRC message can be used for sending an indication to its connected L2 child UE(s), which may trigger RRC connection re-establishment for L2 child UE; or

- indicating to upper layer to trigger PC5 unicast link release.

Upon detecting PC5 RLF or PC5 link release, the L2 U2N Remote UE may trigger RRC connection re-establishment.

16.12.5.3 RRC Connection Re-establishment

The L2 U2N Remote UE may perform the following actions during the RRC connection re-establishment procedure:

- If only suitable cell(s) are available, the L2 U2N Remote UE initiates RRC re-establishment procedure towards a suitable cell;

- If only suitable L2 U2N Relay UE(s) are available, the L2 U2N Remote UE initiates RRC re-establishment procedure towards a suitable relay UE's serving cell via selected suitable L2 U2N Relay;

- If both a suitable cell and a suitable relay are available, the L2 U2N Remote UE can select either one to initiate RRC re-establishment procedure based on implementation.

16.12.5.4 RRC Connection Resume

The RRC connection resume procedure described in clause 9.2.2 is applied to L2 U2N Remote UE.

16.12.5.5 System Information

The in-coverage L2 U2N Remote UE is allowed to acquire any necessary SIB(s) over Uu interface irrespective of its PC5 connection to L2 U2N Relay UE.

The intermediate L2 U2N Relay UE acquires the SIB(s) requested from the child UE(s) or the SIB(s) of its own concerned. If the intermediate L2 U2N Relay UE is in the same cell of the last L2 U2N Relay UE, it is allowed to acquire any necessary SIB(s) over Uu interface irrespective of its PC5 connection to L2 U2N Relay UE.

The L2 U2N Remote UE or intermediate L2 U2N Relay UE can also receive the system information from the parent UE after PC5 connection establishment with L2 U2N Relay UE.

The L2 U2N Remote UE in RRC_CONNECTED can use the on-demand SIB framework as specified in TS 38.331 [12] to request the SIB(s) via L2 U2N Relay UE. The L2 U2N Remote UE in RRC_IDLE or RRC_INACTIVE can inform L2 parent UE of its requested SIB type(s) via PC5-RRC message. Then, the L2 U2N Relay UE in single-hop, the last L2 U2N Relay UE or the intermediate L2 U2N Relay UE triggers on-demand SI/SIB acquisition procedure as specified in TS 38.331 [12] according to its own RRC state (if needed) and sends the acquired SI(s)/SIB(s) to L2 child UE via PC5-RRC message.

Any SIB that the RRC_IDLE or RRC_INACTIVE L2 U2N Remote UE has a requirement to use (e.g., for relay purpose) can be requested by the L2 U2N Remote UE (from the L2 U2N Relay UE or the network). For SIBs that have been requested by the L2 U2N Remote UE from the L2 U2N Relay UE, the L2 U2N Relay UE forwards them again in case of any update for requested SIB(s). In case of RRC_CONNECTED L2 U2N Remote UE(s), it is the responsibility of the network to send updated SIB(s) to L2 U2N Remote UE(s) when they are updated. The L2 U2N Remote UE de-configures SI request with L2 U2N Relay UE when entering into RRC_CONNECTED state.

For SIB1 forwarding, for L2 U2N Remote UE, both request-based delivery (i.e., SIB1 request by the U2N Remote UE) and unsolicited forwarding are supported by L2 U2N Relay UE, of which the usage is left to L2 U2N Relay UE implementation. If SIB1 changes, for L2 U2N Remote UE in RRC_IDLE or RRC_INACTIVE, the L2 U2N Relay UE always forwards SIB1.

For the L2 U2N Remote UE in RRC_IDLE or RRC_INACTIVE, the short message over Uu interface is not forwarded by the L2 U2N Relay UE to the L2 U2N Remote UE. The L2 U2N Relay UE can forward PWS SIBs to its connected L2 U2N Remote UE(s).

RAN sharing is supported for L2 U2N Relay UE. In particular, the L2 U2N Relay UE may forward, via discovery message, cell access related information before the establishment of a PC5-RRC connection.

16.12.5.6 Paging

When both L2 U2N Relay UE and L2 U2N Remote UE are in RRC IDLE or RRC INACTIVE, the L2 U2N Relay UE monitors paging occasions of its connected L2 U2N Remote UE(s). When a L2 U2N Relay UE needs to monitor paging for a L2 U2N Remote UE, the L2 U2N Relay UE should monitor all POs of the L2 U2N Remote UE.

When the intermediate L2 U2N Relay UE is in RRC_IDLE or RRC_INACTIVE, and the intermediate L2 U2N Relay UE exists in the same cell as the last L2 U2N Relay UE, the intermediate L2 U2N Relay UE can monitor paging via the Uu link for all the downstream UE(s) if the intermediate L2 U2N Relay UE hasn't requested paging monitoring to the parent UE.

When L2 U2N Relay UE is in RRC_CONNECTED and L2 U2N Remote UE(s) or child UE(s) is in RRC_IDLE or RRC_INACTIVE, there are two options for paging delivery:

- The L2 U2N Relay UE monitors POs of its connected L2 U2N Remote UE(s) or of all the downstream UE(s) if the active DL BWP of the L2 U2N Relay UE is configured with common search space including paging search space;
- The delivery of the L2 U2N Remote UE's paging or of all the downstream UE(s)’paging can be performed through a dedicated RRC message from the gNB to the L2 U2N Relay UE. The dedicated RRC message for delivering L2 U2N Remote UE paging to the RRC_CONNECTED L2 U2N Relay UE may contain one or more Remote UE IDs (5G-S-TMSI or I-RNTI).

It is up to network implementation to decide which of the above two options to use. The L2 U2N Relay UE in RRC_CONNECTED, if configured with paging search space, can determine whether to monitor POs for a L2 U2N Remote UE based on the indication within the PC5-RRC signalling received from the L2 U2N Remote UE.

The L2 U2N Remote UE in RRC_IDLE provides 5G-S-TMSI and UE specific DRX cycle (if configured by upper layer) to the L2 U2N Relay UE for requesting to perform PO monitoring. The L2 U2N Remote UE in RRC_INACTIVE provides the minimum value of two UE specific DRX cycles (if configured respectively by upper layer and NG-RAN), 5G-S-TMSI and I-RNTI to the L2 U2N Relay UE for PO monitoring. The L2 U2N intermediate Relay UE in RRC_IDLE or RRC_INACTIVE can provide the received information for paging monitoring from the child UE(s) to the parent UE. The L2 U2N Relay UE in RRC_CONNECTED can notify the L2 U2N Remote UE or all the downstream UE information (i.e. 5G-S-TMSI/I-RNTI) to the gNB via the *SidelinkUEInformationNR* message for paging delivery purpose. The L2 U2N Relay UE receives paging messages to check the 5G-S-TMSI/I-RNTI and sends relevant paging record to the L2 U2N Remote UE or child UE accordingly.

The L2 U2N Relay UE uses unicast signalling to send paging to the L2 U2N Remote UE via PC5.

16.12.5.7 Access Control

The L2 U2N Remote UE performs unified access control as defined in TS 38.331 [12]. The L2 U2N Relay UE does not perform UAC for L2 U2N Remote UE's data.

16.12.5.8 Mobility Registration Update and RAN Area Update

The L2 U2N Remote UE performs Mobility Registration Update/RNAU based on the L2 U2N Relay UE's serving cell when it is connected with the L2 U2N Relay UE. A L2 U2N Remote UE in RRC_IDLE or RRC_INACTIVE initiates Mobility Registration Update/RNAU procedure if the serving cell changes (due to cell change by the L2 U2N Relay UE) and the new serving cell is outside of the L2 U2N Remote UE's configured RNA/TA.

16.12.6 Service Continuity for L2 U2N relay

16.12.6.0 General

The service continuity procedure is applicable for the mobility cases of path switch from indirect to direct path and from direct to indirect path when the L2 U2N Remote UE and L2 U2N Relay UE belong to the same gNB or different gNB. This procedure is also applicable for the mobility cases of path switch from indirect to indirect path when the two L2 U2N Relay UEs belong to the same gNB or different gNBs. For inter-gNB path switching, the source gNB decides to trigger path switching and the path switch type.

If the target path is multi-hop, it is assumed that all L2 U2N Relay UEs along the target path are in the RRC_CONNECTED. However, if the target path is a single-hop, the target U2N Relay UE can be in any RRC state.

16.12.6.1 Switching from single/multi-hop indirect to direct path

For service continuity of L2 U2N Relay, the following procedure is used, in case of L2 U2N Remote UE switching from indirect to direct path under the same gNB. The Figure 16.12.6.1-1a describes a single-hop indirect path to direct path switching and Figure 16.12.6.1-1b describes a multi-hop indirect path to direct path switching:

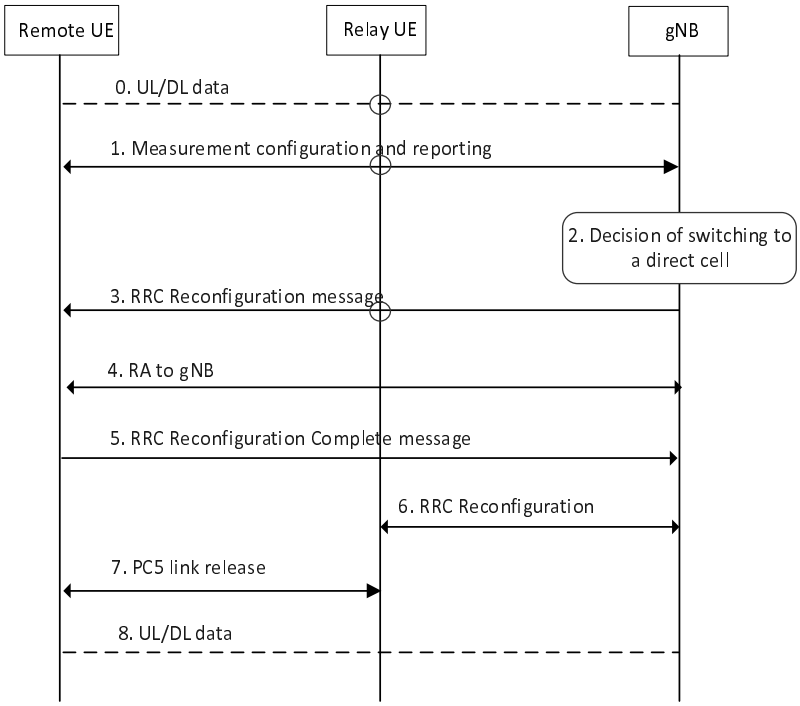


Figure 16.12.6.1-1a: Procedure for L2 U2N Remote UE intra-gNB switching from single-hop indirect to direct path

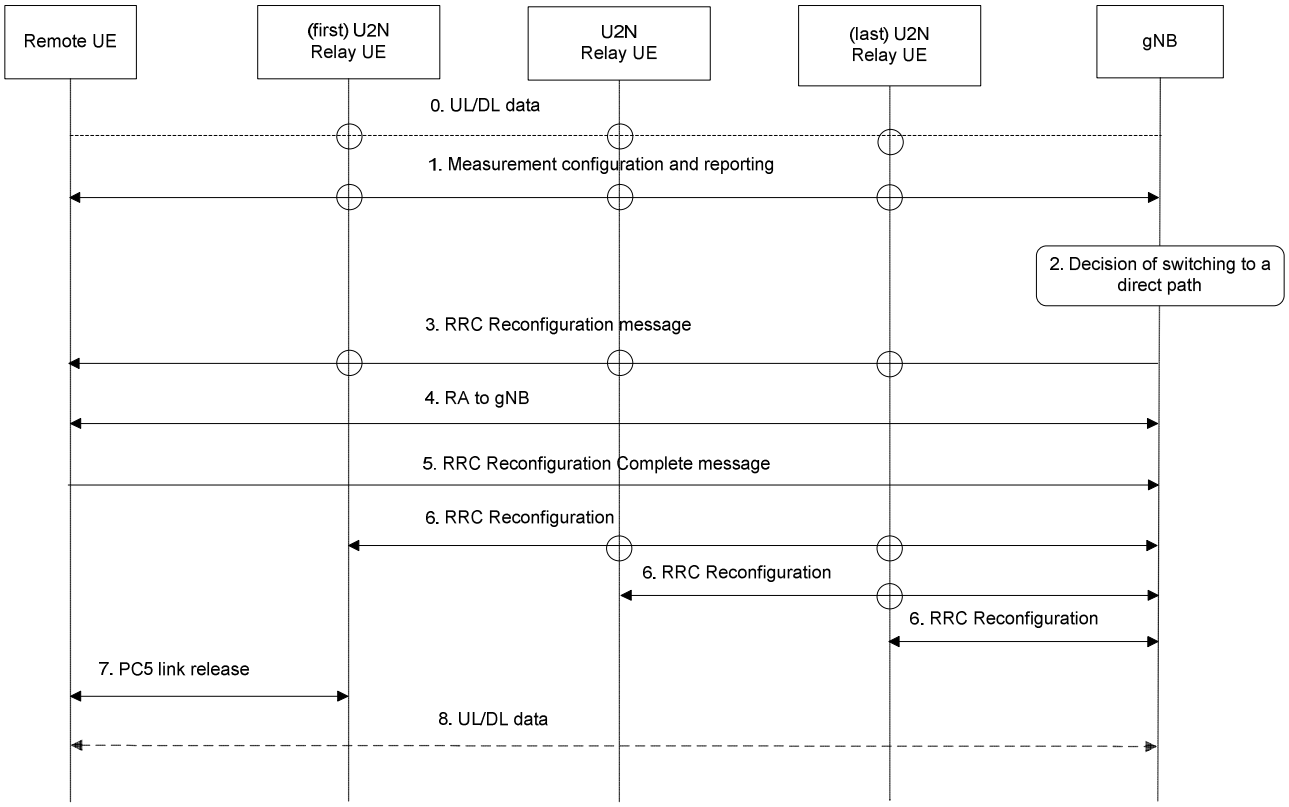


Figure 16.12.6.1-1b: Procedure for L2 U2N Remote UE intra-gNB switching from multi-hop indirect to direct path

1. The Uu measurement configuration and measurement report signalling procedures are performed to evaluate both relay link measurement and Uu link measurement. The measurement results from L2 U2N Remote UE are reported when configured measurement reporting criteria are met. The sidelink relay measurement report shall include at least L2 U2N Relay UE's source L2 ID, serving cell ID (i.e., NCGI/NCI), and sidelink measurement quantity result. The sidelink measurement quantity can be SL-RSRP of the serving L2 U2N Relay UE, and if SL-RSRP is not available, SD-RSRP is used.

2. The gNB decides to switch the L2 U2N Remote UE onto direct Uu path.

3. The gNB sends the *RRCReconfiguration* message to the L2 U2N Remote UE. The L2 U2N Remote UE stops User Plane and Control Plane transmission via the L2 U2N Relay UE(s) after reception of the *RRCReconfiguration* message with the path switch configuration.

4. The L2 U2N Remote UE synchronizes with the gNB and performs Random Access.

5. The UE (i.e., L2 U2N Remote UE in previous steps) sends the *RRCReconfigurationComplete* message to the gNB via the direct path, using the configuration provided in the *RRCReconfiguration* message. From this step, the UE (i.e., L2 U2N Remote UE in previous steps) uses the RRC connection via the direct path to the gNB.

6. The gNB sends the *RRCReconfiguration* message to the L2 U2N Relay UE(s) on the source path to reconfigure the connection between the L2 U2N Relay UE and the gNB. The *RRCReconfiguration* message to the L2 U2N Relay UE(s) on the source path can be sent any time after step 3 based on gNB implementation (e.g., to release Uu Relay RLC Channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration related to the L2 U2N Remote UE).

7. Either L2 U2N Relay UE or L2 U2N Remote UE's AS layer indicates upper layers to release PC5 unicast link after receiving the *RRCReconfiguration* message from the gNB. The timing to execute link release is up to UE implementation.

8. The data path is switched from indirect path to direct path between the UE (i.e., previous L2 U2N Remote UE) and the gNB. The PDCP re-establishment or PDCP data recovery in uplink is performed by the UE (i.e., previous L2 U2N Remote UE) for lossless delivery during path switch if gNB configures it.

NOTE 1: Step 8 can be executed any time after step 4. Step 8 is independent of step 6 and step 7.

For service continuity of L2 U2N Relay, the following procedure is used, in case of L2 U2N Remote UE switching from indirect to direct path under another gNB:

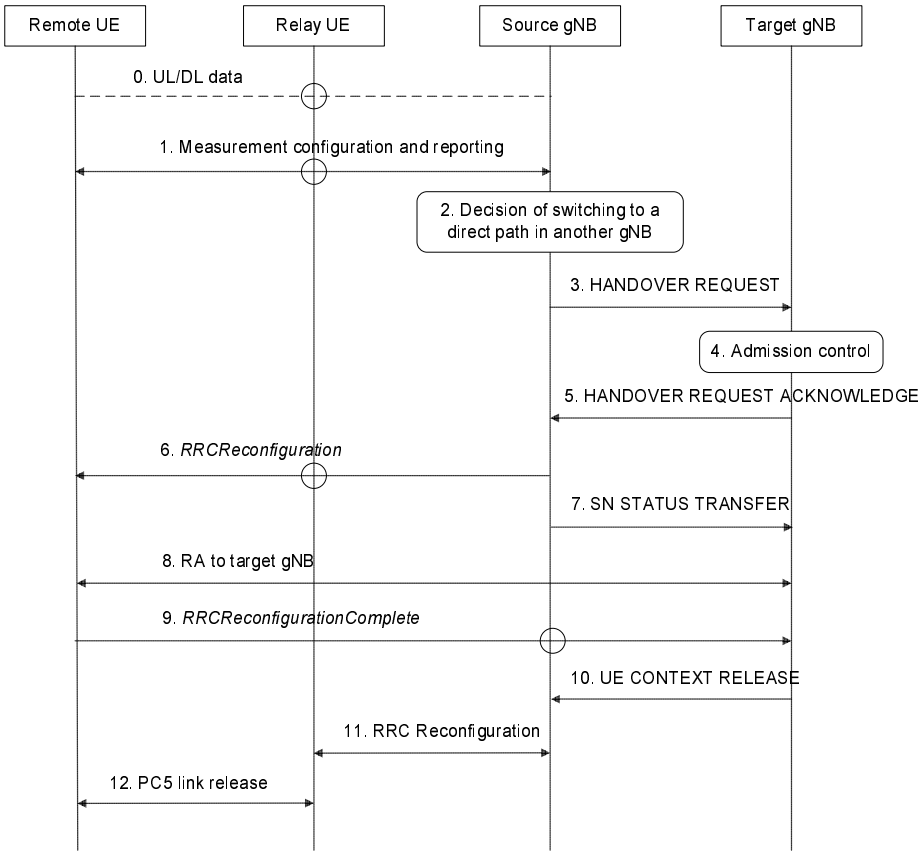


Figure 16.12.6.1-2: Procedure for L2 U2N Remote UE inter-gNB switching from indirect to direct path

1. The Uu measurement configuration is configured by the source gNB, and measurement report signalling procedures are performed by the L2 U2N Remote UE to evaluate both relay link measurement and Uu link measurement. The measurement results from L2 U2N Remote UE are reported when configured measurement reporting criteria are met. The sidelink relay measurement report shall include at least L2 U2N Relay UE's source L2 ID, serving cell ID (i.e., NCGI/NCI), and sidelink measurement quantity result. The sidelink measurement quantity can be SL-RSRP of the serving L2 U2N Relay UE, and if SL-RSRP is not available, SD-RSRP is used.

2. The source gNB decides to trigger path switch for the L2 U2N Remote UE, onto direct path.

3. The source gNB sends the HANDOVER REQUEST message to the target gNB with necessary information to prepare the handover at the target side.

NOTE 2: In order to support the DL lossless path switch for the L2 U2N Remote UE, the source gNB may not discard the DL data even though the delivery of the data has been acknowledged by the L2 U2N Relay UE based on the gNB implementation. Then, the source gNB forwards the buffered DL data to the target gNB during the data forwarding procedure.

4. Admission Control may be performed by the target gNB.

5. The target gNB sends the HANDOVER REQUEST ACKNOWLEDGE message to the source gNB, which contains RRC configuration for the L2 U2N Remote UE at the target side.

6. The source gNB triggers the path switch by sending an *RRCReconfiguration* message to the L2 U2N Remote UE, containing at least cell ID and the information required to access the target cell. The L2 U2N Remote UE stops User Plane and Control Plane transmission via the L2 U2N Relay UE after reception of the *RRCReconfiguration* message.

7. The source gNB sends the SN STATUS TRANSFER message to the target gNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of the L2 U2N Remote UE's DRBs for which PDCP status preservation applies (i.e. for RLC AM).

8. The L2 U2N Remote UE synchronizes with the target gNB and performs Random Access.

9. The L2 U2N Remote UE sends *RRCReconfigurationComplete* message to target gNB via the direct path.

10. The target gNB sends the UE CONTEXT RELEASE message to inform the source gNB about the success of the path switch.

11. The source gNB sends *RRCReconfiguration* message to the L2 U2N Relay UE to reconfigure the connection between the L2 U2N Relay UE and the source gNB. The *RRCReconfiguration* message to the L2 U2N Relay UE can be sent any time after step 6 based on source gNB implementation (e.g., to release Uu Relay RLC channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration related to the L2 U2N Remote UE).

12. Either L2 U2N Relay UE or L2 U2N Remote UE's AS layer indicates upper layer to release PC5 unicast link after receiving the *RRCReconfiguration* message from the source gNB. The timing to execute link release is up to UE implementation.

16.12.6.2 Switching from direct to indirect path

The gNB can select a L2 U2N Relay UE in any RRC state i.e., RRC_IDLE, RRC_INACTIVE, or RRC_CONNECTED, as a target L2 U2N Relay UE for switching from a direct path to an indirect path if the target path is a single-hop. If the target path is a multi-hop, the gNB selects L2 U2N Relay UE in RRC_CONNECTED as a target first L2 U2N Relay UE.

For service continuity of L2 U2N Remote UE, the following procedure is used, in case of the L2 U2N Remote UE switching from direct to indirect path under the same gNB via a L2 U2N Relay UE in RRC_CONNECTED:

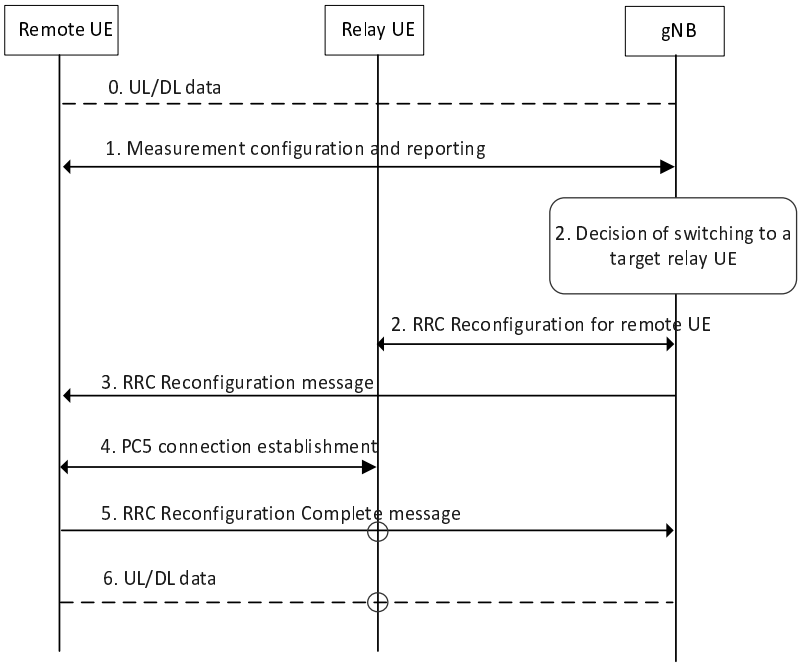


Figure 16.12.6.2-1a: Procedure for L2 U2N Remote UE intra-gNB switching from direct to single-hop indirect path via a L2 U2N Relay UE in RRC_CONNECTED

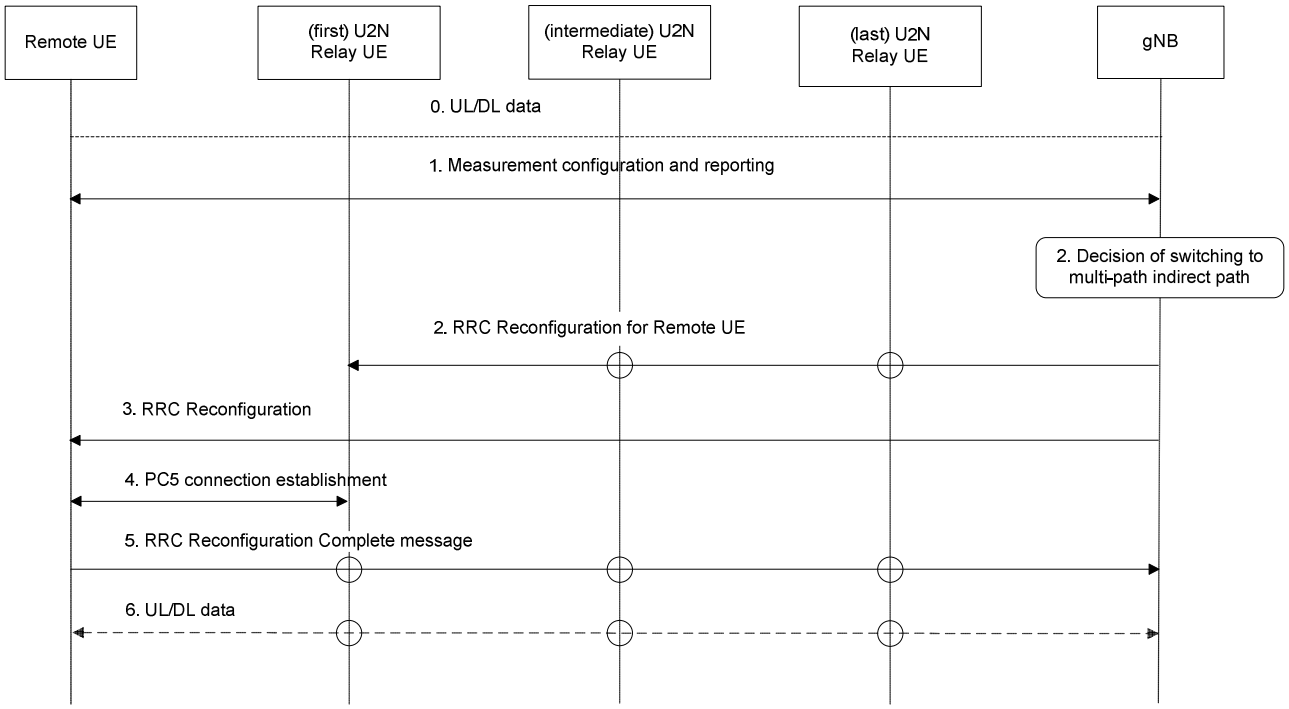


Figure 16.12.6.2-1b: Procedure for L2 U2N Remote UE intra-gNB switching from direct to multi-hop indirect path via a L2 U2N Relay UE in RRC_CONNECTED

1. The L2 U2N Remote UE reports one or multiple candidate L2 U2N Relay UE(s) and Uu measurements, after it measures/discovers the candidate L2 U2N Relay UE(s):

   - The L2 U2N Remote UE filters the appropriate L2 U2N Relay UE(s) according to relay selection criteria before reporting. The L2 U2N Remote UE shall report only the L2 U2N Relay UE candidate(s) that fulfil the higher layer criteria;

   - The reporting includes at least a L2 U2N Relay UE ID, a L2 U2N Relay UE's serving cell ID, and a sidelink measurement quantity information. SD-RSRP is used as sidelink measurement quantity.

2. The gNB decides to switch the L2 U2N Remote UE to a target L2 U2N Relay UE. Then the gNB sends an *RRCReconfiguration* message to the target L2 U2N Relay UE, which includes at least the L2 U2N Remote UE's local ID and L2 ID, Uu Relay RLC channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration.

3. The gNB sends the *RRCReconfiguration* message to the L2 U2N Remote UE. The *RRCReconfiguration* message includes at least the L2 U2N Relay UE ID, Remote UE's local ID, PC5 Relay RLC channel configuration for relay traffic and the associated end-to-end Uu radio bearer(s). The L2 U2N Remote UE stops User Plane and Control Plane transmission over the direct path after reception of the *RRCReconfiguration* message from the gNB.

4. The L2 U2N Remote UE establishes PC5-RRC connection with target L2 U2N Relay UE.

5. The L2 U2N Remote UE completes the path switch procedure by sending the *RRCReconfigurationComplete* message to the gNB via the L2 U2N Relay UE.

6. The data path is switched from direct path to indirect path between the L2 U2N Remote UE and the gNB.

For service continuity of L2 U2N Remote UE, the following procedure is used, in case of the L2 U2N Remote UE switching from direct to indirect path via a L2 U2N Relay UE in RRC_CONNECTED under another gNB:

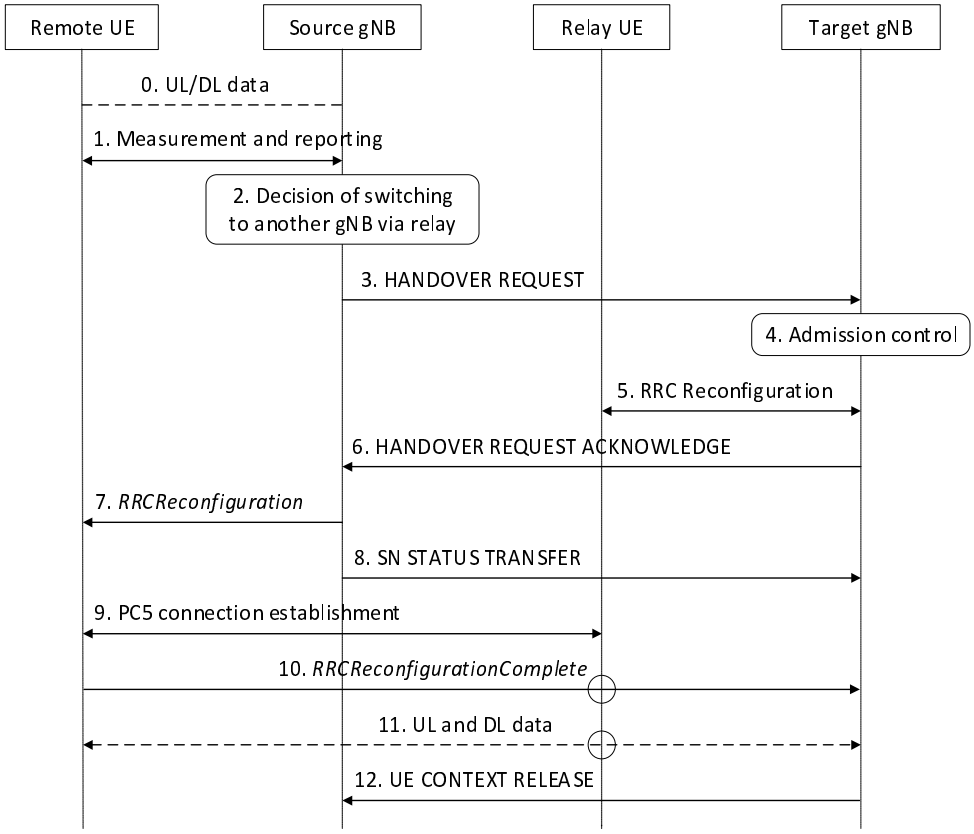


Figure 16.12.6.2-2: Procedure for L2 U2N Remote UE inter-gNB switching from direct to indirect path via a L2 U2N Relay UE in RRC_CONNECTED

1. The L2 U2N Remote UE reports one or multiple candidate L2 U2N Relay UE(s) and Uu measurements to the source gNB, after it measures/discovers the candidate L2 U2N Relay UE(s):

   - The L2 U2N Remote UE filters the appropriate L2 U2N Relay UE(s) according to relay selection criteria before reporting. The L2 U2N Remote UE shall report only the L2 U2N Relay UE candidate(s) that fulfil the higher layer criteria;

   - The reporting includes at least a L2 U2N Relay UE ID, a L2 U2N Relay UE's serving cell ID, and a sidelink measurement quantity information. SD-RSRP is used as sidelink measurement quantity.

2. The source gNB decides to trigger path switch for the L2 U2N Remote UE onto indirect path of the target gNB, based on *MeasurementReport* and RRM information.

3. The source gNB sends a HANDOVER REQUEST message to the target gNB to prepare the path switch at the target side. The HANDOVER REQUEST message includes Remote UE L2 ID and a list of candidate target Relay UE IDs belonging to one cell of the target gNB.

4. Admission Control may be performed by the target gNB.

5. The target gNB selects one target Relay UE from the list of candidate Relay UEs provided by the source gNB, and sends the *RRCReconfiguration* message to L2 U2N Relay UE for relaying configuration, which includes at least the L2 U2N Remote UE's local ID and L2 ID, Uu Relay RLC channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration. If the target gNB fails to select a target Relay UE from the list of candidate Relay UEs, the target gNB rejects the handover request from the source gNB.

6. The target gNB sends the HANDOVER REQUEST ACKNOWLEDGE message to the source gNB, which contains RRC configuration for L2 U2N Remote UE at the target side.

7. The source gNB sends the *RRCReconfiguration* message to the L2 U2N Remote UE, which includes at least the L2 U2N Relay UE ID, Remote UE's local ID, PC5 Relay RLC channel configuration for relay traffic and the

associated Uu end-to-end radio bearer(s). The L2 U2N Remote UE stops User Plane and Control Plane transmission over the direct path after reception of the *RRCReconfiguration* message from the source gNB.

8. The source gNB sends the SN STATUS TRANSFER message to the target gNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of the L2 U2N Remote UE's DRBs for which PDCP status preservation applies (i.e. for RLC AM).

9. The L2 U2N Remote UE establishes PC5 connection with L2 U2N Relay UE.

10. The L2 U2N Remote UE sends the *RRCReconfigurationComplete* message to target gNB via the L2 U2N Relay UE.

11. The data path is switched from direct path to indirect path between the L2 U2N Remote UE and the target gNB via the target L2 U2N Relay UE.

12. The target gNB sends the UE CONTEXT RELEASE message to inform the source gNB about the success of the path switch.

In case the selected L2 U2N Relay UE for direct to single-hop indirect path switch is in RRC_IDLE or RRC_INACTIVE, after receiving the path switch command, the L2 U2N Remote UE establishes a PC5 link with the L2 U2N Relay UE and sends the *RRCReconfigurationComplete* message via the L2 U2N Relay UE, which triggers the L2 U2N Relay UE to enter RRC_CONNECTED state. The procedure for L2 U2N Remote UE switching to single-hop indirect path in Figure 16.12.6.2-1a can be also applied for the case that the selected L2 U2N Relay UE for direct to single-hop indirect path switch is in RRC_IDLE or RRC_INACTIVE with the exception that the *RRCReconfiguration* message is sent from the gNB to the L2 U2N Relay UE after the L2 U2N Relay UE enters RRC_CONNECTED state, which happens during step 5 in Figure 16.12.6.2-1a, and during step 10 in Figure 16.12.6.2-2.

16.12.6.3 Switching from multi/single-hop indirect to multi/single-hop indirect path

The gNB can select an L2 U2N Relay UE in any RRC state i.e., RRC_IDLE, RRC_INACTIVE, or RRC_CONNECTED, as a target L2 U2N Relay UE for switching from multi/single-hop indirect path to single-hop indirect path.

For service continuity of L2 U2N Remote UE, the following Figure 16.12.6.3-1a describes the case of the L2 U2N Remote UE switching from single-hop indirect path via L2 U2N Relay UE to single-hop indirect path via a target L2 U2N Relay UE in RRC_CONNECTED under the same gNB. The Figure 16.12.6.3-1b describes the case of the L2 U2N Remote UE switching from multi-hop indirect path via the source first L2 U2N Relay UEs to single-hop indirect path via a target L2 U2N Relay UE in RRC_CONNECTED under the same gNB. The Figure 16.12.6.3-1c describes the case of the L2 U2N Remote UE switching from single-hop indirect path via source L2 U2N Relay UE to multi-hop indirect path via target first L2 U2N Relay UE in RRC_CONNECTED under the same gNB:

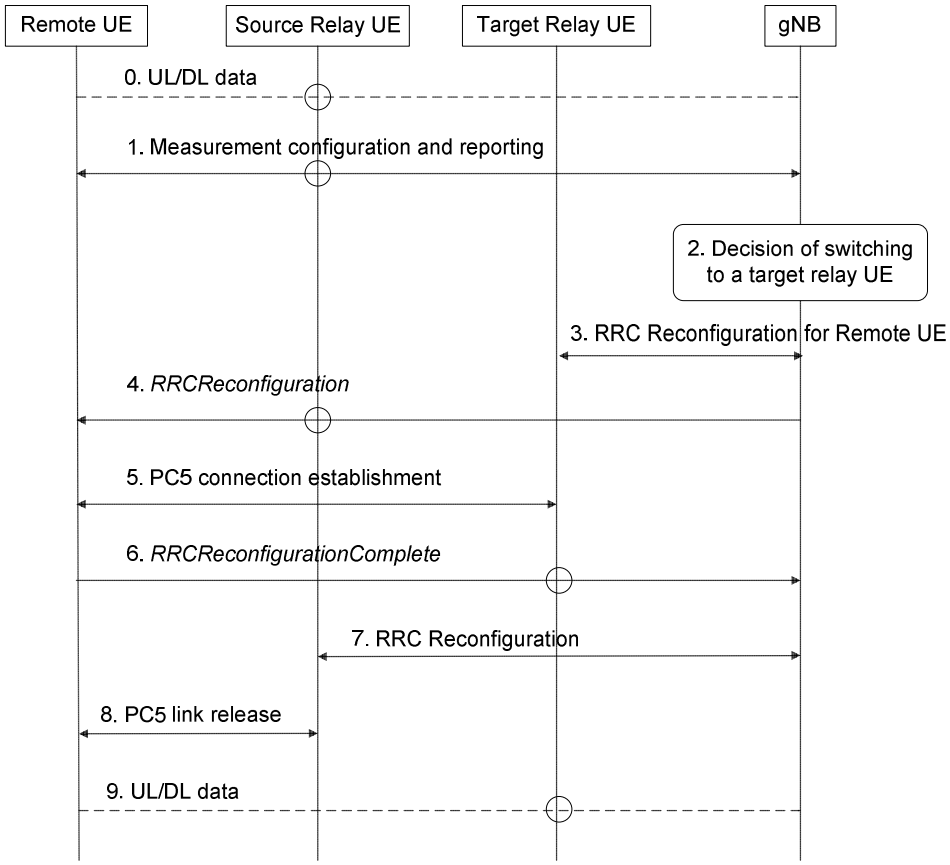


Figure 16.12.6.3-1a: Procedure for L2 U2N Remote UE intra-gNB switching from single-hop indirect to single-hop indirect path via a target L2 U2N Relay UE in RRC_CONNECTED

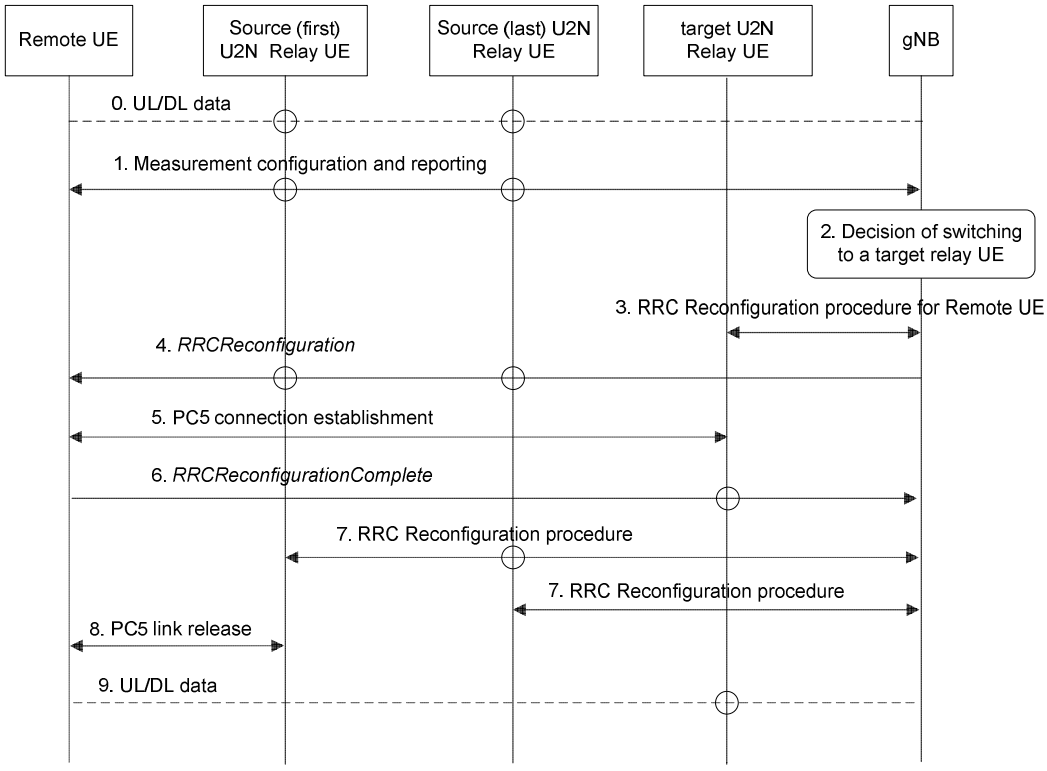


Figure 16.12.6.3-1b: Procedure for L2 U2N Remote UE intra-gNB switching from multi-hop indirect to single-hop indirect path via a target L2 U2N Relay UE in RRC_CONNECTED

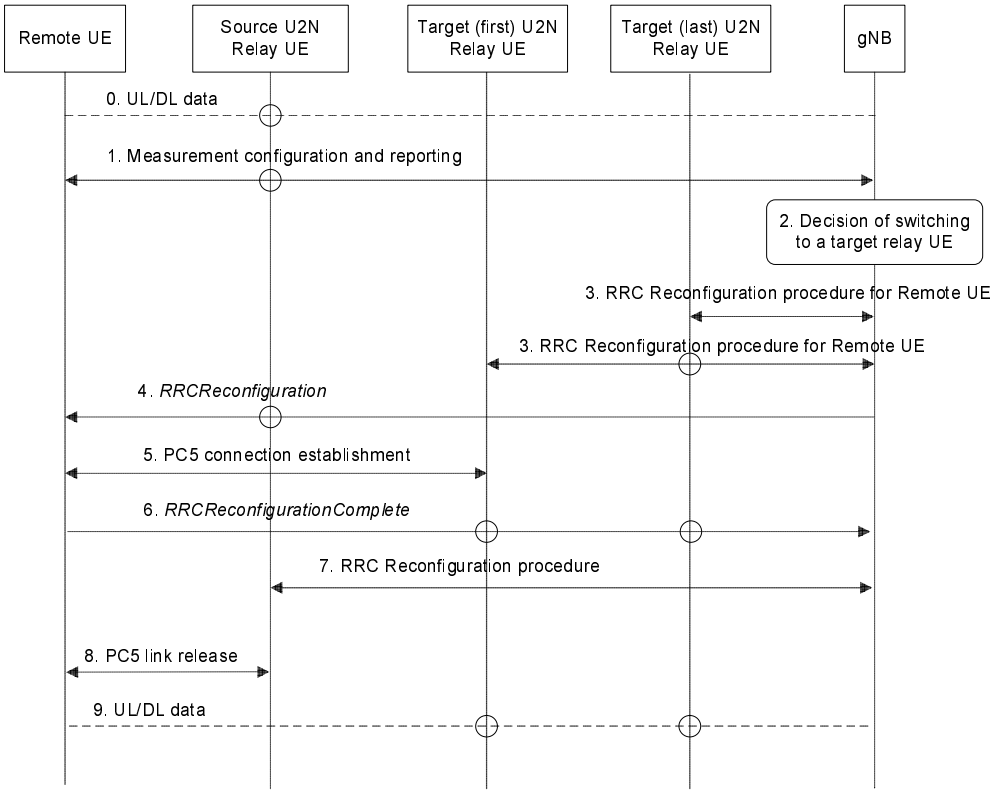


Figure 16.12.6.3-1c: Procedure for L2 U2N Remote UE intra-gNB switching from single-hop indirect to multi-hop indirect path via a target L2 U2N Relay UE in RRC_CONNECTED

1. The L2 U2N Remote UE reports one or multiple candidate L2 U2N Relay UE(s) and sidelink measurement between the L2 U2N Remote UE and the parent UE to the source gNB, after it measures/discovers the candidate L2 U2N Relay UE(s):

   - The L2 U2N Remote UE filters the appropriate L2 U2N Relay UE(s) according to relay selection criteria before reporting. The L2 U2N Remote UE shall report only the L2 U2N Relay UE candidate(s) that fulfil the higher layer criteria;

   - The reporting includes at least a L2 U2N Relay UE ID, a L2 U2N Relay UE's serving cell ID, and a sidelink measurement quantity information. SD-RSRP is used as sidelink measurement quantity.

2. The gNB decides to switch the L2 U2N Remote UE to a target L2 U2N Relay UE under the same gNB.

3. The gNB sends an *RRCReconfiguration* message to the target L2 U2N Relay UE, which includes at least the L2 U2N Remote UE's local ID and L2 ID, Uu and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration.

4. The gNB sends the *RRCReconfiguration* message to the L2 U2N Remote UE. The *RRCReconfiguration* message includes at least the target L2 U2N Relay UE ID, Remote UE's local ID, PC5 Relay RLC channel configuration for relay traffic, and the associated end-to-end radio bearer(s). The L2 U2N Remote UE stops User Plane and Control Plane transmission over the indirect path via the source L2 U2N Relay UE(s) after the reception of the *RRCReconfiguration* message from the gNB.

5. The L2 U2N Remote UE establishes PC5-RRC connection with the target L2 U2N Relay UE.

6. The L2 U2N Remote UE sends *RRCReconfigurationComplete* message to the gNB via the target L2 U2N Relay UE.

7. The gNB sends the *RRCReconfiguration* message to the source L2 U2N Relay UE(s) on the source path to reconfigure the connection between the source L2 U2N Relay UE and the gNB. The *RRCReconfiguration* message to the source L2 U2N Relay UE(s) on the source path can be sent any time after step 4 based on gNB implementation (e.g., to release Uu and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration related to the L2 U2N Remote UE).

8. Either source L2 U2N Relay UE's AS layer or L2 U2N Remote UE's AS layer indicates upper layers to release PC5 unicast link after receiving the *RRCReconfiguration* message from the gNB. The timing to execute link release is up to UE implementation after step 4 or step7.

9. The data path is switched from the source L2 U2N Relay UE(s) to the target L2 U2N Relay UE between the L2 U2N Remote UE and the gNB. This step can be any time after step 6.

For service continuity of L2 U2N Remote UE between gNBs, the following procedure is used, in case of the L2 U2N Remote UE, which is connected to indirect path, switching to another indirect path via a target L2 U2N Relay UE in RRC_CONNECTED under another gNB:

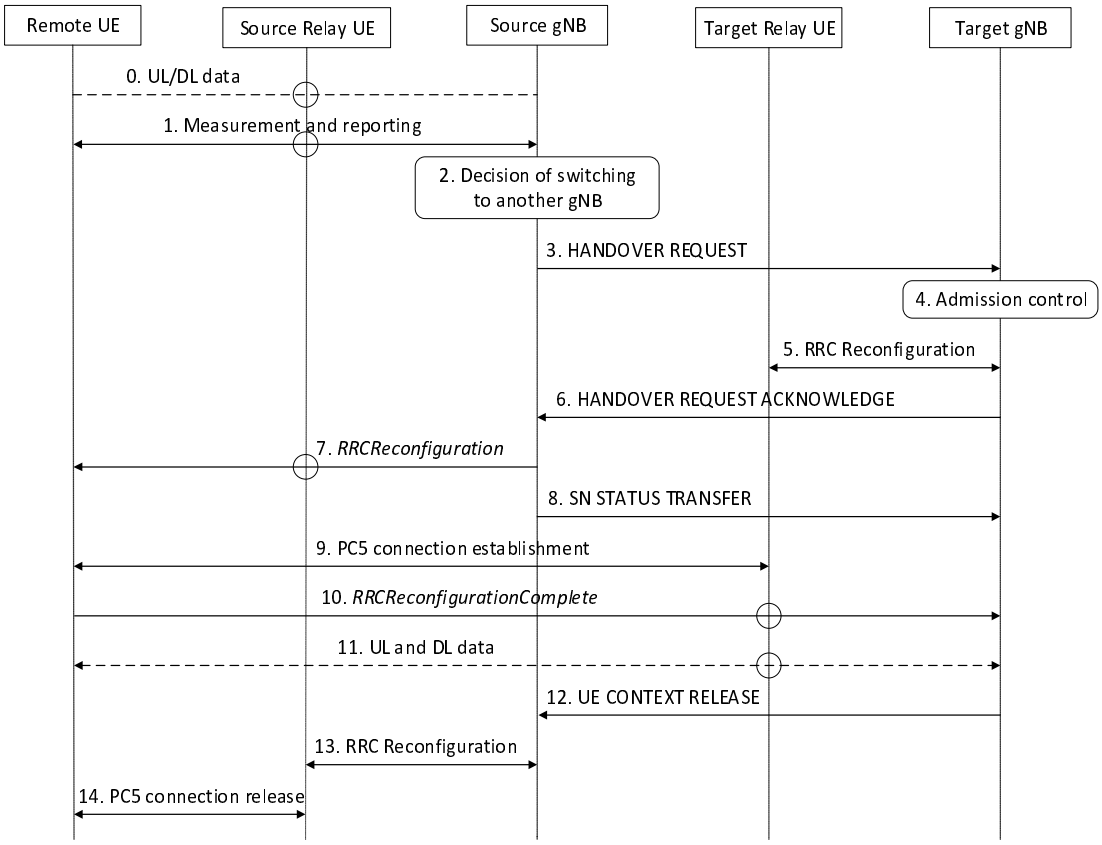


Figure 16.12.6.3-2: Procedure for L2 U2N Remote UE inter-gNB switching from indirect to indirect path via a target L2 U2N Relay UE in RRC_CONNECTED

1. The L2 U2N Remote UE reports one or multiple candidate L2 U2N Relay UE(s) and sidelink measurement between the L2 U2N Remote UE and the source L2 U2N Relay UE to the source gNB, after it measures/discovers the candidate L2 U2N Relay UE(s):

   - The L2 U2N Remote UE filters the appropriate L2 U2N Relay UE(s) according to relay selection criteria before reporting. The L2 U2N Remote UE shall report only the L2 U2N Relay UE candidate(s) that fulfil the higher layer criteria;

   - The reporting includes at least a L2 U2N Relay UE ID, a L2 U2N Relay UE's serving cell ID, and a sidelink measurement quantity information. SD-RSRP is used as sidelink measurement quantity.

2. The source gNB decides to trigger the L2 U2N Remote UE to switch to an indirect path of another gNB.

3. The source gNB sends a HANDOVER REQUEST message to the target gNB to prepare the path switch at the target side. The HANDOVER REQUEST message includes Remote UE L2 ID and a list of candidate target Relay UE IDs belonging to one cell of the target gNB.

NOTE: In order to support the DL lossless path switching for the L2 U2N Remote UE, the source gNB may not discard the DL data even though the delivery of the data has been acknowledged by the source L2 U2N Relay UE based on the gNB implementation. Then, the source gNB forwards the buffered DL data to the target gNB during the data forwarding procedure.

4. Admission Control may be performed by the target gNB.

5. The target gNB selects one target Relay UE from the list of candidate Relay UEs provided by the source gNB, sends the *RRCReconfiguration* message to the L2 U2N Relay UE for relaying configuration, which includes at least the L2 U2N Remote UE's local ID and L2 ID, Uu Relay RLC channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration. If the target gNB fails to select one target Relay UE from the list of candidate Relay UEs, the target gNB rejects the handover request from the source gNB.

6. The target gNB sends the HANDOVER REQUEST ACKNOWLEDGE message to the source gNB, which contains RRC configuration for L2 U2N Remote UE at the target side.

7. The source gNB sends the *RRCReconfiguration* message to the L2 U2N Remote UE, which includes at least the target L2 U2N Relay UE ID, Remote UE's local ID, PC5 Relay RLC channel configuration for relay traffic and the associated end-to-end Uu radio bearer(s). The L2 U2N Remote UE stops User Plane and Control plane transmission over the (source) indirect path after reception of the *RRCReconfiguration* message from the source gNB.

8. The source gNB sends the SN STATUS TRANSFER message to the target gNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of the L2 U2N Remote UE's DRBs for which PDCP status preservation applies (i.e. for RLC AM).

9. The L2 U2N Remote UE establishes PC5 connection to the target L2 U2N Relay UE.

10. The L2 U2N Remote UE sends the *RRCReconfigurationComplete* message to the target gNB via the target L2 U2N Relay UE.

11. The data path is switched from indirect path to indirect path between the L2 U2N Remote UE and the target gNB via the target L2 U2N Relay UE.

12. The target gNB sends the UE CONTEXT RELEASE message to inform the source gNB about the success of the path switch.

13. The source gNB sends the *RRCReconfiguration* message to the source L2 U2N Relay UE to reconfigure the connection between the source L2 U2N Relay UE and the source gNB. The *RRCReconfiguration* message to the source L2 U2N Relay UE can be sent any time after step 7 based on source gNB implementation (e.g., to release Uu Relay RLC channel and PC5 Relay RLC channel configuration for relaying, and bearer mapping configuration related to the L2 U2N Remote UE).

14. Either L2 U2N Relay UE or L2 U2N Remote UE's AS layer indicates upper layer to release PC5 unicast link after receiving the *RRCReconfiguration* message from the source gNB. The timing to execute link release is up to UE implementation.

In case the selected L2 U2N Relay UE for multi/single-hop indirect to single-hop indirect path switch is in RRC_IDLE or RRC_INACTIVE, after receiving the path switch command, the L2 U2N Remote UE establishes a PC5 link with the L2 U2N Relay UE and sends the *RRCReconfigurationComplete* message via the L2 U2N Relay UE, which triggers the L2 U2N Relay UE to enter RRC_CONNECTED state. The above procedures for L2 U2N Remote UE switching to indirect path can be also applied for the case that the selected L2 U2N Relay UE for indirect to indirect path switch is in RRC_IDLE or RRC_INACTIVE with the exception that the *RRCReconfiguration* message is sent from the gNB to the L2 U2N Relay UE after the L2 U2N Relay UE enters RRC_CONNECTED state, which happens during step 6 in Figure 16.12.6.3-1a, and during step 10 in Figure 16.12.6.3-2.

16.12.7 Control plane procedures for L2 U2U Relay

The L2 U2U Remote UE needs to establish end-to-end SL-SRB/DRBs with the peer L2 U2U Remote UE before user plane data transmission.

The following high level connection establishment procedure in Figure 16.12.7-1 applies to a L2 U2U Relay UE, L2 U2U Remote UE and the peer U2U Remote UE, where steps 5 to 9 are also performed by the peer U2U Remote UE:

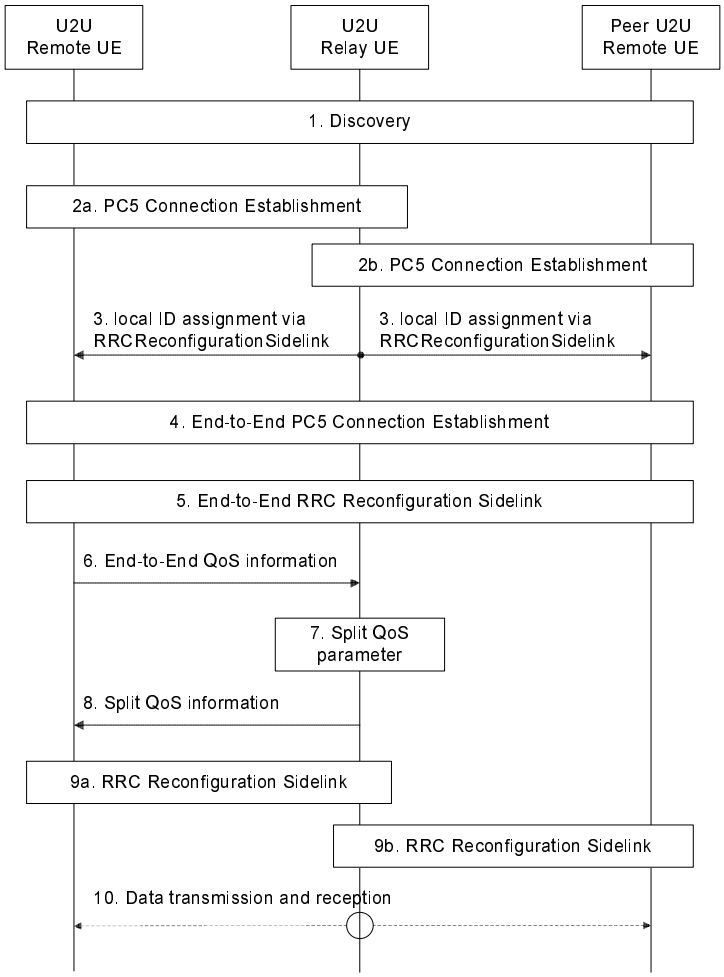


Figure 16.12.7-1: Procedure for L2 U2U Remote UE connection establishment

1. The L2 U2U Remote UE, L2 U2U Relay UE, and peer L2 U2U Remote UE perform discovery procedure or integrated discovery procedure.

2a. The L2 U2U Remote UE establishes/modifies a PC5-RRC connection with the selected L2 U2U Relay UE (i.e., as specified in TS 23.304 [48]).

2b. The L2 U2U Relay UE establishes/modifies a PC5-RRC connection with the peer L2 U2U Remote UE (i.e., as specified in TS 23.304 [48]).

3. The L2 U2U Relay UE allocates two local IDs and the two local IDs are delivered via *RRCReconfigurationSidelink* message to each of the L2 U2U Remote UEs: one local ID to identify the L2 U2U Remote UE, the other local ID to identify the peer L2 U2U Remote UE. When the local IDs are delivered, an L2 ID of the peer L2 U2U Remote UE is also delivered to the U2U Remote UE for making the association between the local ID and the L2 ID of the peer U2U Remote UE.

NOTE 1: It is up to L2 U2U Relay UE implementation on how to allocate the local ID(s) to support SRAP operation as specified in TS 38.351 [65].

4. The L2 U2U Remote UE establishes end-to-end PC5-RRC connection with the peer L2 U2U Remote UE via the L2 U2U Relay UE. For the end-to-end connection establishment, fixed indexes (i.e., 0/1/2/3) are defined for end-to-end SL-SRB 0/1/2/3 respectively, and specified PC5 Relay RLC Channel configuration is used on each hop. The sidelink UE capability is exchanged between the L2 U2U Remote UEs via PC5-RRC (e.g., SL-SRB3) message.

5. The L2 U2U Remote UE obtains PDCP and SDAP configuration for the intended end-to-end SL-DRB(s) via SIB/pre-configuration or dedicated RRC signalling. The L2 U2U Remote UE provides the portion of the configuration related to reception of the end-to-end SL-DRB(s) to the peer L2 U2U Remote UE using end-to-end

RRCReconfigurationSidelink message. The end-to-end bearer IDs for SL-SRB and SL-DRB are used as input for the L2 U2U Relay ciphering and integrity protection at SL PDCP.

6. The L2 U2U Remote UE sends to the L2 U2U Relay UE the QoS profiles for the end-to-end QoS flows and the mapping of the end-to-end QoS flows to SLRB via PC5-RRC message.

7. The L2 U2U Relay UE performs QoS split only for PDB, per each end-to-end QoS flow.

NOTE 2: It is up to L2 U2U Relay UE implementation on how to split PDB.

8. The L2 U2U Relay UE sends the split QoS value (i.e., PDB) via PC5-RRC message to the L2 U2U Remote UE.

9a. The L2 U2U Remote UE obtains first hop configuration (e.g. PC5 Relay RLC Channel configuration) for each end-to-end for SL-DRB via dedicated RRC signalling or based on merged first hop QoS in RB-level via SIB/pre-configuration. The L2 U2U Remote UE provides the L2 U2U Relay UE with the configuration related to receiving on the first hop (i.e., Rx by the relay UE), using per-hop *RRCReconfigurationSidelink* message.

9b. The L2 U2U Relay UE obtains second hop configuration (e.g. PC5 Relay RLC Channel configuration) for each end-to-end SL-DRB via dedicated RRC signalling or based on merged second hop QoS in RB-level via SIB/pre-configuration. The Relay UE provides the peer L2 U2U Remote UE with the configuration related to receiving on the second hop (i.e., RX by the peer remote UE), using per-hop *RRCReconfigurationSidelink* message.

10. The L2 U2U Remote UE and the peer L2 U2U Remote UE transmit or receive data via L2 U2U Relay UE.

16.13 Support of Reduced Capability (RedCap) and enhanced Reduced Capability (eRedCap) NR devices

16.13.1 Introduction

A RedCap UE has reduced capabilities with the intention to have lower complexity with respect to non-RedCap UEs. It is mandatory for a RedCap UE to support 20 MHz maximum UE channel bandwidth in FR1 and 100 MHz in FR2. An eRedCap UE has further reduced capabilities with the intention to have lower complexity with respect to RedCap UEs. It is mandatory for an eRedCap UE to support reduced DL/UL peak data rate of 10 Mbps, with or without reduced baseband bandwidth of 5 MHz for unicast PDSCH/PUSCH in FR1.

16.13.2 Capabilities

CA, MR-DC, DAPS, NCR and IAB related capabilities are not supported by (e)RedCap UEs, as defined together with other limitations in TS 38.306 [11]. It is up to the network to prevent (e)RedCap UEs from using radio capabilities not intended for (e)RedCap UEs.

16.13.3 Identification, access and camping restrictions

A RedCap UE can be identified by the network during Random Access procedure via MSG3/MSGA from a RedCap specific LCID(s) and optionally via MSG1/MSGA (PRACH occasion or PRACH preamble). An eRedCap UE can be identified by the network during Random Access procedure via MSG3/MSGA from an eRedCap specific LCID(s) and optionally via MSG1. For RedCap UE identification via MSG1/MSGA, RedCap specific Random Access configuration may be configured by the network. For eRedCap UE identification via MSG1, eRedCap specific Random Access configuration may be configured by the network. For MSG3/MSGA, an (e)RedCap UE is identified by the dedicated LCID(s) indicated for CCCH identification (CCCH or CCCH1) regardless whether (e)RedCap specific Random Access configuration is configured by the network.

(e)RedCap UEs with 1 Rx branch and 2 Rx branches can be allowed separately via system information. In addition, (e)RedCap UEs in Half-Duplex FDD mode can be allowed via system information. A RedCap specific IFRI can be provided in SIB1, when absent, RedCap UEs access is not allowed. An eRedCap specific IFRI can be provided in SIB1, when absent, eRedCap UEs access is not allowed. Information on which frequencies (e)RedCap UE access is allowed can be provided in system information.

An (e)RedCap UE with 1 Rx branch applies the associated offset for broadcasted cell specific RSRP thresholds for random access, SDT, cell edge condition and cell (re)selection criterion as specified in TS 38.133 [13].

NOTE: It is up to the E-UTRA network, if possible, to avoid handover attempts of an (e)RedCap UE to a target NR cell not supporting (e)RedCap as specified in TS 36.300 [2]. It is up to the (e)RedCap UE implementation, if possible, to recover from handover attempts to a target NR cell not supporting (e)RedCap.

16.13.4 RRM measurement relaxations

RRM measurement relaxation is enabled and disabled by the network. In RRC_IDLE and RRC_INACTIVE an (e)RedCap UE is allowed to relax neighbour cell RRM measurements when the stationary criterion is met or when both stationary criterion and not-at-cell-edge criterion are met. Network may configure stationary criterion for an (e)RedCap UE in RRC_CONNECTED and the UE reports its RRM measurement relaxation fulfilment status using UE Assistance Information when the stationarity criterion is met or no longer met.

16.13.5 BWP operation

An (e)RedCap UE in RRC_IDLE or RRC_INACTIVE monitors paging only in an initial BWP (default or RedCap specific) associated with CD-SSB and performs cell (re-)selection and related measurements on the CD-SSB. If a RedCap-specific initial UL BWP is configured and NUL is selected, (e)RedCap UEs shall use only the RedCap-specific initial UL BWP to perform RACH procedure in RRC_IDLE and RRC_INACTIVE or to perform CG-SDT procedure (as described in clause 18.0) in RRC_INACTIVE.

An (e)RedCap UE may be configured with multiple NCD-SSBs provided that each BWP is configured with at most one SSB. NCD-SSB may be configured for an (e)RedCap UE in RRC_CONNECTED to perform RLM, BFD, and RRM measurements and RA resource selection when the active BWP does not contain CD-SSB.

An (e)RedCap UE may be configured with NCD-SSB for a RedCap-specific initial DL BWP to perform SDT procedure in RRC_INACTIVE (as described in clause 18.0) in case the RedCap-specific initial DL BWP does not contain CD-SSB.

16.14 Non-Terrestrial Networks

16.14.1 Overview

Figures 16.14.1-1 and 16.14.1-2 below illustrate examples of a Non-Terrestrial Network (NTN) providing non-terrestrial NR access to the UE by means of an NTN payload and an NTN Gateway, depicting a service link between the NTN payload and a UE, and a feeder link between the NTN Gateway and the NTN payload. In Figure 16.14.1-1, the payload is transparent; in Figure 16.14.1-2 the payload is regenerative and hosts a gNB.

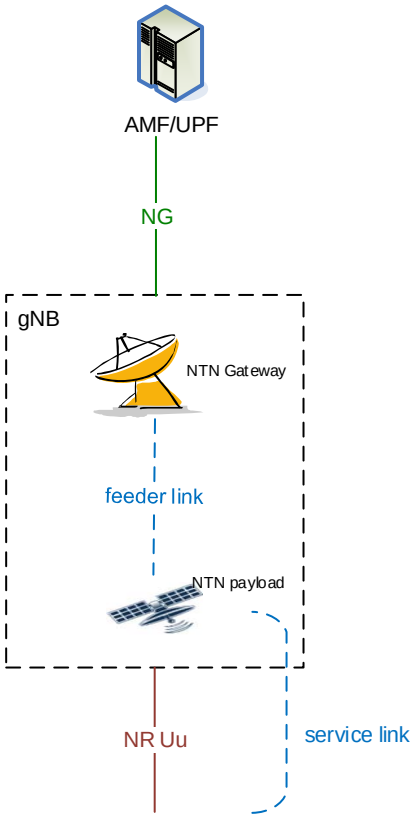


Figure 16.14.1-1: Overall illustration of an NTN with transparent payload

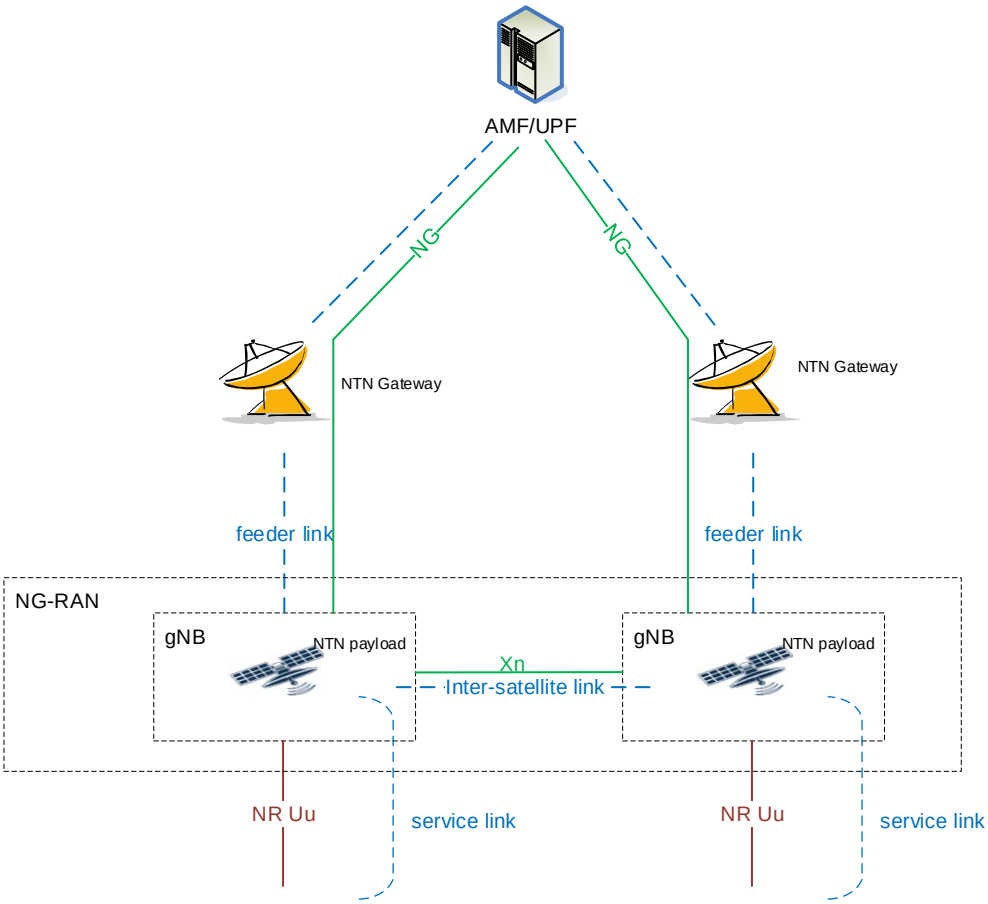


Figure 16.14.1-2: Overall illustration of an NTN with regenerative payload hosting a gNB

NOTE 1: Figure 16.14.1-1 and 16.14.1-2 illustrate an NTN; RAN4 aspects are out of scope.

The transparent NTN payload transparently forwards the radio protocol received from the UE (via the service link) to the NTN Gateway (via the feeder link) and vice-versa. The regenerative NTN payload terminates the Uu (via the service link), NG and Xn interfaces. The following connectivity is supported by the NTN payload:

- An NTN gateway may serve multiple NTN payloads;
- An NTN payload may be served by multiple NTN gateways.

NOTE 2: In this release, the transparent NTN-payload may change the carrier frequency, before re-transmitting it on the service link, and vice versa (respectively on the feeder link).

The following connectivity is supported by the NTN regenerative payload:

- A regenerative NTN payload may terminate one or more inter-satellite links toward other regenerative payloads.

For NTN, the following applies in addition to Network Identities as described in clause 8.2:

- A Tracking Area corresponds to a fixed geographical area. Any respective mapping is configured in the RAN;
- A Mapped Cell ID as specified in clause 16.14.5.

NTN can be deployed to provide coverage with earth-moving cell, quasi-earth-fixed cell and earth-fixed cell which are supported respectively by the following three types of service link:

- Earth-fixed: provisioned by beam(s) continuously covering the same geographical areas all the time (e.g., the case of GSO satellites);
- Quasi-Earth-fixed: provisioned by beam(s) covering one geographic area for a limited period and a different geographic area during another period (e.g., the case of NGSO satellites generating steerable beams);

- Earth-moving: provisioned by beam(s) whose coverage area slides over the Earth surface (e.g., the case of NGSO satellites generating fixed or non-steerable beams).

With NGSO satellites, the gNB can provide either quasi-Earth-fixed service link or Earth-moving service link, while gNB operating with GSO satellite can provide Earth fixed service link or quasi-Earth-fixed service link.

In this release, the UE supporting NTN is GNSS-capable.

In NTN, the distance refers to Euclidean distance.

In this release, NTN is only applicable to FDD system.

16.14.2 Timing and Synchronization

16.14.2.1 Scheduling and Timing

DL and UL are frame aligned at the uplink time synchronization reference point (RP) with an offset given by $N_{TA,offset}$ (see clause 4.2 of TS 38.213 [38]).

To accommodate the propagation delay in NTNs, several timing relationships are enhanced by a Common Timing Advance (Common TA) and two offsets K_{offset} and K_{mac}:

- Common TA is a configured timing offset that is equal to the RTT between the RP and the NTN payload.
- K_{offset} is a configured scheduling offset that needs to be larger or equal to the sum of the service link RTT and the Common TA.
- K_{mac} is a configured offset (see TS 38.331 [12]) that is approximately equal to the RTT between the RP and the gNB.

The scheduling offset K_{offset} is used to allow the UE sufficient processing time between a downlink reception and an uplink transmission, see TS 38.213 [38].

The offset K_{mac} is used to delay the application of a downlink configuration indicated by a MAC CE command on PDSCH, see TS 38.213 [38], and in estimation of UE-gNB RTT, see TS 38.321 [6]. It may be provided by the network when downlink and uplink frame timing are not aligned at gNB. The K_{mac} is also used in the random access procedure, to determine the start time of RAR window/MsgB window after a Msg1/MsgA transmission (see TS 38.213 [38]).

The Service link RTT, Feeder link RTT, RP, Common TA, K_{mac} and T_{TA} (see clause 16.14.2.2) are illustrated in Figure 16.14.2.1-1.

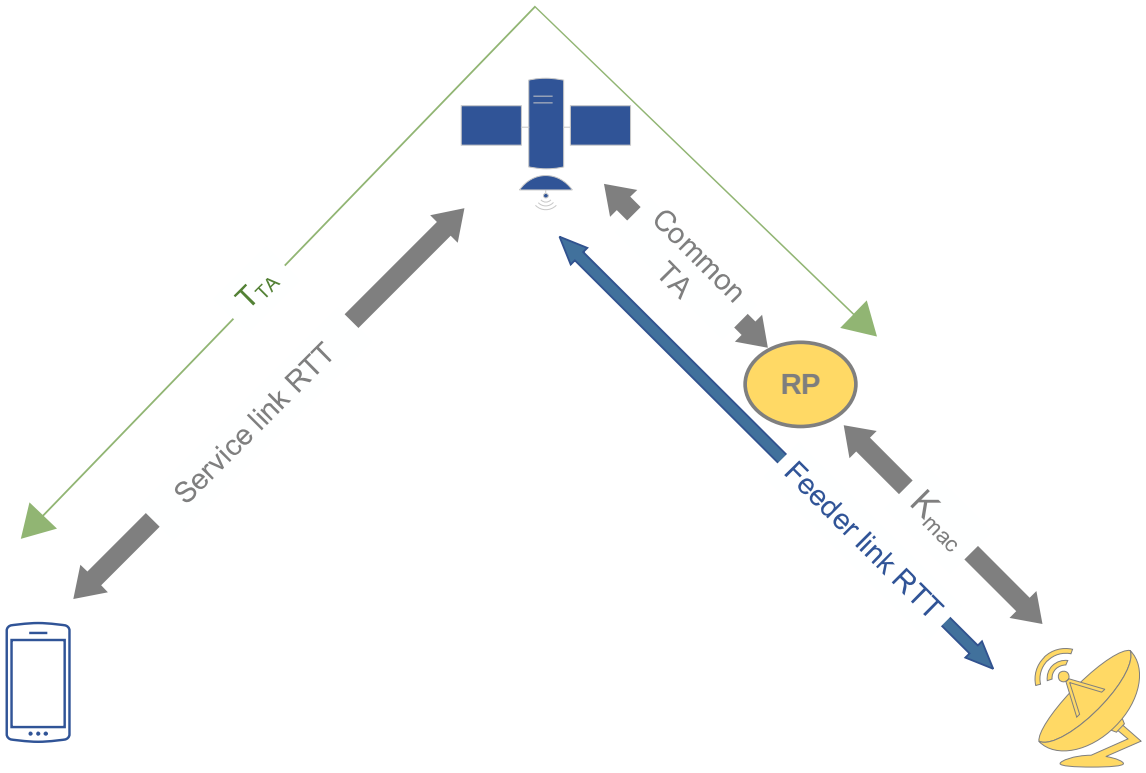


Figure 16.14.2.1-1: Illustration of timing relationship (for collocated gNB and NTN Gateway)

The network may configure the HARQ operation as follows:

- For downlink, HARQ feedback can be enabled or disabled per HARQ process (as specified in clause 5.3.2.2 and clause 5.7 of TS 38.321 [6]). Disabling HARQ feedback allows scheduling a HARQ process before one HARQ RTT has elapsed since last scheduled.
- For uplink, HARQ mode (i.e. HARQ mode A or HARQ mode B) can be configured per HARQ process (as specified in clause 5.4.3.1 and clause 5.7 of TS 38.321 [6]). HARQ mode B allows scheduling a HARQ process before one HARQ RTT has elapsed since last scheduled.

NOTE: For the HARQ processes configured with HARQ feedback enabled/disabled, it is up to network implementation to ensure a proper configuration of HARQ feedback (e.g., either all enabled or all disabled) for HARQ processes used by an SPS configuration. For the HARQ processes configured with HARQ mode, it is up to network implementation to ensure a proper configuration of HARQ mode (e.g., either all HARQ mode A or all HARQ mode B) for HARQ processes used by a CG configuration.

16.14.2.2 Timing Advance and Frequency Pre-compensation

For the serving cell, the network broadcast valid ephemeris information and Common TA parameters. The UE shall have valid GNSS position as well as ephemeris and Common TA before connecting to an NTN cell. To achieve synchronisation, before and during connection to an NTN cell, the UE shall compute the RTT between UE and the RP based on the GNSS position, the ephemeris, and the Common TA parameters (see clause 4.2 in TS 38.213 [38]), and autonomously pre-compensate the T_{TA} for the RTT between the UE and the RP as illustrated in Figure 16.14.2.1-1 (see clause 4.3 of TS 38.211 [52]).

The UE shall compute the frequency Doppler shift of the service link, and autonomously pre-compensate for it in the uplink transmissions, by considering UE position and the ephemeris. If the UE does not have a valid GNSS position and/or valid ephemeris and Common TA, it shall not transmit until both are regained.

In connected mode, the UE shall be able to continuously update the Timing Advance and frequency pre-compensation.

The UE may be configured to report Timing Advance during Random Access procedures or in connected mode. In connected mode, event-triggered reporting of the Timing Advance is supported.

Figure 16.14.2.2-1: Void

While the pre-compensation of the instantaneous Doppler shift experienced on the service link is to be performed by the UE, the management of Doppler shift experienced over the feeder link and transponder frequency error is left to the network implementation.

16.14.3 Mobility and State transition

16.14.3.1 Mobility in RRC_IDLE and RRC_INACTIVE

The same principles as described in 9.2.1 apply to mobility in RRC_IDLE for NTN and the same principles as described in 9.2.2 apply to mobility in RRC_INACTIVE for NTN unless hereunder specified.

The network may broadcast multiple Tracking Area Codes (TACs) per PLMN in an NR NTN cell. A TAC change in the System Information is under network control, i.e. it may not be exactly synchronised with real-time illumination of beams on ground.

For the NTN-TN mobility, the network may broadcast cell information on NR TN and EUTRA TN coverage areas in SIB25. This is supported for Earth-Fixed, Quasi-Earth-fixed and Earth-Moving cells. The coverage information consists in a list of geographical TN areas, with associated frequency information also indicated. UE can skip TN measurement based on the broadcast TN coverage information.

The UE can determine the network type (terrestrial or non-terrestrial) implicitly by the existence of *cellBarredNTN* in SIB1.

The NTN ephemeris is provided in SIB19. In an NTN cell, it includes serving cell's NTN payload ephemeris and optionally neighbouring cell's NTN payload ephemeris.

The UE may be provided with NTN payload assistance to assist in searching for NTN cells for the purpose of redirection from TN to NTN or from NTN to NTN.

The network may provide assistance information (e.g., ephemeris information, carrier frequency), which a UE may use for cell selection from NR NTN to IoT NTN.

16.14.3.2 Mobility in RRC_CONNECTED

16.14.3.2.1 Handover

The same principle as described in 9.2.3.2 applies unless hereunder specified:

During mobility between NTN and TN, a UE is not required to connect to both NTN and TN at the same time.

NOTE: NTN TN handover refers to mobility in both directions, i.e. from NTN to TN (hand-in) and from TN to NTN (hand-out).

DAPS handover is not supported for NTN in this release of the specification.

UE may support mobility between gNBs operating with NTN payloads, transparent and/or regenerative, in different orbits (e.g., GSO, NGSO at different altitudes).

RACH-less handover as specified in 9.2.3.6, in TS 38.321 [6] and in TS 38.331 [12] is supported in NTNs.

16.14.3.2.2 Conditional Handover

The same principle as described in 9.2.3.4 applies to NTN unless hereunder specified.

NTN supports the following additional trigger conditions upon which UE may execute CHO to a candidate cell, as defined in TS 38.331 [12]:

- The RRM measurement-based event A4;
- A time-based trigger condition;
- A location-based trigger condition.

Time-based or location-based trigger conditions may be configured independently from the RRM measurement-based trigger conditions for CHO in NTN in some scenarios, e.g., when the service discontinuity gap time length is zero or negligible.

It is up to UE implementation how the UE evaluates the time- or location-based trigger condition together with the RRM measurement-based event.

When a time-based trigger condition is used, the source gNB may signal the corresponding parameters to a target gNB in an NG-C based handover, see TS 23.502 [22], or Xn based handover. The source gNB signals the corresponding CHO configuration to the UE in the RRC Reconfiguration message for handover.

When time-based trigger condition is used, the source NG-RAN node should consider the time indicated to the UE to decide when to start the early data forwarding to the target NG-RAN node.

Time-based CHO can be performed via RACH-less.

16.14.3.2.3 Satellite switch with re-synchronization

For transparent payload, upon both hard and soft satellite switch over in the quasi-Earth fixed scenario with the same SSB frequency and the same gNB, the satellite switch with re-synchronization procedure is supported. The satellite switch with re-sync avoids a L3 mobility for UEs in the cell by maintaining the same PCI on the geographical area covered by quasi-Earth fixed beam.

For soft satellite switch over, the UE can start synchronizing with the target satellite before the source satellite ends to serve the cell. It is not required for the UE to be connected to source satellite when the UE switches to target satellite.

For hard satellite switch over, the UE can only start synchronizing with the target satellite after the source satellite ends to serve the cell.

When both CHO and Satellite switch with re-synchronization are configured, it is up to UE implementation which procedure to initiate, if both of them are triggered simultaneously.

For the re-synchronization to the target satellite, random access can be triggered by a PDCCH order via the target satellite.

16.14.3.3 Measurements

The same principle as described in 9.2.4 applies to measurements in NTN unless hereunder specified.

The network can configure:

- multiple SMTCs in parallel per carrier and for a given set of cells depending on UE capabilities;
- measurement gaps based on multiple SMTCs;
- assistance information (e.g., ephemeris, Common TA parameters, k_{mac}) provided in SIB19 for UE to perform measurement on neighbour cells in RRC_IDLE/RRC_INACTIVE/RRC_CONNECTED;
- two different SMTC periodicities for SMTCs per frequency layer for UE in RRC_IDLE/RRC_INACTIVE/RRC_CONNECTED;
- up to 7 SMTCs for UE in RRC_IDLE/RRC_INACTIVE for the (quasi-)Earth fixed cells, including the SMTC of the serving cell, where the UE may down-select SMTCs associated with the closest reference locations.

NW-controlled adjustment of SMTCs can be based on UE assistance information reported in RRC_CONNECTED. The UE may be configured to report the closest reference locations to assist configuration of SMTC and measurement gap. A UE in RRC_IDLE/RRC_INACTIVE can adjust SMTCs based on its location and assistance information in SIB19.

UE assistance information consists of the service link propagation delay difference(s) between serving the cell and neighbour cell(s).

For a UE in idle/inactive mode, it is up to UE implementation whether to perform NTN neighbour cell measurements on a cell indicated in SIB3/SIB4 but not included in SIB19.

For a UE in connected mode, it is up to UE implementation whether to perform NTN neighbour cell measurements on a cell included in the measurement configuration, but without corresponding satellite information in measurement configuration or in SIB19.

UE can perform time-based and location-based measurements on neighbour cells in RRC_IDLE/RRC_INACTIVE:

- The timing and location information associated to the serving cell is provided in SIB19;
- Timing information refers to the UTC time when the serving cell stops serving the current geographical area;
- Location information refers:
  - In the (quasi-)Earth fixed cell scenario, to the reference location of the serving cell and a distance threshold to the reference location.
  - In the Earth moving cell scenario, to the reference location of the serving cell at the epoch time and a distance threshold to the reference location.

The time-based measurement initiation may be applicable for the feeder link switchover case for cell re-selection.

Measurement rules for cell re-selection based on timing information and location information are specified in clause 5.2.4.2 in TS 38.304 [10].

16.14.4 Switchover

16.14.4.1 Definitions

A feeder link switchover is the procedure where the feeder link is changed from a source NTN Gateway to a target NTN Gateway for an NTN payload. The feeder link switchover is a Transport Network Layer procedure. Service link switch refers to a change of the serving NTN payload.

Both hard and soft feeder link switchover are supported in NTN payloads.

16.14.4.2 Assumptions

A feeder link switch over may result in transferring the established connection for the affected UEs between two gNBs.

For soft feeder link switch over, an NTN payload is able to connect to more than one NTN Gateway during a given period, i.e. a temporary overlap can be ensured during the transition between the feeder links.

For hard feeder link switch over, an NTN payload connects to only one NTN Gateway at any given time, i.e. a radio link interruption may occur during the transition between the feeder links.

In this version of the specification, for regenerative payload it is assumed that the UE’s serving AMF is not changed due to feeder link switch over.

16.14.4.3 Procedures

The NTN Control function (see Annex B.4) determines the point in time when the feeder link switch over is performed. The transfer of the affected UE(s)' at feeder link switch over is performed by means of handover or TNL functionality, and it depends on the gNBs' implementation and configuration information provided to the gNBs by the NTN Control function.

NOTE: In case of TNL address change due to feeder link switchover, existing procedures (e.g., Path Switch Request procedure, PDU Session Resource Modify Indication procedure) may be used.

16.14.5 NG-RAN signalling

The Cell Identity, as defined in TS 38.413 [26] and TS 38.423 [50], used in following cases corresponds to a Mapped Cell ID, irrespective of the orbit of the NTN payload or the types of service links supported:

- The Cell Identity indicated by the gNB to the Core Network as part of the User Location Information;
- The Cell Identity used for Paging Optimization in NG interface;
- The Cell Identity used for Area of Interest;
- The Cell Identity used for PWS;
- The Cell Identity used for MBS broadcast service.

The Cell Identity included within the target identification of the handover messages allows identifying the correct target cell. The cell identity used in the NG and Xn handover messages, Xn Setup and Xn NG-RAN Node Configuration Update procedures is expected to be Uu Cell ID.

The Cell Identities used in the RAN Paging Area during Xn RAN paging allow the identification of the correct target cells for RAN paging.

NOTE 1: The Cell Identity used for RAN Paging is assumed to typically represent a Uu Cell ID.

The mapping between Mapped Cell IDs and geographical areas is configured in the RAN and Core Network.

NOTE 2: A specific geographical location may be mapped to multiple Mapped Cell ID(s), and such Mapped Cell IDs may be configured to indicate differerent geographical areas (e.g. overlapping and/or with different dimensions).

The gNB is responsible for constructing the Mapped Cell ID based on the UE location information received from the UE, if available. The mapping may be pre-configured (e.g., up to operator's policy) or up to implementation.

NOTE 3: As described in TS 23.501 [3], the User Location Information may enable the AMF to determine whether the UE is allowed to operate at its present location. Special Mapped Cell IDs or TACs may be used to indicate areas outside the serving PLMN's country.

The gNB reports the broadcasted TAC(s) of the selected PLMN to the AMF as part of ULI. In case the gNB knows the UE's location information, the gNB may determine the TAI the UE is currently located in and provide that TAI to the AMF as part of ULI.

The AMF may provide the gNB with the service area information for MBS broadcast service. This information may be signaled as cell ID list, TAI list, and/or MBS intended service area list, as defined in TS 38.413 [26]. Based on this received information, the gNB provides the intended service area information to the UEs in the relevant cell(s) as defined in TS 38.331 [12].

16.14.6 AMF (Re-)Selection

The gNB implements the NAS Node Selection Function specified in TS 38.410 [16].

For an RRC_CONNECTED UE, when the gNB is configured to ensure that the UE connects to an AMF that serves the country in which the UE is located, if the gNB detects that the UE is in a different country to that served by the serving AMF, then it should perform an NG handover to change to an appropriate AMF, or initiate an UE Context Release Request procedure towards the serving AMF (in which case the AMF may decide to de-register the UE).

For the purpose of selecting an appropriate AMF, the 5GC may verify the UE location according to TS 23.501 [3] and TS 38.305 [42] after the UE has attached to the network.

NOTE: UE location verification for AMF selection should not be necessary if NTN cell(s) do not extend across countries.

16.14.7 O&M Requirements

The following NTN related parameters shall be provided by O&M to the gNB providing NTN access:

- Ephemeris information describing the orbital trajectory information or coordinates for the NTN payload of the serving cell, and optionally for the NTN payload(s) of neighbour cell(s). This information is provided on a regular basis or upon demand to the gNB;
- Two different sets of ephemeris format shall be supported:
  - Set 1: NTN payload position and velocity state vectors:
    - Position;
    - Velocity.
  - Set 2: At least the following parameters in orbital parameter ephemeris format:
    - Semi-major axis;
    - Eccentricity;
    - Argument of periapsis;
    - Longitude of ascending node;
    - Inclination;
    - Mean anomaly at epoch time.
- The explicit epoch time associated to ephemeris data, with respect to the J2000,0 reference epoch;
- The location of the NTN Gateways;

NOTE 1: The ephemeris of the NTN payloads and the location of the NTN Gateways, are used at least for the Uplink timing and frequency synchronization. It may also be used for the random access and the mobility management purposes.

- Additional information to enable gNB operation for feeder/service link switch overs.

NOTE 2: The NTN related parameters provided by O&M to the gNB may depend on the type of supported service links, i.e., Earth-fixed, quasi-Earth-fixed, or Earth-moving.

16.14.8 Coarse UE location reporting

Upon network request, after AS security is established in connected mode, a UE should report its coarse UE location information (most significant bits of the GNSS coordinates, ensuring an accuracy in the order of 2 km) to the NG-RAN if available.

16.14.9 Support for NR NTN coverage enhancements

To improve NR uplink coverage in NTN, the following enhancements are supported:

- PUCCH repetition for Msg4 HARQ-ACK configured in system information or dynamically in DCI for Msg4 when multiple repetition factors are configured in the system information:
  - UEs reports the capability of PUCCH repetition for Msg4 HARQ-ACK in Msg3 PUSCH;
  - When Msg4 HARQ-ACK is repeated, PUCCH repetition is applied for all PUCCH transmission before dedicated PUCCH resource is provided.
- Improved channel estimation by NTN-specific PUSCH DMRS bundling enhancement that enables DMRS bundling in presence of timing drift, where the UE maintains phase continuity by considering effects of transmission delay variation between the UE and the uplink time synchronization reference point.

To improve NR downlink coverage in NTN, the following enhancements are supported for NTN operating in FR1-NTN bands:

- Repetition of PDCCH in common search space;
- Repetitions of PDSCH carrying Msg4:
  - UEs reports the capability of PDSCH repetition for Msg4 in Msg3 PUSCH.
- Repetitions of PDSCH carrying SIB1 within 20 ms.

To extend the NR downlink coverage for NTN operating in, for FR1-NTN and FR2-NTN bands: extended periodicity of 160 ms (apart from the existing 20ms value) for the half frames with SS/PBCH blocks is assumed by UE during initial cell selection.

16.14.10 Verification of UE location

The core network may trigger a network verification procedure for a UE in RRC_CONNECTED to verify it is consistent with the network-based assessed location. It is up to network implementation how to handle UEs which does not support the location verification.

For UE location verification based on multi-RTT with single satellite in NTN, at least the following UE and gNB measurements specified in TS 38.215 [59] are reported: gNB receive-transmit time difference at the uplink time synchronization reference point, UE receive-transmit time difference, UE receive-transmit time difference subframe offset and DL timing drift.

The assistance information provided to the CN may include ephemeris information including accurate satellite position and velocity at the time of multi-RTT measurement, and common TA parameters (*ta-Common*, *ta-CommonDrift*, *ta-CommonDriftVariant*), and Epoch time.

16.14.11 Support for NR NTN capacity enhancements

To improve uplink capacity in NTN, the following enhancements are supported for PUSCH transmission:

- Inter-slot orthogonal cover code with length 2 to multiplex up to two UEs;
- Inter-slot orthogonal cover code with length 4 to multiplex up to four UEs.

Inter-slot orthogonal cover code is also supported for RACH-less handover, as described in clause 9.2.3.6, for intra-gNB intra-satellite handover procedure.

16.14.12 Support of ISA for MBS Broadcast in NTN

An intended service area (ISA) is a geographical area that can be signaled for MBS broadcast services. The ISA(s) is broadcasted in *SIB27* and associated to MBS broadcast service(s) by indicating the ISA identifier(s) in MCCH. It may be included in USD within target service area [46].

The NTN-capable UE supporting the MBS broadcast may initiate the broadcast MRB establishment procedure and prioritize the frequency providing these MBS broadcast service(s) when it is inside an ISA. The UE may initiate the broadcast MRB release procedure and no longer prioritize the frequency providing MBS broadcast service(s) when the UE leaves an ISA, as specified in clause 5.9.3 of TS 38.331 [12] and clause 5.2.4.1 of TS 38.304 [10].

NOTE: When using ISA(s) for MBS broadcast service reception or MBS service continuity, it is up to the UE implementation how to determine if it is in the ISA(s) of MBS broadcast service or not.

16.14.13 Support of Half-Duplex UE in NR NTN

To support Reduced Capability (RedCap) UEs and enhanced RedCap (eRedCap) UEs in NR NTN operating in FR1-NTN bands, enhancements to address issues caused by Timing Advance (TA) mismatch for Half-Duplex UE in paired spectrum are specified. This mismatch occurs between the actual TA used by the UE and the assumed TA for the UE at the gNB. The enhancements specifically target the issues in half-duplex collision cases at the UE side, including scenarios where semi-statically configured downlink reception collides with semi-statically configured uplink

transmission, and where dynamically scheduled downlink reception collides with dynamically scheduled uplink transmission (see clause 17.2 of TS 38.213 [38]).

16.14.14 NG Removal

For the case of regenerative payload, when disconnecting from an AMF is required due to e.g. the satellite movement in a LEO constellation, the gNB on board the satellite may request the removal of the NG interface by initiating the NG Removal procedure toward the AMF based on e.g. ephemeris information.

NOTE: After a successful NG removal, the gNB may initiate a new NG Setup procedure, if required, based on e.g. ephemeris information.

16.15 eXtended Reality Services

16.15.1 General

This clause describes the functionalities for the support of eXtended Reality (XR) services that require high data rate and low latency communications. An overview of XR services is available in TR 38.835 [57], while the service requirements are documented in TS 22.261 [19]. Please note however that some of those functionalities need not be limited to the provision of XR services.

16.15.2 Awareness

XR-Awareness relies on QoS flows, PDU Sets, Data Bursts and traffic assistance information (see TS 23.501 [3]).

The following **PDU Set QoS Parameters** may be provided by the SMF to the gNB as part of the QoS profile of the QoS flow:

- PDU Set Delay Budget (PSDB): as defined in TS 23.501 [3], upper bound for the duration between the reception time of the first PDU (at the UPF for DL, at the UE for UL) and the time when all PDUs of a PDU Set have been successfully received (at the UE in DL, at the UPF in UL). When available, supersedes the PDB of the QoS flow.

- PDU Set Error Rate (PSER): as defined in TS 23.501 [3], upper bound for a rate of non-congestion related PDU Set losses between RAN and the UE. When available, it supersedes the PER of the QoS flow.

NOTE 1: In this release, a PDU set is considered as successfully delivered only when all PDUs of a PDU Set are delivered successfully.

- PDU Set Integrated Handling Information (PSIHI): indicates whether all PDUs of the PDU Set are needed for the usage of PDU Set by application layer, as defined in TS 23.501 [3].

NOTE 2: For a given QoS flow, the PDU Set QoS parameters are common for all PDU Sets but can be different for UL and DL. PSDB and PSER, if provided, should be provided together.

The PDU Set based handling can be enabled based on the PDU Set QoS Parameters, or based on the DL PDU Set Information Marking Support Indication received from SMF.

During the Xn-handover preparation procedure, the source gNB sends the stored PDU Set QoS Parameters as part of the QoS profile or the DL PDU Set Information Marking Support Indication to the target NG-RAN node. For NG handover, the AMF provides the PDU Set QoS parameters or the DL PDU Set Information Marking Support Indication to the target gNB by means of the NGAP HANDOVER REQUEST message.

The UPF can identify PDUs that belong to PDU Sets, and may indicate to the gNB the following **PDU Set Information** in the GTP-U header:

- PDU Set Sequence Number;

- Indication of End PDU of the PDU Set;

- PDU Sequence Number within a PDU Set;

- PDU Set Size in bytes;
- PDU Set Importance (PSI), which identifies the relative importance of a PDU Set compared to other PDU Sets within the same QoS Flow.

NOTE 3: PDU Set Information can be provided without PDU Set QoS Parameters.

5GC may provide XR traffic assistance information to gNB through NG AP TSC Assistance Information (TSCAI) as specified in clause 5.37.8 of TS 23.501[3] (for both GBR and non-GBR QoS flows):

- UL and/or DL Periodicity;
- N6 Jitter Information (i.e. between UPF and Data Network) associated with the DL Periodicity.

This assistance information can be used by the gNB to configure DRX to enable better UE power saving.

In addition, 5GC may provide the following information through NG-U as specified in clause 5.37.5.2 of TS 23.501[3]:

- Indication of End of Data Burst in the GTP-U header of the last PDU in downlink:
  - this information can be used by the gNB to push the UE back to sleep when possible.
- Burst Size in the GTP-U header of the first PDUs of the data burst in downlink: this information can be used by the gNB to assist radio resource management.
- Time To Next Burst in the GTP-U header in downlink: this information represents the interval between the transmission of the last PDU in the current data burst and the first PDU of the next data burst, and can be used by the gNB to assist scheduling in downlink.

During the data forwarding for handover, the source gNB provides the Indication of End of Data Burst, Burst Size, and Time to Next Burst received from the UPF to target gNB in case one or more PDUs of the data burst is forwarded to target gNB.

Finally, 5GC may provide the Multi-modal Service ID (MMSID) to NG-RAN, as part of the QoS parameters of the QoS flow, when establishing and/or updating the corresponding QoS Flows. It is up to the gNB's implementation to use this information for multi-modality service.

In the uplink, the UE needs to be able to identify PDU Sets and Data Bursts dynamically, including PSI. How this is done is left up to UE implementation but when possible for a QoS flow, this is indicated to the gNB via UE Assistance Information.

16.15.3 Power Saving

Most XR video frame rates (15, 30, 45, 60, 72, 90 and 120 fps) correspond to periodicities that are not an integer (66.66, 33.33, 22.22, 16.66, 13.88, 11.11 and 8.33 ms respectively). The gNB may configure a DRX cycle expressed in rational numbers so that the DRX cycle matches those periodicities, e.g. for the traffic with a frame rate of 60 fps, the network may configure the UE with a DRX cycle of 50/3 ms.

Configured grants may be configured without the need for the UE to wake up to monitor possible grants for UL retransmissions of configured grants, thus increasing the number of power saving opportunities for the UE.

16.15.4 Capacity

16.15.4.1 Physical Layer Enhancements

The following enhancements for configured grant-based PUSCH transmission are introduced:

- Support of multiple CG PUSCH transmission occasions within a single period of a CG configuration;
- Indication of unused CG PUSCH occasion(s) of a CG configuration with Uplink Control Information multiplexed in CG PUSCH transmission of the CG configuration.

16.15.4.2 Layer 2 Enhancements

16.15.4.2.1 Assistance Information

In order to enhance the scheduling of uplink resources for XR, the following improvements are introduced:

- One additional buffer size table to reduce the quantisation errors in BSR and DSR (defined below) reporting (e.g. for high bit rates):
  - Whether, for an LCG, the new table can be used in addition to the regular one is configured by the gNB;
  - When the new table is configured for an LCG, it is used whenever the amount of the buffered data of that LCG to be reported is within the range of the new table, otherwise the regular table is used.
- Delay Status Report (DSR) of buffered data via a dedicated MAC CE:
  - Triggered for an LCH when the remaining time before discard of any buffered PDCP SDU goes below a configured threshold (threshold configured per LCG by the gNB);
  - When triggered for an LCH, reports for each threshold configured , the buffer size and the shortest remaining time before discard of buffered PDCP SDUs associated to this threshold.
- Reporting of uplink assistance information (jitter range, burst arrival time, UL data burst periodicity, possibility for the UE to identify PDU sets and/or PSI) per QoS flow by the UE via UE Assistance Information. In case target gNB receives the burst arrival time from source gNB during the handover preparation procedure, the target gNB may use it by considering the SFN offset of the source gNB.

16.15.4.2.2 Discard

When the PSIHI indicates that all PDUs of the PDU Set are needed for a QoS flow, as soon as one PDU of a PDU set is known to be lost, the remaining PDUs of that PDU Set can be considered as no longer needed by the application and may be subject to discard operation at the transmitter to free up radio resources.

NOTE 1: It cannot always be assumed that the remaining PDUs are not useful and can safely be discarded. Also, in case of Forward Error Correction (FEC), active discarding of PDUs when assuming that a large enough number of packets have already been transmitted for FEC to recover without the remaining PDUs is not recommended as it might trigger an increase of FEC packets.

In uplink, the UE may be configured with PDU Set based discard operation for a specific DRB. When configured, the UE discards all packets in a PDU set when one PDU belonging to this PDU set is discarded due to discard timer expiry.

The gNB may perform downlink PDU Set discarding based on implementation by taking at least PSDB, PSI, PSIHI parameters into account.

In case of congestion, for downlink, the gNB may perform PDCP SDU discarding based on PSI. For uplink, dedicated downlink signalling is used to request the UE to apply a shorter discard timer to PDCP SDUs belonging to *low importance* PDU Sets in PDCP.

NOTE 2: How PDU Sets are identified as *low importance* is left up to UE implementation. When a PSI is available, it can be used according to the guidelines specified in TS 26.522 [58].

The transmitting PDCP entity can inform the receiving one of gaps in the sequence of transmitted PDCP SN, resulting from PDCP SDU discard, via a PDCP control PDU.

16.15.4.2.3 Logical Channel Priority Adjustment

An LCH may be configured to apply an additional priority when any of its buffered PDCP SDU(s) has a remaining time before discard falling below a configured threshold.

16.15.4.2.4 RLC Retransmissions

For operation of RLC AM, the following improvements are introduced:

- To avoid unnecessary RLC retransmissions:

- On the transmitter side, when the RLC entity receives a discard indication for an SDU from PDCP, it stops any further transmission or retransmission of that SDU and its corresponding segment(s) if any;

- On the receiver side, a complete PDU detected as missing can be discarded after a configured duration, and positively acknowledged through a status report.

- To ensure timely RLC retransmissions, on the transmitter side, when the remaining time before discard of an RLC SDU:

  - Falls below a configured retransmission threshold, a retransmission of this RLC SDU may be triggered; and/or

  - Falls below a configured polling threshold, polling is triggered.

16.15.4.2.5 Uplink Rate Control

To enable faster adaptation of the uplink source rate (e.g. to handle uplink congestion), an uplink physical-layer bit rate available to a QoS flow can be suggested by the gNB via a downlink MAC CE, and the UE can also request a desired one via an uplink MAC CE.

NOTE: The bit rate is linked to the QoS flow regardless of how many cell groups are configured.

The 5GC may provide the gNB the information indicating that the QoS Flow allows rate adaptation in the uplink direction. During the Xn-based handover preparation procedure, the source gNB will forward this information for the QoS flow to the target gNB, which allows target gNB to perform uplink rate control.

16.15.5 Non-Homogeneous support of PDU set based handling in NG-RAN

During a handover from a gNB supporting PDU Set based handling to another gNB, the source gNB signals the PDU Set Information over Xn-U if the target node has signalled the support of PDU Set based handling in the Xn Handover Request Acknowledge message.

During a handover, transition from RRC_INACTIVE to RRC_CONNECTED or RRC re-establishment from a gNB not supporting PDU Set based handling to a gNB supporting PDU Set based handling, the target/new serving gNB may indicate the support of PDU Set based handling to the SMF during the Path Switch Request procedure or Handover Resource Allocation procedure (in case of NG handover), the SMF will act as specified in TS 23.501[3]. If the indication is absent, the SMF infers that PDU Set based handling is not supported by the target/new serving gNB node, then the SMF will act as specified in TS 23.501[3].

During a handover, transition from RRC_INACTIVE to RRC_CONNECTED or RRC re-establishment from a gNB node not supporting PDU Set based handling to a gNB node supporting PDU Set based handling, the target/new serving gNB node may receive unmarked PDU(s) (i.e. PDU(s) without PDU Set Information Container) forwarded from the source/last serving gNB, node and marked PDU(s) (i.e. PDU(s) with PDU Set Information Container) from UPF, how the target/new serving gNB node handles the marked and unmarked PDUs for the same QoS flow is up to implementation.

16.15.6 Measurement Gaps

To enable the transmission and reception during some of the measurements gaps configured for RRM measurements, a measurement gap occasion may be cancelled via DCI.

In addition, the UE may provide, via UE Assistance information, a recommended gap occasion cancellation ratio per measurement gap configuration.

16.16 ECN marking for L4S and congestion information exposure

In order to support ECN marking for L4S at gNB as specified in TS 23.501[3], SMF provides ECN marking request per QoS flow level to the gNB as part of PDU Session Resource Management procedure. If the gNB supports ECN marking, it provides the status indication back to the SMF which is used by the SMF as specified in TS 23.501[3]. During Xn Handover Preparation procedure, source gNB provides the ECN marking request to target gNB.

When ECN marking for L4S at gNB is enabled for downlink or uplink, the gNB should set the Congestion Experienced (CE) codepoint in downlink or uplink SDAP SDU(s) as per the recommendations in IETF RFC 9330 [61], IETF RFC 9331 [62] and IETF RFC 9332 [63].

For ECN marking for L4S at UPF, SMF requests the gNB to report congestion information per QoS flow level as part of PDU Session Resource Management procedure. If the gNB supports ECN marking for L4S at UPF, it provides the status indication back to the SMF which is used by SMF as specified in TS 23.501[3]. During Xn Handover Preparation procedure, source gNB provides the ECN marking UPF request to target gNB.

For congestion reporting from gNB to UPF, SMF requests the gNB to report congestion information per QoS flow level as part of PDU Session Resource Management procedure. If the NG-RAN supports congestion information reporting, it provides the status indication back to the SMF which is used by the SMF as specified in TS 23.501[3]. During Xn Handover Preparation procedure, source gNB provides the congestion information request to target gNB.

16.17 Support for TSN enabled Transport Network

The NG-RAN may support the TSN enabled Transport Network as specified in TS 23.501 [3].

16.18 Support for Aerial UE Communication

16.18.1 General

NR connectivity for UEs capable of Aerial communication is supported via the following functionalities:

- Subscription-based Aerial UE identification and authorization, as specified in TS 23.502 [22], clause 5.2.3.3.1;
- Altitude reporting based on the measurement event(s) where the UE's altitude has crossed a network-configured reference altitude threshold;
- Altitude-dependent configurations which apply only to specific altitude regions;
- Interference detection based on a measurement reporting that is triggered when a configured number of cells (i.e. larger than one) fulfils the triggering criteria simultaneously;
- Signalling of flight path information from UE to NG-RAN and from the source gNB to target gNB during handover;
- Location information reporting, including UE's horizontal and vertical velocity;
- Transmitting of BRID and DAA messages via PC5 interface;
- Flight information reporting for Aerial UE as specified in TS 23.256 [60], clause 5.16.

16.18.2 Subscription-based Identification of Aerial UE

Support for Aerial UE functions is stored in the user's subscription information in UDM. UDM transfers this information to the AMF during Registration, Service Request and Mobility Registration Update procedures.

The Aerial UE subscription information can be provided by the AMF to the NG-RAN node via the NGAP INITIAL CONTEXT SETUP REQUEST message during the Registration, Mobility Registration Update and Service Request procedures. The subscription information can also be updated via the NGAP UE Context Modification procedure and NGAP Path Switch Request procedure. In addition, for Xn-based handover, the source NG-RAN node can include the Aerial UE subscription information in the XnAP HANDOVER REQUEST message and RETRIEVE UE CONTEXT RESPONSE message to the target NG-RAN node.

For intra- and inter-AMF NG-based handover, the AMF provides the Aerial UE subscription information to the target NG-RAN node after the handover procedure.

16.18.3 Altitude-based Reporting for Aerial UE Communication

An Aerial UE can be configured with altitude-dependent, event-based measurement reporting (i.e., *eventH1* and *eventH2* as defined in TS 38.331 [12]). An Aerial UE sends a measurement report when its altitude becomes higher or lower than configured threshold. The UE includes its altitude and location information in the measurement report if configured to do so by NG-RAN.

The Aerial UE can also be configured to trigger measurement reporting only when both an altitude-dependent condition and an RSRP/RSRQ/SINR-based condition are met (i.e., *eventA3H1*, *eventA3H2*, *eventA4H1*, *eventA4H2*, *eventA5H1* and *eventA5H2* in TS 38.331 [12], commonly denoted as *eventAxHy*). For the content of *eventAxHy* measurement report, the same rules as described above for *eventH1* and *eventH2* apply.

16.18.4 Altitude-dependent Configurations for Aerial UE Communication

An Aerial UE can be configured with multiple altitude-dependent configurations, each of which is applied in its corresponding altitude range. Altitude-dependent configurations can be provided independently in measurement object (i.e. *SSB-ToMeasureAltitudeBased* in TS 38.331 [12]) and an Aerial UE uses those when in RRC_CONNECTED. Altitude-dependent measurement configurations can also be provided independently in SIB2 and/or SIB4 (i.e. *SSB-ToMeasureAltitudeBased* in TS 38.331 [12]) and an Aerial UE uses those when in RRC_IDLE or RRC_INACTIVE.

16.18.5 Interference Detection and Mitigation for Aerial UE Communication

For interference detection, an Aerial UE can be configured with RRM event A3, A4, A5 or AxHy that triggers measurement report when individual (per cell) RSRP/RSRQ/SINR values (for events A3, A4, A5) or RSRP/RSRQ/SINR and measured Aerial UE's altitude (for events AxHy) for a configured number of cells fulfil the configured event. Once such condition is met and a measurement report is sent, the list of triggered cells is updated when subsequent cell(s) fulfil the event. However, further measurement reports are not sent while the list of triggered cells remains larger than or equal to the configured number of cells unless *reportOnLeave* is configured (see TS 38.331 [12] for details).

16.18.6 Flight Path Information Reporting for Aerial UE Communication

NG-RAN can request the Aerial UE to report flight path information based on the indication from the Aerial UE that flight path information is available or without such indication from the Aerial UE. Flight path information consists of a number of waypoints defined as 3D locations, as defined in TS 37.355 [43]. Aerial UE reports up to a configured number of waypoints if flight path information is available at the UE. The report can also contain a time stamp per waypoint if configured by the NG-RAN and if available at the UE.

The flight path information can be also provided by the source gNB to the target gNB during handover. If configured by the NG-RAN and if the associated distance- or time-based condition (see *flightPathUpdateDistanceThr* and *flightPathUpdateTimeThr* in TS 38.331 [12], respectively) for indication reporting are met for any of the waypoints, the Aerial UE indicates the availability of the updated flight path information. The Aerial UE can also indicate the availability of the updated flight path information if a new waypoint has been added or if a future waypoint has been removed from the flight path information.

16.18.7 Location Reporting for Aerial UE Communication

Location information for Aerial UE communication can include horizontal and vertical speed if configured. Location information can be included in RRM report and in altitude-based reporting (as described in 16.18.3).

16.18.8 BRID and DAA Support via A2X Communication

The Aerial UE supports A2X communication, as defined in 3.2. BRID relies on broadcasting while DAA can be provided either via unicast or broadcast transmissions in NR sidelink. BRID and DAA message transmission is supported in both in-coverage and out-of-coverage scenarios and relies on UE autonomous resource selection for NR sidelink communication.

BRID and DAA follow the QoS framework defined for NR sidelink and dedicated A2X PQI values are specified in table 6.2.4.1-1 of TS 23.256 [60]. The NG-RAN can configure separate SL Tx resource pool(s) for BRID and/or DAA. The procedure for SL Tx pool selection for A2X is described in TS 38.321 [6], clause 5.22.

16.18.9 Altitude-based CHO for Aerial UE Communication

An Aerial UE can be configured to trigger CHO execution only when both an altitude-dependent condition and an RSRP/RSRQ/SINR-based condition are met (i.e., *condEventA3H1*, *condEventA3H2*, *condEventA5H1* and *condEventA5H2* in TS 38.331 [12], commonly denoted as *condEventAxHy*).

16.18.10 UAV prioritized frequency for Aerial UE cell reselection

UAV prioritized frequency can be indicated via SIB2 and/or SIB4, an Aerial UE may consider the cell reselection priority of the UAV prioritized frequency is higher than other frequencies. Optionally, an altitude range can be configured by network, and the Aerial UE may only consider the cell reselection priority of the UAV prioritized frequency is higher than other frequencies when it is within this altitude range.

16.18.11 Flight Information Reporting for Aerial UE

Core network can instruct a gNB to perform flight information reporting for an Aerial UE by providing multiple pairs of altitude reporting thresholds and, for each pair, the corresponding TAI or cell ID or NG-RAN ID and optionally reporting periodicity as specified in TS 23.256 [60], clause 5.16.

The gNB should report the Aerial UE flight information and corresponding time stamp when the gNB receives such information from the Aerial UE.

Core Network can also instruct the gNB to stop performing the flight information reporting for the Aerial UE. The gNB can also indicate to the Core network that an ongoing flight information reporting is failed.

16.19 Support for Air to Ground Networks

16.19.1 Overview

In Air-to-ground (ATG) network, an NG-RAN consisting of ground-based gNBs, which provide cell towers that send signals up to an aircraft's antenna(s) of onboard ATG terminal, with typical vertical altitude of around 10,000m and take-off/landing altitudes down to 3000m.

DC is not supported for ATG in this release of the specification.

16.19.2 Timing and Synchronization

16.19.2.1 Scheduling and Timing

To accommodate the propagation delay in ATG, the timing relationship is enhanced by one cell-specific offset K_{offset}:

- K_{offset} is a configured scheduling offset that needs to be larger or equal to the max RTT.

The scheduling offset K_{offset} is used to allow the UE sufficient processing time between a downlink reception and an uplink transmission, see TS 38.213 [38].

16.19.2.2 Timing Advance

For the serving cell, the network broadcasts coarse gNB location information. The UE shall have valid GNSS position as well as gNB location before connecting to an ATG cell. To achieve synchronisation, before and during connection to an ATG cell, the UE shall compute the RTT between UE and the gNB based on the GNSS position and the gNB location parameters, and autonomously pre-compensate the T_{TA} for the RTT between the UE and the gNB.

In connected mode, the UE shall be able to continuously update the Timing Advance.

The UE may be configured to report Timing Advance during Random Access procedures or in connected mode. For an RRC_CONNECTED UE, event-triggered reporting of the Timing Advance is supported.

16.19.3 Mobility

16.19.3.1 Mobility in RRC_IDLE and RRC_INACTIVE

The same principles as described in 9.2.1 apply to mobility in RRC_IDLE for ATG and the same principles as described in 9.2.2 apply to mobility in RRC_INACTIVE for ATG unless hereunder specified. The gNB reference location of the serving cell and neighbour cell(s) provided in *SIB22* can be used for the UE to perform the idle/inactive measurement and mobility.

The UE can determine whether a network is for ATG connectivity implicitly by the existence of *cellBarredATG* in SIB1.

16.19.3.2 Mobility in RRC_CONNECTED

16.19.3.2.1 Handover

The same principle as described in 9.2.3.2 applies to ATG unless hereunder specified.

16.19.3.2.2 Conditional Handover

The same principle as described in 9.2.3.4 applies to ATG unless hereunder specified.

ATG supports the following additional trigger conditions upon which UE may execute CHO to a candidate cell, as defined in TS 38.331 [12]:

- The RRM measurement-based event A4;
- A location-based trigger condition.

A location-based trigger condition is always configured together with one of the measurement-based trigger conditions (CHO events A3/A4/A5) as defined in TS 38.331 [12].

16.19.3.3 Measurements

A UE in RRC_CONNECTED can skip the neighbour Secondary Cell measurement based on network configuration.

16.20 Support of AI/ML for NG-RAN

16.20.1 General

Support of AI/ML for NG-RAN, as a RAN function, is used to facilitate Artificial Intelligence (AI) and Machine Learning (ML) techniques in NG-RAN.

The objective of AI/ML for NG-RAN is to improve network performance and user experience, through analysing the data collected and autonomously processed by the NG-RAN, which can yield further insights, e.g., for Network Energy Saving, Load Balancing, Mobility Optimization, Network Slicing, CCO.

16.20.2 Principles

Support of AI/ML for NG-RAN requires inputs from neighbour NG-RAN nodes (e.g., predicted information, feedback information, measurements) and/or UEs (e.g., measurement results).

Signalling procedures used for the exchange of information to support AI/ML for NG-RAN, are use case and data type agnostic, which means that the intended usage (e.g., input, output, feedback) of the data exchanged via these procedures is not indicated.

AI/ML algorithms and models are out of 3GPP scope. Model-specific performance information, e.g. model performance indicators specified in clause 6 of TS 28.105 [64], is not exchanged over NG-RAN interfaces in TS 38.401 [4].

Support of AI/ML for NG-RAN does not apply to ng-eNB.

For the deployment of AI/ML for NG-RAN the following scenarios may be supported:

- AI/ML Model Training is located in the OAM and AI/ML Model Inference is located in the NG-RAN node;
- AI/ML Model Training and AI/ML Model Inference are both located in the NG-RAN node.

AI/ML Model Training follows the definition of the "ML model training" as specified in clause 3.1 of TS 28.105 [64]. An AI/ML Model needs to be trained, validated and tested before deployment for AI/ML Model Inference.

AI/ML Model Inference follows the definition of the "AI/ML inference" as defined in clause 3.1 of TS 28.105 [64].

16.20.3 Data Collection and Reporting

The following information can be configured to be reported by an NG-RAN node:

- Predicted resource status information, including predicted radio resource status per slice;
- UE performance feedback, including per-slice UE performance;
- Measured UE trajectory;
- Energy Cost (EC);
- Predicted slice available capacity.

The collection and reporting of the above information are configured through the Data Collection Reporting Initiation procedure, while the actual reporting is performed through the Data Collection Reporting procedure.

The collection of measured UE trajectory and UE performance feedback is triggered at successful Handover.

Cell-based UE trajectory prediction, which can be used, e.g., for the Mobility Optimization use case, is transferred to the target NG-RAN node via the Handover Preparation procedure to provide information for, e.g., subsequent mobility decisions. Cell-based UE trajectory prediction is limited to the first-hop target NG-RAN node.

An NG-RAN node may derive predicted CCO issues and the corresponding future coverage states for its affected cells and beams. The NG-RAN node may notify its neighbour NG-RAN nodes, via the NG-RAN Node Configuration Update procedure, about the future coverage state changes together with modification cause and time information. The NG-RAN node may also notify its neighbour NG-RAN nodes that previously notified coverage state changes together with the corresponding modification cause have been cancelled.

At any given point in time, for a list of predicted affected cells and beams, there is only one predicted CCO issue generated by a gNB.

16.20.4 OAM Requirements

OAM configures the following for EC reporting:

- The minimum and maximum energy consumption values corresponding to the minimum and maximum EC index values respectively, based on an implementation-specific mapping rule, which is unified within a defined area; and
- The recommended time interval within which an NG-RAN node selects an implementation-specific time window for averaging of the measurements of the NG-RAN node's consumed energy.

OAM may further configure Continuous Management-based MDT as defined in TS 37.320 [71] towards the NG-RAN. OAM provides specific information to the NG-RAN for the NG-RAN to identify Continuous Management-based MDT, as specified in TS 37.320 [71].

16.21 Multi-path Relay

16.21.1 General

In multi-path relay scenario, a MP Remote UE is connected to a single gNB via one direct path and one indirect path while the MP Remote UE is in RRC_CONNECTED state. For the indirect path, both L2 and L3 MP Relay architectures are supported for MP Relay using PC5 interface, and only L2 MP Relay architecture is supported for MP Relay using N3C interface. The L3 MP Relay architecture is transparent to the serving NG-RAN of the MP Relay UE, except for controlling sidelink resources. In the case of MP Remote UE using SL indirect path, mode 1 resource allocation is supported only for intra-DU case, with the SR/BSR and grant sent on the direct path.

In multi-path relay, the interface between MP Remote UE and MP Relay UE can be either PC5 or N3C. When the interface between MP Remote UE and MP Relay UE is N3C interface, the relationship of MP Remote UE and MP Relay UE is pre-configured or static, and it is up to the implementation of the MP Remote UE and MP Relay UE how to pre-configure or make it static. More than one MP Relay UEs can be configured to MP Remote UE via N3C interface.

Multi-path relay supports MP Remote UE and MP Relay UE when they are in the same gNB, and PCell is always on the direct path.

Multi-path relay is supported in the following cell deployment scenarios:

- The MP Relay UE and MP Remote UE are served by the same cell;
- The MP Relay UE and MP Remote UE are served by different intra-frequency cells of the same gNB;
- The MP Relay UE and MP Remote UE are served by different inter-frequency cells of the same gNB.

Multi-path relay is supported in the following sidelink scenarios:

- Sidelink TX/RX and Uu link share the same carrier at the MP Remote UE;
- Sidelink TX/RX and Uu link use different carriers at the MP Remote UE;
- Sidelink TX/RX and Uu link share the same carrier at the MP Relay UE;
- Sidelink TX/RX and Uu link use different carriers at the MP Relay UE.

16.21.2 Protocol Architecture

From L2 MP Remote UE perspective, three bearer types exist: direct bearer, indirect bearer, and split bearer. For direct bearer, only Uu radio resources are involved, and for indirect bearer, only PC5 or N3C radio resources are involved. For split bearer, both Uu and PC5/N3C radio resources are involved.

16.21.2.1 L2 MP Relay using SL indirect path

For multi-path relay operation by using SL indirect path, the protocol stacks for the user plane and control plane of L2 MP Relay architecture are illustrated in Figure 16.21.2.1-1, 16.21.2.1-2.

If PC5 interface is used between L2 MP Remote UE and L2 MP Relay UE, the SRAP sublayer is placed above the RLC sublayer for both CP and UP at both PC5 interface and Uu interface of the indirect path. For the direct path, the Uu SDAP, PDCP, RLC, MAC, PHY, and RRC are terminated at gNB and L2 MP Remote UE. But for the indirect path, only the Uu SDAP, PDCP and RRC are terminated at gNB and L2 MP Remote UE, while SRAP, RLC, MAC, and PHY are terminated in each hop (i.e., the link between L2 MP Remote UE and L2 MP Relay UE and the link between L2 MP Relay UE and the gNB). PDCP duplication is supported for the MP split bearer.

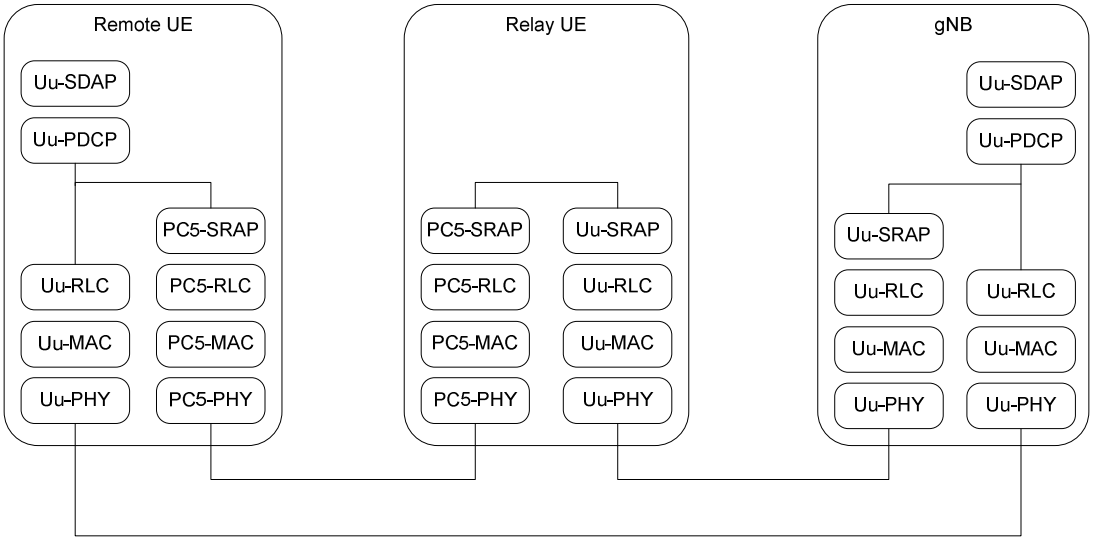


Figure 16.21.2.1-1: User plane protocol stack for L2 Multi-path Relay using SL indirect path

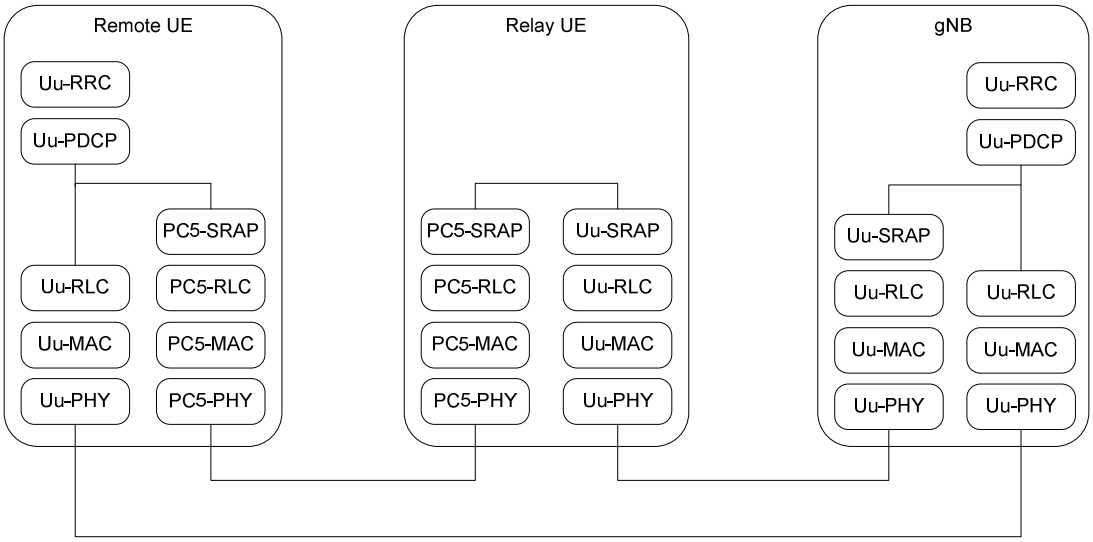


Figure 16.21.2.1-2: Control plane protocol stack for L2 Multi-path Relay using SL indirect path

16.21.2.2 L2 MP Relay using N3C indirect path

For the multi-path relay using N3C indirect path between the L2 MP Remote UE and L2 MP Relay UE(s), at least one MP Relay UE(s) can be configured with MP Remote UE via N3C interface. The protocol stacks for the user plane and control plane of L2 MP Relay architecture are illustrated in Figure 16.21.2.2-1 and Figure 16.21.2.2-2.

In the multi-path relay using N3C indirect path, the SRAP sublayer does not exist on the protocol stack. For the direct path, the Uu SDAP, PDCP, RLC, MAC, PHY and RRC are terminated at gNB and L2 MP Remote UE. While RLC, MAC, and PHY in Uu hop of indirect path are terminated at L2 MP Relay UE and gNB. Without the SRAP sublayer over N3C, an UL PDCP PDU in the L2 MP Remote UE is delivered to RLC entity in the L2 MP Relay UE via N3C link based on UE implementation. It is supported for more than one RB over the Uu link of the L2 MP Relay UE by configuring 1:1 bearer mapping between the Radio bearer in the L2 MP Remote UE and Uu Relay RLC channel in the L2 MP Relay UE. The Uu logical channels for the PDU delivery of the L2 MP Relay UE's local traffic and relay traffic are configured differently. Bearer identification except LCID is not needed in L2 PDU over the Uu link. If split bearer is configured, it is up to MP Remote UE implementation to decide which MP Relay UE is used for transmission of a UL PDCP PDU, when more than one MP Relay UEs are configured to MP Remote UE in N3C interface. If the split bearer is configured and the PDCP duplication is activated, the duplicated PDCP PDUs are delivered via both direct path and indirect path, and it is up to MP Remote UE implementation to decide which MP Relay UE(s) is(are) used for

transmission of a UL PDCP PDU when more than one MP Relay UEs are configured to MP Remote UE in N3C interface.

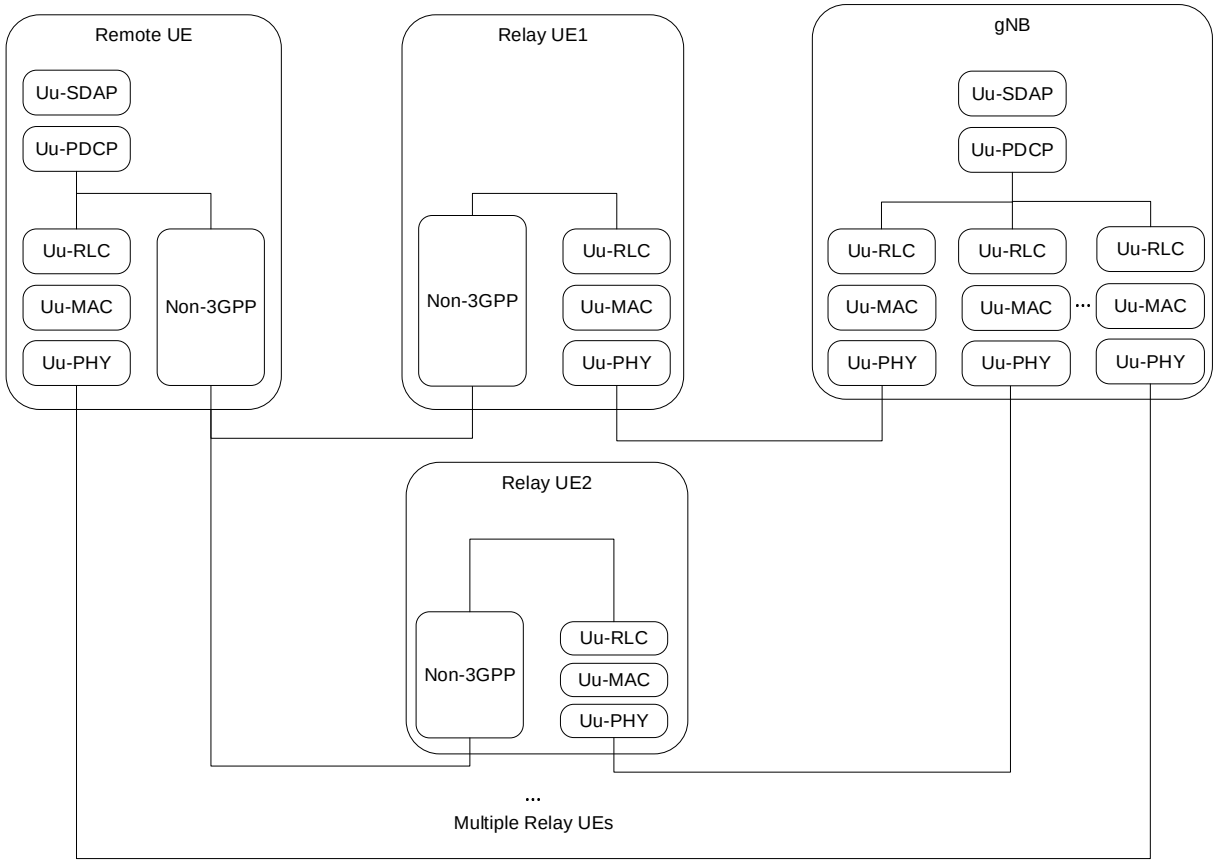


Figure 16.21.2.2-1: User plane protocol stack for L2 Multi-path Relay(s) using N3C indirect path

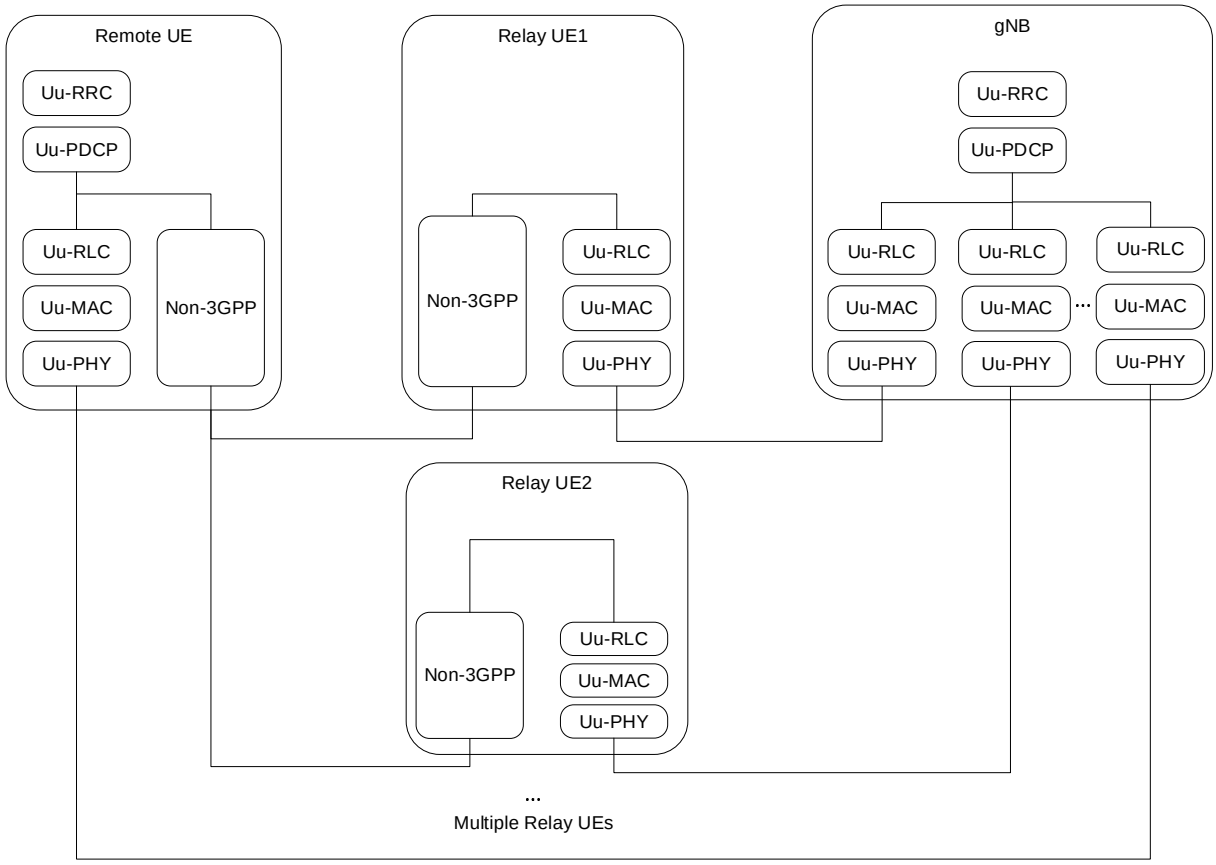


Figure 16.21.2.2-2: Control plane protocol stack for L2 Multi-path Relay(s) using N3C indirect path

16.21.3 Control plane procedure for multi-path relaying

16.21.3.1 Path Management

The L2 MP Remote UE needs to establish both a direct path and an indirect path. The L2 MP Remote UE adds the indirect path using PC5 link on top of the direct path under the same gNB. And also, the L2 MP Remote UE using PC5 link adds the direct path on top of the indirect path under the same gNB.

Meanwhile, the L2 MP Remote UE adds the indirect path using N3C link on top of the only direct path under the same gNB. But it is not allowed that the L2 MP Remote UE using N3C indirect path adds the direct path on top of the indirect path. The MP Relay UE using N3C indirect path is restricted to serve only one L2 MP Remote UE.

For L2 MP Remote UE, the direct path and the indirect path should be in the same gNB. The primary path of split SRB1 and SRB2 is always configured on direct path. In the L2 MP Remote UE, non-split SRB1/2 is allowed to be configured only on direct path.

Figure 16.21.3.1-1 describes the procedures for the indirect path addition on top of the direct path for the L2 MP relaying. This procedure is applicable to the L2 MP Remote UE using SL indirect path or N3C indirect path (except step 5).

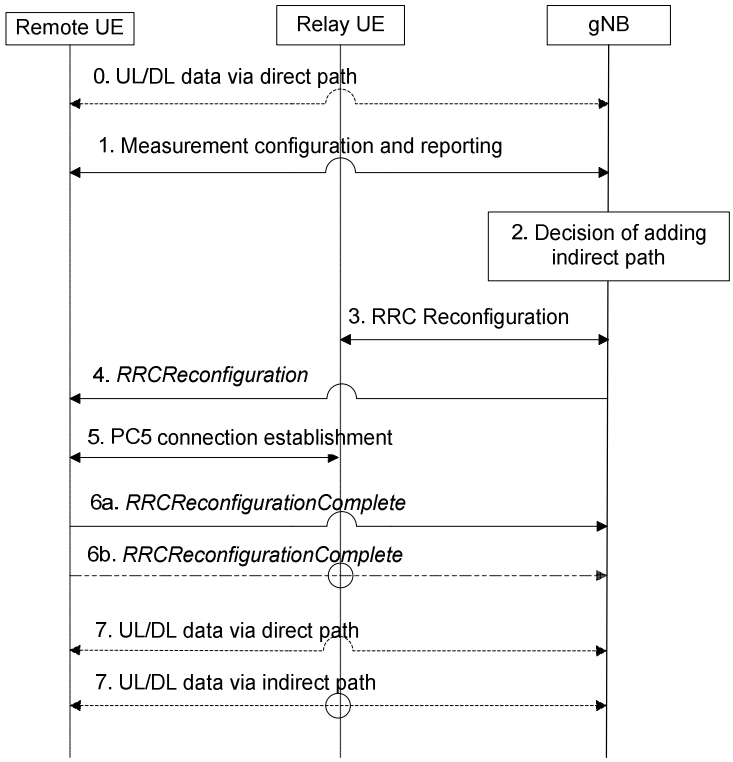


Figure 16.21.3.1-1: Procedure for indirect path addition on top of direct path

0. The L2 MP Remote UE performs data transmission and reception by using direct path on PCell.

1. If the L2 MP Remote UE will be connected with L2 MP Relay UE using PC5 link, the L2 MP Remote UE reports at least the list of the candidate L2 MP Relay UE ID and the cell ID of the candidate L2 MP Relay UEs based on the measurement configuration from the gNB.

   Meanwhile, if the MP Remote UE will be connected with L2 MP Relay UE using N3C link, the MP Remote UE reports at least the list of the C-RNTI and the cell ID of the candidate MP Relay UEs using *UEAssistanceInformation* message to the gNB.

NOTE 1: The C-RNTI and cell ID of MP Relay UE using N3C link can be reported only if the secure connection between MP Remote UE and MP Relay UE is established.

2. The gNB decides to add the indirect path for the L2 MP Remote UE. The cell serving the direct path and the cell serving the L2 MP Relay UE on the indirect path belong to the same gNB but can be same or different.

3. The gNB sends an *RRCReconfiguration* message to the L2 MP Relay UE to configure the indirect path of the L2 MP Remote UE, if the L2 MP Relay UE is in RRC_CONNECTED.

4. The gNB sends the *RRCReconfiguration* message to the L2 MP Remote UE.

5. The L2 MP Remote UE establishes a PC5 unicast link with the target L2 MP Relay UE.

NOTE 2: For the N3C indirect path addition, step 5 is omitted. It is L2 MP Remote UE's implementation how to make N3C indirect path between L2 MP Remote UE and L2 MP Relay UE.

6a. The L2 MP Remote UE sends the *RRCReconfigurationComplete* message to the gNB at least via the direct path in order to complete the indirect path addition procedure.

6b. If a split SRB1 with duplication is configured, the L2 MP Remote UE also sends the *RRCReconfigurationComplete* message to the gNB via the indirect path served by the L2 MP Relay UE.

NOTE 3: Step 5 can be executed after step 6a. Step 5 is independent of step 6a.

7. The L2 MP Remote UE performs data transmission and reception by using both the direct path on PCell and the indirect path served by a L2 MP Relay UE.

In the case that the selected L2 MP Relay UE for indirect path addition is in RRC_IDLE or RRC_INACTIVE, after receiving the path addition command, the L2 MP Remote UE should trigger the L2 MP Relay UE in RRC_IDLE or RRC_INACTIVE to move to RRC_CONNECTED. If the L2 MP Remote UE and L2 MP Relay UE are connected by using N3C link, it is L2 MP Remote/Relay UE's implementation on how to trigger the RRC_IDLE/RRC_INACTIVE L2 MP Relay UE to initiate RRC connection establishment/resume procedure.

If the split SRB1 with duplication is not configured at the L2 MP Remote UE, the L2 MP Remote UE using SL indirect path sends PC5-RRC message to the L2 MP Relay UE. Upon receiving the PC5-RRC message, the L2 MP Relay UE in RRC_IDLE or RRC_INACTIVE initiates a Uu RRC connection establishment or an RRC connection resume.

If the split SRB1 with duplication is configured, the L2 MP Remote UE sends the *RRCReconfigurationComplete* message via the L2 MP Relay UE. The *RRCReconfigurationComplete* message triggers that the L2 U2N Relay UE in RRC_IDLE or RRC_INACTIVE initiates a Uu RRC connection establishment or an RRC connection resume for sending the *RRCReoncfigurationComplete* message to the gNB.

Figure 16.21.3.1-2 describes the procedures for the indirect path change under a single direct path in the L2 MP Relay operation. This procedure is applicable to the L2 MP Remote UE using SL indirect path or N3C indirect path (except step 5).

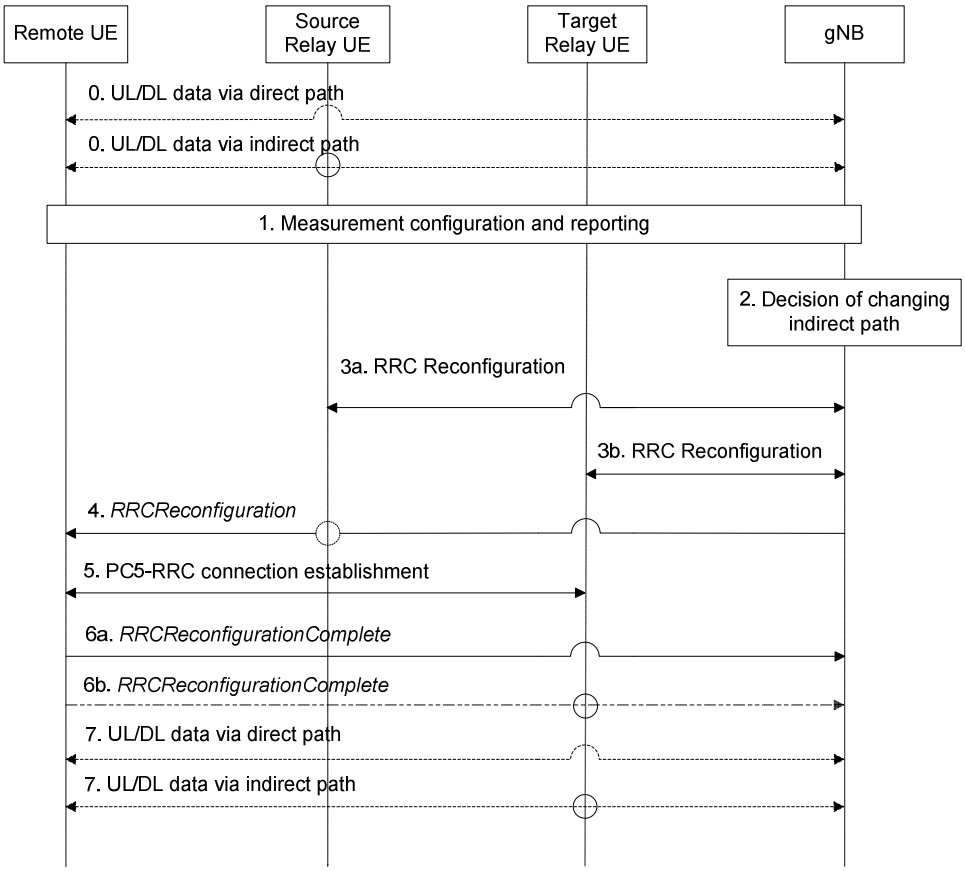


Figure 16.21.3.1-2: Procedure for indirect path change

0. The L2 MP Remote UE performs data transmission and reception by using both the direct path on PCell and the indirect path served by a source L2 MP Relay UE.

1. The L2 MP Remote UE performs measurements based on measurement configuration. When the measurement reporting is triggered, the L2 MP Remote UE using SL indirect link reports at least signal strength (e.g., SD-RSRP/SL-RSRP) of the serving indirect path, the list of the candidate L2 MP Relay UE ID and the cell ID of the candidate L2 MP Relay UEs.

Meanwhile, the MP Remote UE using N3C link reports at least the list of the C-RNTI and the cell ID of the candidate MP Relay UEs.

2. The gNB decides to change the indirect path of L2 MP Remote UE from the source L2 MP Relay UE to a target L2 MP Relay UE. The cell serving the direct path and the cell serving the source/target L2 MP Relay UE on the indirect path belong to the same gNB but can be same or different.

3a. The gNB sends an *RRCReconfiguration* message to the source L2 MP Relay UE to release the indirect path of the L2 MP Remote UE.

3b. The gNB sends an *RRCReconfiguration* message to the target L2 MP Relay UE to add the indirect path for the L2 MP Remote UE.

4. The gNB sends the *RRCReconfiguration* message to the L2 MP Remote UE on the direct path or both paths for indirect path change. If split SRB1 is configured, it is up to gNB implementation whether the *RRCReconfiguration* is sent via one of the paths or both paths.

NOTE 3a: The ordering among step 3a, step 3b, and step 4 is up to gNB implementation.

5. The L2 MP Remote UE establishes a PC5-RRC connection with the target L2 MP Relay UE for using SL indirect path.

NOTE 4: For the N3C indirect path addition, step 5 is omitted. It is L2 MP Remote UE's implementation how to make N3C indirect path between L2 MP Remote UE and L2 MP Relay UE.

6a. The L2 MP Remote UE sends the *RRCReconfigurationComplete* message to the gNB at least via the direct path in order to complete the indirect path change procedure.

NOTE 5: Step 5 can be executed after step 6a. Step 5 is independent of step 6a.

6b. If a split SRB1 with duplication is configured, the L2 MP Remote UE also sends the *RRCReconfigurationComplete* message to the gNB via the indirect path served by the target L2 MP Relay UE.

7. The L2 MP Remote UE performs data transmission and reception by using both the direct path on PCell and the indirect path served by a target L2 MP Relay UE.

In the case that the selected target L2 MP Relay UE for indirect path change is in RRC_IDLE or RRC_INACTIVE, after receiving the path change command, the L2 MP Remote UE should trigger the target L2 MP Relay UE in RRC_IDLE or RRC_INACTIVE to be in RRC_CONNECTED. If the L2 MP Remote UE and L2 MP Relay UE are connected by N3C link, it is L2 MP Remote/Relay UE's implementation on how to trigger the RRC_IDLE/RRC_INACTIVE L2 MP Relay UE to initiate RRC connection establishment/resume procedure. If the target L2 MP Relay UE is not in RRC_CONNECTED in step 3, the gNB sends an *RRCReconfiguration* message to the target L2 MP Relay UE after the target L2 MP Relay UE enters RRC_CONNECTED.

If the split SRB1 with duplication is not configured, at the L2 MP Remote UE, the L2 MP Remote UE sends the *RRCReconfigurationComplete* message only on the direct path in Step 6a. The L2 MP Remote UE using SL indirect path can send a PC5-RRC message to the target L2 MP Relay UE in RRC_IDLE or RRC_INACTIVE after or during Step 5. The target L2 MP Relay UE in RRC_IDLE or RRC_INACTIVE initiates an RRC connection establishment or an RRC connection resume upon receiving the PC5-RRC message from the L2 MP Remote UE.

If the split SRB1 with duplication is configured, the L2 MP Remote UE sends the *RRCReconfigurationComplete* message via the target L2 MP Relay UE. The *RRCReconfigurationComplete* message triggers that the L2 U2N Relay UE in RRC_IDLE or RRC_INACTIVE initiates an RRC connection establishment or an RRC connection resume for sending the *RRCReconfigurationComplete* message to the gNB at Step 6b. If the target L2 MP Relay UE is in RRC_IDLE or RRC_INACTIVE, the *RRCReconfigurationComplete* message at Step 6b is sent to the gNB after the target L2 MP Relay UE enters RRC_CONNECTED.

Figure 16.21.3.1-3 describes the procedures for the direct path addition on top of the indirect path for the L2 MP Relay operation. This procedure is only applicable to the L2 MP Remote UE using SL indirect path.

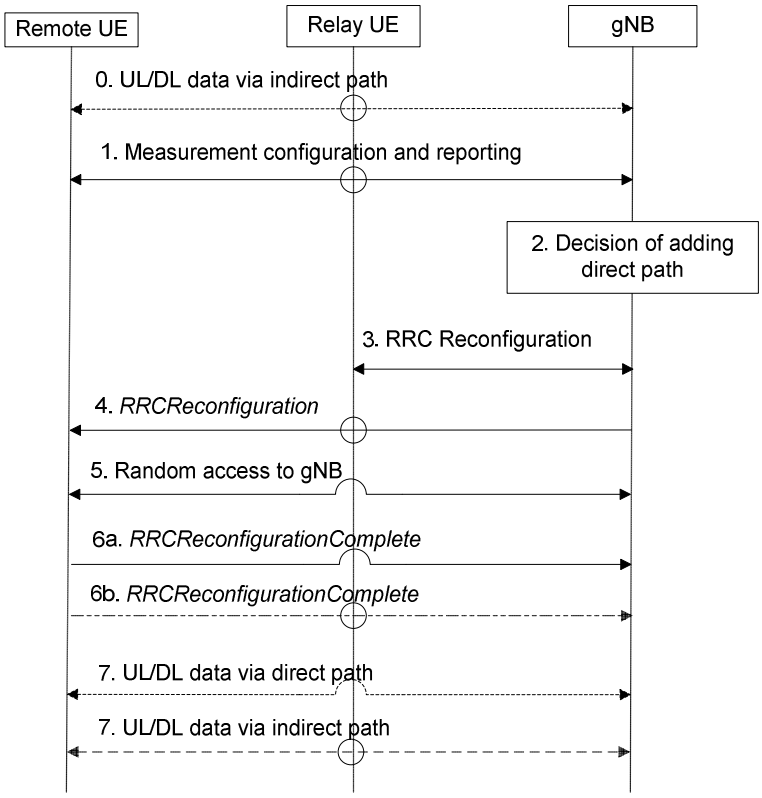


Figure 16.21.3.1-3: Procedure for direct path addition on top of indirect path

0. The L2 MP Remote UE performs data transmission and reception by using indirect path via PC5 link.

1. The L2 MP Remote UE performs measurements based on measurement configuration. When the measurement reporting is triggered, the L2 MP Remote UE reports at least the Uu signal strength of neighbour cells with the cell IDs (i.e., NCGI/NCI).

2. The gNB decides to add the direct path for the L2 MP Remote UE. The cell serving the direct path and the cell serving the L2 MP Relay UE on the indirect path belong to the same gNB but can be same or different.

3. The gNB sends an *RRCReconfiguration* message to the L2 MP Relay UE to update the indirect path configuration, if necessary.

4. The gNB sends the *RRCReconfiguration* message to the L2 MP Remote UE via the L2 MP Relay UE. The contents in the *RRCReconfiguration* message includes at least a target cell within direct path addition configuration.

NOTE 6: The ordering of step 3 and step 4 is up to gNB implementation.

5. The L2 MP Remote UE synchronizes to DL of the target cell serving the direct path and performs random access procedure towards the cell serving the direct path. The L2 MP Remote UE configures the target cell as PCell.

6a. The L2 MP Remote UE sends the *RRCReconfigurationComplete* message to the gNB at least via the direct path in order to complete the direct path addition procedure.

6b. If a split SRB1 with duplication is configured, the L2 MP Remote UE also sends the *RRCReconfigurationComplete* message to the gNB via the indirect path served by the L2 MP Relay UE.

7. The L2 MP Remote UE performs data transmission and reception by using both the direct path on PCell and the indirect path served by a L2 MP Relay UE.

Figure 16.21.3.1-4 describes the procedures for the direct path change on top of the indirect path for the L2 MP Relay operation. This procedure is only applicable to the L2 MP Remote UE using SL indirect path.

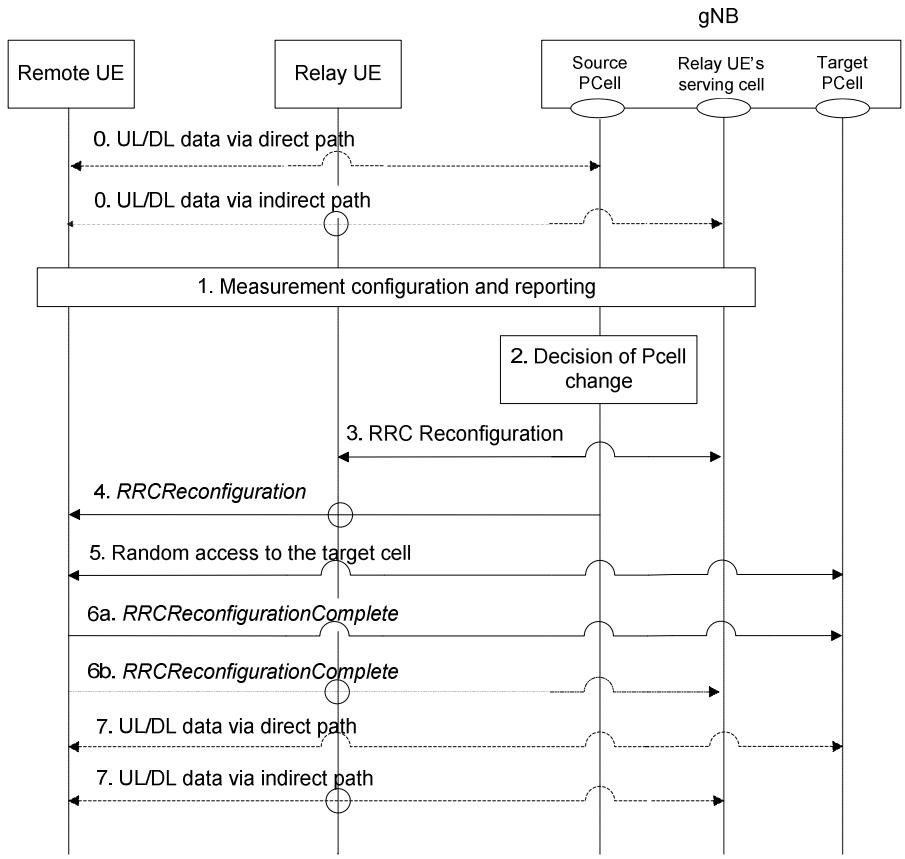


Figure 16.21.3.1-4: Procedure for direct path change

0. The L2 MP Remote UE performs data transmission and reception by using both the direct path on the source PCell and the indirect path served by a L2 MP Relay UE.

1. The L2 MP Remote UE performs measurements based on measurement configuration. The L2 MP Remote UE may report measurement results.

2. The gNB decides to change the direct path of the L2 MP Remote UE from the PCell (i.e. source PCell) to a new cell (i.e. target PCell). The source/target PCell serving the old/new direct path and the cell serving the L2 MP Relay UE on the indirect path belong to the same gNB but can be same or different.

3. The gNB sends an *RRCReconfiguration* message to the L2 MP Relay UE to update the indirect path configuration, if necessary.

4. The gNB sends the *RRCReconfiguration* message to the L2 MP Remote UE on the direct path and/or the indirect path for direct path change.

NOTE 7: The ordering of step 3 and step 4 is up to gNB implementation.

5. The L2 MP Remote UE synchronizes to DL of the target PCell serving the new direct path and performs random access procedure towards the target PCell serving the new direct path.

6a. The L2 MP Remote UE sends the *RRCReconfigurationComplete* message to the gNB at least via the direct path in order to complete the direct path change procedure.

6b. If a split SRB1 with duplication is configured, the L2 MP Remote UE also sends the *RRCReconfigurationComplete* message to the gNB via the indirect path served by the L2 MP Relay UE.

7. The L2 MP Remote UE performs data transmission and reception by using both the direct path on the target PCell and the indirect path served by a L2 MP Relay UE.

If the direct path addition/change is failed, the L2 U2N Remote UE always shall trigger *RRCReestablishment*.

16.21.3.2 Path Failure Report

The L2 MP Remote UE in RRC_CONNECTED performs Uu RLM (as described in clause 9.2.7).

When the L2 MP Remote UE detects Uu Radio Link Failure (RLF) on the direct path, the L2 MP Remote UE triggers path failure reporting through the indirect path via a RRC message if split SRB1 is configured and the indirect path is not suspended. Otherwise, RRC connection re-establishment is initiated.

When the L2 MP Remote UE using PC5 indirect path detects PC5 Radio Link Failure (RLF) and/or Uu link failure on the indirect path, the L2 MP Remote UE triggers path failure reporting through the direct path via a RRC message, if the direct path is not suspended.

When the L2 MP Remote UE using N3C indirect path detects N3C link failure and/or Uu link failure on the indirect path, the L2 MP Remote UE triggers path failure reporting through the direct path via a RRC message, if the direct path is not suspended.

16.21.3.3 System Information

The L2 MP Remote UE can acquire any necessary SIB(s) over Uu interface or indirect path. If common search space for system information is configured with the active BWP on PCell, the L2 MP Remote UE can perform direct system information acquisition on PCell. The L2 MP Remote UE can also receive system information at lease PBCH/MIB on the direct path and directly acquires SFN from MIB on the direct path. Besides, the L2 MP Remote UE can receive the system information via dedicated RRC signalling via SRB1.

16.22 Support of 2Rx XR devices

16.22.1 Introduction

A 2Rx XR UE is an XR UE that is not (e)RedCap and is equipped with only two Rx antenna ports in frequency bands where 4Rx antenna ports are mandated as specified in TS 38.101-1 [18], in which it is also defined as two antenna port XR UE. No other relaxations in UE capabilities are allowed for 2Rx XR UEs.

2Rx XR UEs are intended only for use in XR devices that are worn on human head and whose constrained form factors have limited volume available for Rx chains.

16.22.2 Identification, access and camping restrictions

A UE capability indicates that the UE is a 2Rx XR UE. A 2Rx XR UE does not identify itself in Msg1 or Msg3 during RACH procedure.

Network indicates whether access to a cell by 2Rx XR UEs is barred via system information. For a cell that operates in a frequency band where 4Rx antenna ports are mandated, presence of this indication in its system information indicates that the cell does not allow 2Rx XR UEs. In addition, an IFRI specific for 2Rx XR UEs can be provided in system information. Information on which neighbour frequencies 2Rx XR UEs are allowed to access can be provided in system information.

NOTE: It is up to the E-UTRA network, if possible, to avoid handover attempts of a 2Rx XR UE to a target NR cell not allowing 2Rx XR UEs as specified in TS 36.300 [2]. It is up to UE implementation, if possible, to recover from handover attempts to a target NR cell not allowing 2Rx XR UEs.

16.23 Support of Ambient IoT

16.23.1 General

A-IoT radio interface provides the communication between A-IoT device(s) and A-IoT reader, as illustrated in Figure 16.23.1-1. In this release, the A-IoT reader is a gNB-reader. A-IoT radio interface can support both inventory procedure and command procedure as defined in TS 23.369 [68]. An A-IoT device monitors the R2D message as long as it has sufficient energy.

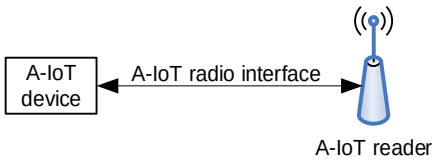


Figure 16.23.1-1: Architecture supporting the A-IoT radio interface

16.23.2 Architecture

The NG-RAN overall architecture as depicted in section 4.1 is applicable for Ambient IoT along the following adaptations and additions:

- For the sake of supporting the provision of A-IoT services, the involved gNBs are enabled to support A-IoT, specifically, the gNB supports communication with A-IoT devices by means of A-IoT radio.
- A gNB may or may not only support communication with A-IoT devices by means of A-IoT radio.
- A gNB serves one or multiple readers.
- A gNB is aware of the mapping relationship between A-IoT Areas and readers by means of OAM configuration.
- An A-IoT Area may include readers belonging to the same or different gNB.
- One reader only belongs to one gNB.
- One reader can be mapped to one or multiple A-IoT Areas.
- As specified in TS 23.369 [68], the A-IoT CN node which the gNB connects to is either the AIOTF (in case of direct connectivity with the AIOTF) or the AMF (in case of indirect connectivity with the AIOTF). A gNB is aware of direct connectivity with the AIOTF via OAM.

NOTE: A deployment with both direct connectivity and indirect connectivity is not expected.

- In this version of the specification, A-IoT specific information is transported between the gNB and the A-IoT CN node via the NG-C interface, the protocol stack in section 4.3.1.2 applies. In case of indirect connectivity with the AIOTF, A-IoT specific information is transferred transparently via the AMF.
- In this version of the specification, no A-IoT specific communication takes place between gNBs.
- In this version of the specification, split gNB architecture is not supported.

The AIOTF may request the gNB to perform an A-IoT operation within a specific area (requested service area). The requested service area may be indicated by means of a list of A-IoT Areas and/or a list of readers. The A-IoT Area is represented by an A-IoT Area ID. The reader is represented by a Reader ID as specified in TS 38.413 [26].

The AIOTF is aware of the area within which the gNB supports provision of A-IoT services by means of OAM configuration. This area may be represented as A-IoT Areas and/or the reader ID list supported by the gNB.

The AIOTF may also be aware of the reader's location by means of OAM configuration.

The AIOTF is aware of the mapping relationship among gNBs, readers and A-IoT areas by means of OAM configuration, as needed.

For Ambient IoT, the following applies in addition to the Network Identities as described in clause 8.2:

- The A-IoT Area ID is constructed from the PLMN identity (may be present together with a NID) the A-IoT area belongs to and the A-IoT Area Code.

16.23.3 Radio Protocol Architecture for A-IoT Communication

The AS protocol stack for A-IoT radio interface contains A-IoT MAC layer and A-IoT physical layer as shown in Figure 16.23.3-1. The AS layer control information and data are handled by A-IoT MAC layer and A-IoT physical layer. For A-IoT radio interface, there is no differentiation between the control plane and the user plane.

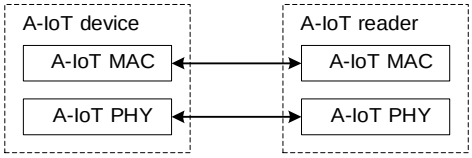


Figure 16.23.3-1: AS protocol stack for A-IoT

16.23.4 A-IoT Physical Layer Functions

16.23.4.1 Waveform, numerology, time and frequency domain structure

The R2D transmission is a DFT-s-OFDM-based OOK waveform with subcarrier spacing $\Delta f = 15 \cdot 10^3$ Hz and normal cyclic prefix. The R2D transmission in each OFDM symbol is described by a number of resource blocks, $N_{\mathrm{RB}}^{\mathrm{R2D}}$, and one resource block consists of 12 consecutive subcarriers. In each OFDM symbol, there are a number of chips to which modulated symbols are mapped. For in-band operation, the starting position of a A-IoT R2D transmission is aligned in time with the starting position of an NR OFDM symbol.

The D2R transmission is described by a set of chips to which modulated symbols are mapped, and based on backscattering on a carrier wave. The carrier wave is a single-tone sinusoid signal.

16.23.4.2 R2D

16.23.4.2.1 Physical reader-to-device channel

The Physical Reader-to-Device Channel (PRDCH) carries an R2D transport block originating from the A-IoT MAC layer. The physical-layer processing of PRDCH consists of the following steps:

- CRC attachment;
- Line encoding with OOK modulation;
- Mapping to chips and OFDM symbols.

16.23.4.2.2 Timing acquisition signal

An R2D timing acquisition signal (R-TAS) is transmitted immediately before a PRDCH, and consists of a start indicator part (SIP) followed by a clock acquisition part (CAP). The device determines that an R2D transmission begins upon determining that a SIP of R-TAS has been received. The CAP indicates the number of chips per OFDM symbol and chip duration for PRDCH.

16.23.4.2.3 Postamble

An R2D postamble is transmitted immediately after the PRDCH.

16.23.4.3 D2R

16.23.4.3.1 Physical device-to-reader channel

The Physical Device-to-Reader Channel (PDRCH) carries the D2R transport block originating from the A-IoT MAC layer. The physical-layer processing of PDRCH consists of the following steps:

- CRC attachment;
- Block repetition;
- Channel coding, which may be omitted;
- Modulation of OOK or BPSK, resulting in small frequency shift;
- Mapping to chips.

16.23.4.3.2 D2R amble signals

A D2R preamble signal for timing acquisition, timing tracking and channel estimation, and zero or more D2R midamble signal(s) for timing tracking and channel estimation, are inserted in a D2R transmission. A D2R preamble signal is transmitted immediately before a PDRCH.

16.23.5 A-IoT MAC Layer Functions

16.23.5.1 Services and functions

The main services and functions of A-IoT MAC layer include (see TS 38.391 [66]):

- Paging;
- Access;
- Transfer of upper layer data;
- Construct MAC PDUs to be mapped onto D2R transport blocks and delivered to the physical layer;
- MAC padding;
- D2R segmentation;
- Process MAC PDUs from R2D transport blocks delivered from the physical layer;
- Failure detection.

16.23.5.2 A-IoT Paging

A-IoT paging allows the A-IoT reader to trigger one, multiple or all A-IoT device(s) to perform A-IoT CBRA or A-IoT CFA. The A-IoT paging message is transmitted on PRDCH. The A-IoT paging message may include zero or one paging identifier, i.e., AIoT Device Permanent Identifier or Filtering Information as specified in TS 23.369 [68]. If a paging identifier is included, the A-IoT paging message may be addressed to a single A-IoT device or a group of A-IoT devices. If no paging identifier is included, the A-IoT paging message is addressed to all A-IoT devices. The A-IoT paging message also provides configuration for A-IoT access procedure.

NOTE: In this release, the A-IoT device is not expected to process parallel service requests indicated by A-IoT paging messages, and relies on network implementation to address the issue of parallel service requests caused by A-IoT reader overlapping scenario.

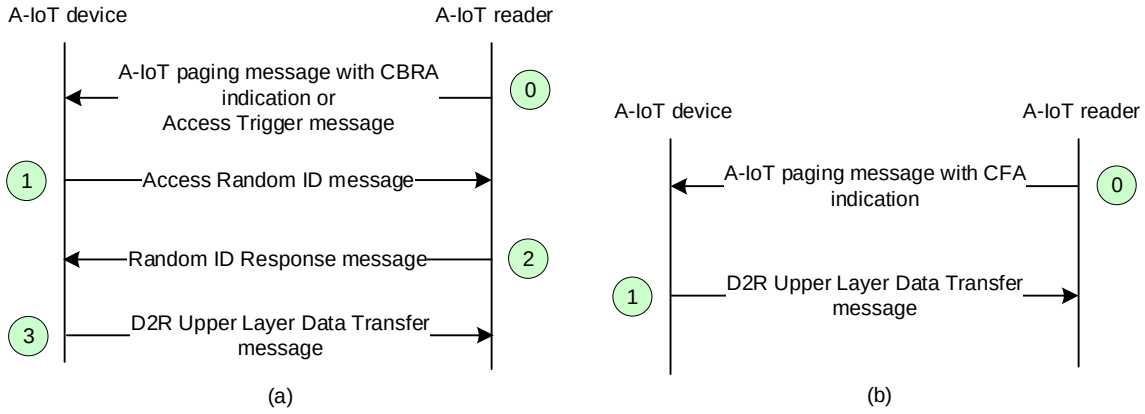
16.23.5.3 A-IoT Access Procedure

Both A-IoT CBRA procedure and A-IoT CFA procedure are supported for A-IoT access. The A-IoT device initiates either A-IoT CBRA or A-IoT CFA based on an explicit indication in the A-IoT paging message, if the device is paged.

For CBRA, the A-IoT device randomly selects one access occasion among access occasions configured in A-IoT paging message. The A-IoT device may then monitor the Access Trigger message(s) to determine the start of the selected access occasion and transmits the A-IoT MSG1 (i.e. the Access Random ID message) on this access occasion as described in TS 38.391 [66]. The start of the first set of A-IoT MSG1 resources is indicated by A-IoT Paging message directly instead of the Access Trigger message. After A-IoT MSG1 transmission, the device monitors A-IoT MSG2 (i.e. the Random ID Response message) from the A-IoT reader for contention resolution until it has received the configured number of Access Trigger messages or subsequent A-IoT Paging message (i.e., the device does not process the A-IoT MSG2 received after that). Upon successful reception of A-IoT MSG2 which contains the matched frequency index (if present) as used and same random ID as transmitted in A-IoT MSG1, the A-IoT device considers the contention resolution as successful, as shown in Figure 16.23.5.3-1(a). Otherwise, the A-IoT device considers the contention resolution as failed. If contention resolution is successful, the A-IoT device transmits the D2R Upper Layer Data Transfer message in the resource provided in A-IoT MSG2. If the A-IoT device considers the contention resolution as failed, the A-IoT device shall perform re-access if an A-IoT Paging message with the same transaction ID is received.

For CFA, the A-IoT device shall use the dedicated resource provided in A-IoT paging message to send the D2R Upper Layer Data Transfer message as shown in Figure 16.23.5.3-1(b). The A-IoT device does not need to monitor the Access Trigger message.

NOTE: For CBRA, the A-IoT reader is expected to transmit enough Access Trigger message(s) to provide a number of access occasions not less than that configured in the A-IoT Paging message, unless the A-IoT reader is about to transmit subsequent A-IoT Paging message with either the same transaction ID or a different transaction ID.



(a) A-IoT CBRA **(b) A-IoT CFA**

Figure 16.23.5.3-1: A-IoT Access Procedures

16.23.5.4 A-IoT Upper-layer Data Transmission

16.23.5.4.1 R2D and D2R data transmission

The A-IoT MAC sublayer supports R2D reception and D2R transmission of upper layer data, including inventory response, command and command response. A D2R A-IoT MAC PDU can include padding bit(s). An A-IoT device adds padding bit(s) to a D2R Upper Layer Data Transfer message so that the scheduled TB size of the A-IoT MAC PDU equals to the size of D2R Upper Layer Data Transfer message. After transmitting a D2R Upper Layer Data Transfer message following the reception of A-IoT MSG2, if an A-IoT MSG2 containing its AS ID is received, the A-IoT device retransmits the D2R Upper Layer Data Transfer message. If a NACK message containing its AS ID is received before receiving subsequent A-IoT paging message or a R2D Upper Layer Data Transfer message addressed to it, the A-IoT device shall initiate re-access as specified in 16.23.5.3, after receiving an A-IoT Paging message with the same transaction ID.

The A-IoT reader may detect the upper layer response as not available yet through the D2R Upper Layer Data Transfer message with no SDU included. Then the A-IoT reader may send a follow-up R2D Upper Layer Data Transfer message at a later time to schedule another D2R Upper Layer Data Transfer message from the A-IoT device. The follow-up R2D Upper Layer Data Transfer message includes the Received Data Size field, which is set to 0, and excludes the upper layer data.

16.23.5.4.2 Segmentation

A D2R upper layer data SDU except for inventory response can be segmented in A-IoT MAC layer so that the size of the D2R Upper Layer Data Transfer message is equal to the scheduled TB size.

Segmentation of R2D upper layer data SDU in A-IoT MAC layer is not supported.

16.23.5.5 AS ID

An A-IoT device can be assigned an AS ID or indicated to reuse the random ID transmitted in A-IoT MSG1 of A-IoT CBRA as the AS ID. The AS ID is used by the A-IoT reader to address a specific A-IoT device for R2D reception and scheduling resource for the device to perform D2R transmission. An A-IoT MSG2 of A-IoT CBRA procedure can assign an AS ID or indicate the A-IoT device to reuse the random ID transmitted in A-IoT MSG1 as the AS ID for the device. For A-IoT CFA, an A-IoT device can be assigned an AS ID by a R2D Upper Layer Data Transfer message.

An A-IoT device is not expected to maintain both AS ID and random ID simultaneously, and it maintains at most one AS ID at a time. The A-IoT device does not expect the reader to assign a different AS ID corresponding to a random ID when A-IoT MSG2 is retransmitted.

The A-IoT device releases the stored AS ID, when any of the following conditions is met:

- It is out of energy;
- It receives a NACK message addressed to it as specified in TS 38.391 [66];
- It receives an A-IoT Paging message for A-IoT CBRA, which includes the same transaction ID as the stored one, and the previous procedure was determined to be failed for this transaction ID as specified in TS 38.391 [66];
- It receives an A-IoT Paging message for A-IoT CBRA, which includes a different transaction ID from the stored one, as specified in TS 38.391 [66];
- It receives an A-IoT Paging message for A-IoT CFA as specified in TS 38.391 [66].

16.23.6 Inventory Procedure

Figure 16.23.6-1 depicts the basic communication between the gNB and the A-IoT CN node for the Inventory procedure.

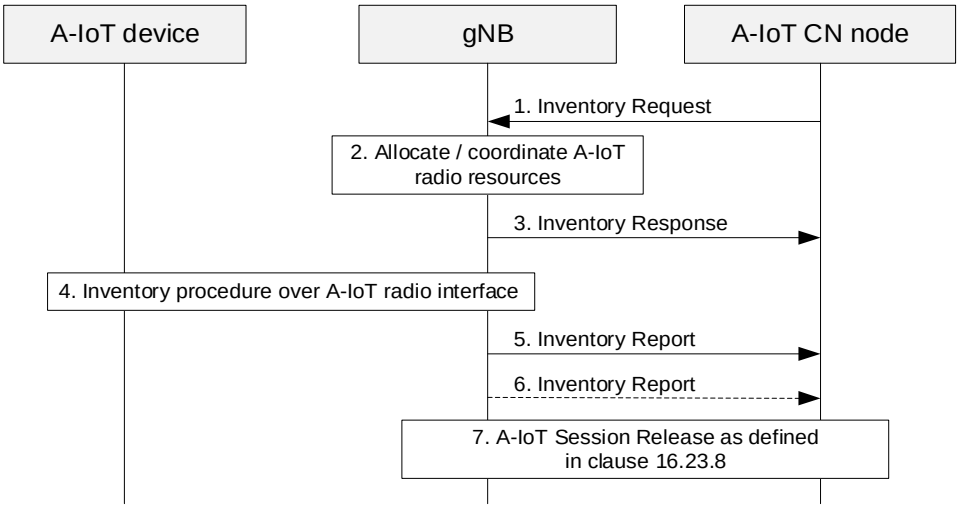


Figure 16.23.6-1: Inventory procedure

1. The A-IoT CN node initiates the Inventory procedure over NG-C by sending the Inventory Request message to the gNB. The Inventory Request message includes a Correlation ID and A-IOTF Identifier to identify the inventory session. The Inventory Request message also includes an A-IoT Device Identification Requested corresponding to the A-IoT device(s) which are targeted for the inventory. The A-IoT Device Identification Requested may indicate inventory for a single device, a group of devices or for all devices.

   The Inventory Request message also includes Requested Service Area Information (list of A-IoT Area IDs and/or reader list). If the Requested Service Area Information contains:

   - Neither the Requested AIoT Area List nor the Requested Reader List, the gNB shall select all readers it serves;
   - The Requested AIoT Area List, the gNB shall select readers within the indicated AIoT Area(s);
   - The Requested Reader List, the gNB shall take the reader list into account to perform inventory.

   The Inventory Request message also includes the Inventory Assistance Information. The Inventory Assistance Information includes the expected D2R message size and may also include e.g., approximate number of Target A-IoT devices, time interval.

The Inventory Request message may also include a follow-on command indicator to indicate that at least for one of the targeted A-IoT device(s) a Command procedure will follow.

2. The gNB allocates and co-ordinates the usage of A-IoT radio resources.

3. The gNB confirms the request from the A-IoT CN node by replying with the Inventory Response message. The Inventory Response message includes the AIOTF Identifier and the Correlation ID received in the Inventory Request message.

NOTE 1: If the gNB is not able to perform the Inventory procedure, it rejects the request and sends an Inventory Failure message to the A-IoT CN node.

4. The Inventory procedure over the A-IoT radio interface is performed, i.e., A-IoT paging, A-IoT Access Procedure and D2R data transmission, as specified in section 16.23.5.

5./6. Upon receiving the response(s) from the A-IoT device(s), the gNB sends the Inventory Report message to the A-IoT CN node. If the Inventory procedure concerns multiple A-IoT devices, multiple Inventory Report messages may be sent to the A-IoT CN node.

The Inventory Report message includes the AIOTF Identifier and the Correlation ID received in the Inventory Request message and further includes the A-IoT NAS PDU(s) carrying the inventoried A-IoT device ID(s).

If a follow-on Command indicator was received at step 1, the Inventory Report message also includes a RAN A-IoT device NGAP ID for each A-IoT device which was inventoried.

Upon completion of the inventory procedure the gNB sends an Inventory Complete Indication in the Inventory Report message.

NOTE 2: If the Inventory procedure concerns multiple A-IoT devices, an Inventory Report may include reports from multiple A-IoT devices.

7. If there is no follow-on command, the A-IOT CN triggers the A-IoT CN node initiated A-IoT Session Release procedure as defined in clause 16.23.8.

16.23.7 Command Procedure

Figure 16.23.7-1 depicts the basic communication between the gNB and the A-IoT CN node for the Command procedure.

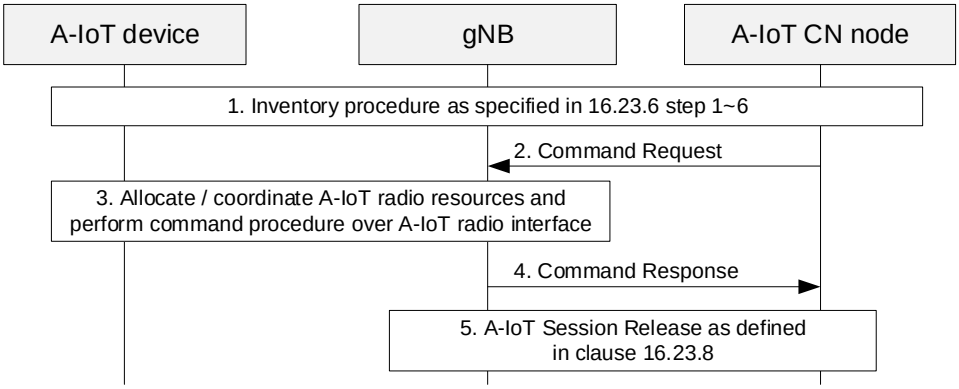


Figure 16.23.7-1: Command procedure

The Command procedure addresses only one A-IoT device.

1. Prior to the Command procedure, the Inventory procedure as defined in clause 16.23.6 steps 1 to 6 is performed involving the concerned device and potentially other A-IoT devices.

NOTE 1: Steps 2/3/4 may happen in parallel of the Inventory procedure involving other A-IoT devices or in parallel to other command procedures targeting other A-IoT devices within the same session.

2. The A-IoT CN node initiates the Command procedure over NG-C by sending the Command Request message to the gNB in order to send a command to a single A-IoT device. The Command Request message includes the same Correlation ID and AIOTF Identifier as the ones used in its corresponding inventory procedure.

   The Command Request also includes the RAN A-IoT device NGAP ID and the A-IoT NAS PDU corresponding to the targeted A-IoT device and may include some command assistance information. This command assistance information may contain the estimate of expected D2R message size.

3. The gNB allocates and co-ordinates the usage of A-IoT radio resources and performs the command procedure over the A-IoT radio interface, i.e., R2D and D2R data transmission, as specified in section 16.23.5.

4. The gNB replies to the Command Request with the Command Response message including the AIOTF Identifier the Correlation ID and the RAN A-IoT device NGAP ID received in the Command Request, and the A-IoT NAS PDU received from the device.

NOTE 2: If the gNB is not able to perform the Command procedure, it rejects the request and sends a Command Failure message to the A-IoT CN node.

5. Upon completion of all the command transmission for all related devices within the session, the A-IOT CN triggers the A-IoT CN node initiated A-IoT Session Release procedure as defined in clause 16.23.8.

16.23.8 A-IoT CN node initiated A-IoT Session Release procedure

Figure 16.23.8-1 depicts the A-IoT CN node initiated A-IoT Session Release procedure, which enables the A-IoT CN node to initiate the release of the A-IoT session context and resources related to a previously established A-IoT Session at the gNB.

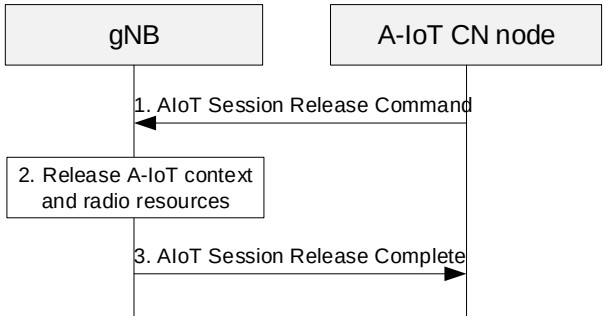


Figure 16.23.8-1: A-IoT CN node initiated A-IoT Session Release procedure

1. The A-IoT CN node initiates the A-IoT Session Release procedure over NG-C by sending the A-IoT Session Release Command message to the gNB. The A-IoT Session Release Command message includes the Correlation ID and the AIOTF Identifier to identify the session to be released.

2. The gNB releases the A-IoT session context, the associated NG resources and the A-IoT radio resources.

3. The gNB confirms the release to the A-IoT CN node by replying with the A-IoT Session Release Complete message. The A-IoT Session Release Complete message includes the AIOTF Identifier and the Correlation ID received in the A-IoT Session Release Command message.

16.23.9 gNB initiated A-IoT Session Release procedure

Figure 16.23.9-1 depicts the gNB initiated A-IoT Session Release Request procedure, which enables the gNB to request the A-IoT CN node to release the A-IoT session context and resources related to a previously established A-IoT Session.

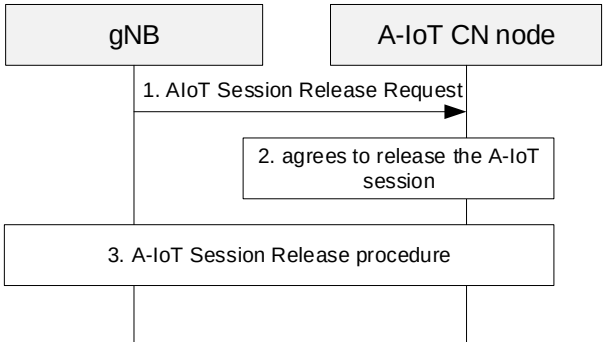


Figure 16.23.9-1: gNB initiated A-IoT Session Release procedure

1. The gNB initiates the A-IoT Session Release Request procedure over NG-C by sending the A-IoT Session Release Request message to the A-IoT CN node in order to request the release of an A-IoT session. The A-IoT Session Release Request message includes the Correlation ID and the AIOTF Identifier to identify the session requested to be released.
2. The A-IoT CN node accepts the request and triggers the A-IoT CN node initiated A-IoT Session Release procedure.
3. The A-IoT CN node initiated A-IoT Session Release procedure is performed as described in section 16.23.8.

16.23.10 Locating A-IoT devices

In this version of specification, the A-IoT device location is reported by the gNB at Reader ID granularity to the AIOTF via Inventory Report procedure. The AIOTF may use the A-IoT device location information in performing A-IoT operations.

17 Interference Management

17.1 Remote Interference Management

The atmospheric ducting phenomenon, caused by lower densities at higher altitudes in the Earth's atmosphere, causes a reduced refractive index, causing the signals to bend back towards the Earth. A signal trapped in the atmospheric duct can reach distances far greater than normal. In TDD networks with the same UL/DL slot configuration, and in the absence of atmospheric ducting, a guard period is used to avoid the interference between UL and DL transmissions in different cells. However, when the atmospheric ducting phenomenon happens, radio signals can travel a relatively long distance, and the propagation delay exceeds the guard period. Consequently, the DL signals of an aggressor cell can interfere with the UL signals of a victim cell that is far away from the aggressor. Such interference is termed as remote interference. The further the aggressor is to the victim, the more UL symbols of the victim will be impacted.

A remote interference scenario may involve a number of victim and aggressor cells, where the gNBs execute Remote Interference Management (RIM) coordination on behalf of their respective cells. Aggressor and victim gNBs can be grouped into semi-static sets, where each cell is assigned a set ID, and is configured with a RIM Reference Signal (RIM-RS) and the radio resources associated with the set ID. Each aggressor gNB can be configured with multiple set IDs and each victim gNB can be configured with multiple set IDs, whereas each cell can have at most one victim set ID and one aggressor set ID. Consequently, each gNB can be an aggressor and a victim at the same time.

To mitigate remote interference, the network enables RIM frameworks for coordination between victim and aggressor gNBs. The coordination communication in RIM frameworks can be wireless- or backhaul-based. The backhaul-based RIM framework uses a combination of wireless and backhaul communication, while in the wireless framework, the communication is purely wireless.

In both frameworks, all gNBs in a victim set simultaneously transmit an identical RIM reference signal carrying the victim set ID over the air.

In the wireless framework, upon reception of the RIM reference signal from the victim set, aggressor gNBs undertake RIM measures, and send back a RIM reference signal carrying the aggressor set ID. The RIM reference signal sent by

the aggressor is able to provide information whether the atmospheric ducting phenomenon exists. The victim gNBs realize the atmospheric ducting phenomenon have ceased upon not receiving any reference signal sent from aggressors.

In the RIM backhaul framework, upon reception of the RIM reference signal from the victim set, aggressor gNBs undertake RIM measures, and establish backhaul coordination towards the victim gNB set. The backhaul messages are sent from individual aggressor gNBs to individual victim gNB, where the signalling is transparent to the core network. The RIM backhaul messages from aggressor to victim gNBs carry the indication about the detection or disappearance of RIM reference signal. Based on the indication from the backhaul message, the victim gNBs realize whether the atmospheric ducting and the consequent remote interference have ceased.

In both frameworks, upon realizing that the atmospheric ducting has disappeared, the victim gNBs stop transmitting the RIM reference signal.

17.2 Cross-Link Interference Management

When different TDD DL/UL patterns are used between neighbouring cells, UL transmission in one cell may interfere with DL reception in another cell: this is referred to as UE-to-UE Cross Link Interference (CLI). In case of Sub-Band Full Duplex (SBFD) operation, UE-to-UE CLI can be present either within the same cell or across different cells: UL transmission may interfere with simultaneous DL reception within one cell or in another cell.

To mitigate UE-to-UE CLI, gNBs can exchange and coordinate their intended TDD DL-UL configurations over Xn and F1 interfaces; and the victim UEs can be configured to perform UE-to-UE CLI measurements. There are two types of UE-to-UE CLI measurements:

- SRS-RSRP measurement in which the UE measures SRS-RSRP over SRS resources of aggressor UE(s);
- CLI-RSSI measurement in which the UE measures the total received power observed over RSSI resources.

A gNB serving victim UEs may indicate to neighbour gNBs to report SRS resources. The neighbour gNB that receives the indication may signal the information concerning SRS resources potentially causing UE-to-UE CLI back to the neighbour gNB(s) that initiated the procedure.

Two types of UE-to-UE CLI reporting are supported: L1-based reporting and L3-based reporting. A UE is not expected to be configured with both L1 CLI measurement and reporting and L3 CLI measurement and reporting simultaneously.

For L3-based UE-to-UE CLI reporting, layer 3 filtering applies to CLI measurement results and both event triggered and periodic reporting are supported.

For L1-based UE-to-UE CLI reporting, the configuration is dependent on the reporting quantity:

- For SRS-RSRP, only aperiodic CSI reporting is supported;
- For CLI-RSSI, the CSI reporting can be periodic or aperiodic.

In addition to UE-to-UE CLI, gNB-to-gNB CLI may also be present when different TDD DL/UL patterns are used between neighbouring cells or when SBFD operation is configured: DL transmission in one cell may interfere with UL reception in another cell.

To mitigate gNB-to-gNB CLI, a victim gNB can report gNB-to-gNB CLI related information of its serving cells to neighbour gNBs. The neighbour gNB should evaluate the received information and it may take CLI mitigation actions when necessary. Additionally, a victim gNB can configure a UE with UL resource muting. When UL resource muting is applied in a symbol, either even or odd sub-carriers of the frequency resource of the PUSCH are available, and the other sub-carriers are not used for the PUSCH transmission.

18 Small Data Transmission

18.0 General

Small Data Transmission (SDT) is a procedure allowing data and/or signalling transmission while remaining in RRC_INACTIVE state (i.e. without transitioning to RRC_CONNECTED state). SDT is enabled on a radio bearer basis and can be initiated either by the UE in case of MO-SDT (Mobile Originated SDT) or by the network in case of MT-

SDT (Mobile Terminated SDT). MO-SDT is initiated by the UE only if less than or equal to a configured amount of UL data awaits transmission across all radio bearers for which SDT is enabled, the DL RSRP is above a configured threshold, and a valid SDT resource is available as specified in clause 5.27.1 of TS 38.321 [6]. MT-SDT is initiated by the network with an indication to the UE in a paging message when DL data awaits transmission for radio bearers configured for SDT; based on the indication, the UE initiates the MT-SDT only if the DL RSRP is above a configured threshold as specified in clause 5.27.1 of TS 38.321 [6]. When MT-SDT is initiated by the UE, a resume cause indicating MT-SDT is included in the *RRCResumeRequest/RRCResumeRequest1*. Maximum duration the SDT procedure can last is dictated by a SDT failure detection timer that is configured by the network (see clause 6.2.2 of TS 38.331 [12]). Network can enable MO-SDT, MT-SDT, or both in a cell.

SDT procedure is initiated with either a transmission over RACH (configured via system information) or over Type 1 CG resources (configured via dedicated signalling in *RRCRelease*). The SDT resources can be configured on initial BWP for both RACH and CG. RACH and CG resources for SDT can be configured on either or both of NUL and SUL carriers. The CG resources for SDT are valid only within the PCell of the UE when the *RRCRelease* with suspend indication is received. CG resources are associated with one or multiple SSB(s). For RACH, the network can configure 2-step and/or 4-step RA resources for MO-SDT. When both 2-step and 4-step RA resources for MO-SDT are configured, the UE selects the RA type according to clause 9.2.6. If MT-SDT procedure is initiated over RACH, only the RACH resources not configured for SDT can be used by the UE. CFRA is not supported for SDT over RACH.

Once initiated, the SDT procedure is either:

- successfully completed after the UE is directed to RRC_IDLE (via *RRCRelease*) or to continue in RRC_INACTIVE (via *RRCRelease or RRCReject*) or to RRC_CONNECTED (via *RRCResume or RRCSetup*); or

- unsuccessfully completed upon cell re-selection, expiry of the SDT failure detection timer, a MAC entity reaching a configured maximum PRACH preamble transmission threshold, an RLC entity reaching a configured maximum retransmission threshold, or integrity check failure while SDT procedure is ongoing, or expiry of SDT-specific timing alignment timer or *configuredGrantTimer* while SDT procedure is ongoing over CG and the UE has not received a response from the network after the initial PUSCH transmission.

Upon successful completion of the SDT procedure via an *RRCRelease* message including *resumeIndication*, the UE triggers the initiation of RRC Resume procedure.

Upon unsuccessful completion of the SDT procedure, the UE transitions to RRC_IDLE.

For SDT, network should not send *RRCReject* in response to *RRCResumeRequest/RRCResumeRequest1* if DL data over any radio bearer configured for SDT is transmitted.

The initial PUSCH transmission during the SDT procedure includes at least the CCCH message. When using CG resources for initial SDT transmission, the UE can perform autonomous retransmission of the initial transmission if the UE does not receive confirmation from the network (dynamic UL grant or DL assignment) before a configured timer expires as specified in clause 5.4.1 of TS 38.321 [6]. After the initial PUSCH transmission, subsequent transmissions are handled differently depending on the type of resource used to initiate the SDT procedure:

- When using CG resources, the network can schedule subsequent UL transmissions using dynamic grants or they can take place on the following CG resource occasions. The DL transmissions are scheduled using dynamic assignments. The UE can initiate subsequent UL transmission only after reception of confirmation (dynamic UL grant or DL assignment) for the initial PUSCH transmission from the network. For subsequent UL transmission, the UE cannot initiate re-transmission over a CG resource.

- When using RACH resources, the network can schedule subsequent UL and DL transmissions using dynamic UL grants and DL assignments, respectively, after the completion of the RA procedure.

When SDT procedure is initiated, AS security is applied for all the radio bearers enabled for SDT as specified in clause 5.3.13.3 of TS 38.331 [12].

While the SDT procedure is ongoing, if data appears in a buffer of any radio bearer not enabled for SDT, the UE initiates a transmission of a non-SDT data arrival indication using *UEAssistanceInformation* message to the network and, if available, includes the resume cause.

While the SDT procedure is ongoing and RA procedure is triggered (e.g., upon UL data arrival as specified in clause 9.2.6), only the RACH resources not configured for SDT can be used by the UE.

SDT procedure over CG resources can only be initiated with valid UL timing alignment. The UL timing alignment is maintained by the UE based on a SDT-specific timing alignment timer configured by the network via dedicated signalling and, for initial CG-SDT transmission, also by DL RSRP of configured number of highest ranked SSBs which are above a configured RSRP threshold. Upon expiry of the SDT-specific timing alignment timer, the CG resources are released while maintaining the CG resource configuration.

Logical channel restrictions configured by the network while in RRC_CONNECTED state and/or in *RRCRelease* message for radio bearers enabled for SDT, if any, are applied by the UE during SDT procedure.

The network may configure UE to apply ROHC continuity for SDT either when the UE initiates SDT in the PCell of the UE when the *RRCRelease* with suspend indication was received or when the UE initiates SDT in a cell of its RNA.

For SDT procedure over CG resources, the network may configure maximum time duration until the next valid CG occasion for initial CG-SDT transmission based on which the UE decides whether SDT procedure over CG resources can be initiated. The maximum time duration is configured per logical channel for MO-SDT and per UE for MT-SDT.

18.1 Support of SDT procedure over RACH

For SDT procedure over RACH, if the UE accesses a gNB other than the last serving gNB, the UL SDT data/signalling is buffered at the receiving gNB, and then the receiving gNB triggers the XnAP Retrieve UE Context procedure. The receiving gNB indicates SDT to the last serving gNB and the last serving gNB decides whether to relocate the UE context or not. Other SDT assistance information (e.g., single packet, multiple packets) may also be provided by the receiving gNB to help the decision of UE context relocation. If the UE is configured with the clock quality control information, the last serving gNB performs full UE context relocation to enable the receiving gNB to provide clock quality information.

If the last serving gNB decides not to relocate the full UE context, it transfers a partial UE context containing SDT RLC context information necessary for the receiving gNB to handle SDT via the Partial UE Context Transfer procedure.

Then, in case SDT is used for user data over DRBs, UL/DL tunnels are established for DRBs configured for SDT between the receiving gNB and the last serving gNB. The PDCP PDU of UL/DL data is transferred over the tunnels, until the last serving gNB terminates the SDT session and directs the UE to continue in RRC_INACTIVE by sending the *RRCRelease* message.

Or in case SDT is used for signalling, SRB PDCP PDUs are transferred between the receiving gNB and the last serving gNB via the XnAP RRC Transfer procedure, until the last serving gNB terminates the SDT session and directs the UE to continue in RRC_INACTIVE by sending the *RRCRelease* message.

During the SDT session, in case the receiving gNB detects that no more packets are to be transmitted, or radio link problem is detected, the receiving gNB may also request to terminate the SDT session to the last serving gNB via the UE Context Retrieve Confirmation procedure.

18.2 SDT with UE context relocation

The overall procedure for SDT procedure over RACH with UE context relocation is illustrated in the figure 18.2-1.

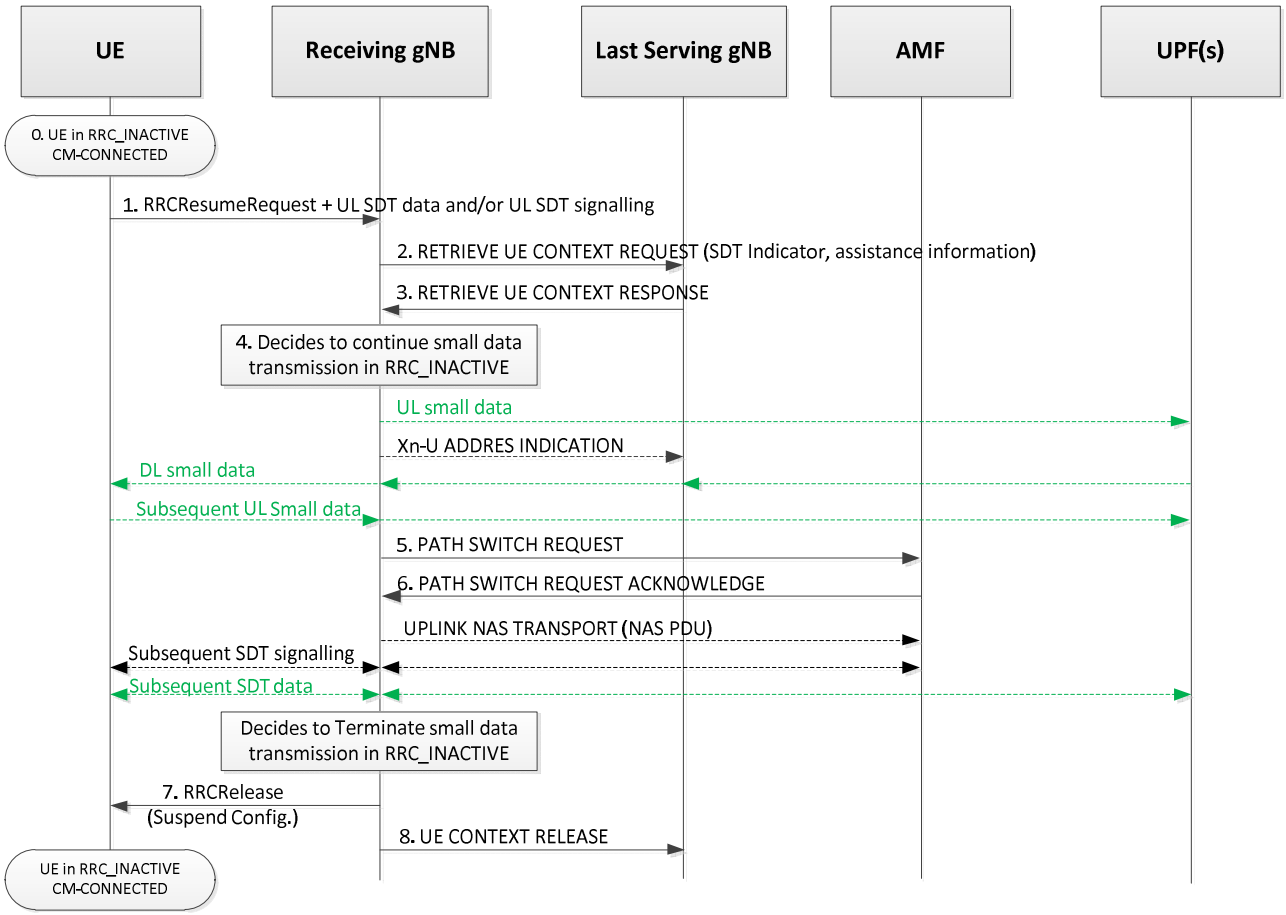


Figure 18.2-1. RA-based SDT with UE context relocation

1. The UE sends an *RRCResumeRequest* as well as UL SDT data and/or UL SDT signalling to the Receiving gNB.

2. The Receiving gNB identifies the Last Serving gNB using the I-RNTI and retrieves the UE context by means of Xn-AP Retrieve UE Context procedure. The Receiving gNB indicates that the UE request is for an SDT and may also provide SDT assistance information (e.g., single packet, multiple packets).

3. The Last Serving gNB decides to relocate UE context and responds with the RETRIEVE UE CONTEXT RESPONSE message. The UL SDT data, if any, is delivered from the Receiving gNB to the UPF. In case that the Last Serving gNB has requested the AMF for CN Buffering as part of step 0 for the UE in RRC INACTIVE state with eDRX cycle longer than 10.24 seconds, reachability of the UE can be indicated to the AMF by the last serving gNB using the MT Communication Handling procedure as described in TS 23.501 [3] and TS 38.413 [26], otherwise, the AMF considers that the UE is reachable (i.e., the MT Communicating Handing is deactivated) upon step 5.

4-6. The Receiving gNB decides to keep UE in RRC_INACTIVE state for SDT. If loss of DL user data buffered in the Last Serving gNB shall be prevented, the Receiving gNB provides forwarding addresses via the Xn-U ADDRESS INDICATION message. The Receiving gNB also initiates NGAP Path Switch Request procedure to establish a NG UE-associated signalling connection to the AMF. After the Path Switch Request procedure, the buffered UL NAS PDU, if any, is delivered from the Receiving gNB to the AMF. And then, the subsequent UL/DL SDT data and/or signalling are transferred between UE and core network via the Receiving gNB.

NOTE 1: If the UP policy received from the Last Serving gNB is different from that received in the PATH SWITCH REQUEST ACKNOWLEDGE message, the Receiving gNB may either send the UE back to RRC_IDLE or move the UE to RRC_CONNECTED to update the security configuration.

7. After the SDT transmission is terminated, the Receiving gNB generates and sends the *RRCRelease* message including the suspend indication to the UE to terminate the SDT procedure and continue in RRC_INACTIVE state.

NOTE 2: In case DL non-SDT data or DL non-SDT signalling arrives, or the UE assistance information (i.e. UL non-SDT data arrival indication) is received from the UE, the Receiving gNB may decide to directly send the UE to RRC_CONNECTED state by sending the *RRCResume* message.

NOTE 3: The Receiving gNB may decide to directly send the UE to RRC_CONNECTED state by sending the *RRCResume* message based on (e.g. large size of) DL SDT data or DL SDT signalling.

NOTE 4: The Receiving gNB may decide to directly send the UE to RRC_CONNECTED state by sending the *RRCResume* message based on the BSR received from the UE in case of uplink SDT data exceeding the data size threshold.

NOTE 5: The Receiving gNB may send the NGAP MT Communication Handling Request message to the AMF to trigger CN buffering when the UE is put again into RRC_INACTIVE state with eDRX cycle longer than 10.24 seconds.

8. The Receiving gNB indicates to the Last Serving gNB to remove the UE context by sending the XnAP UE CONTEXT RELEASE message. The XnAP UE CONTEXT RELEASE message can be sent after step 6.

18.3 SDT without UE context relocation

The overall procedure for SDT procedure over RACH without UE context relocation is illustrated in the figure 18.3-1.

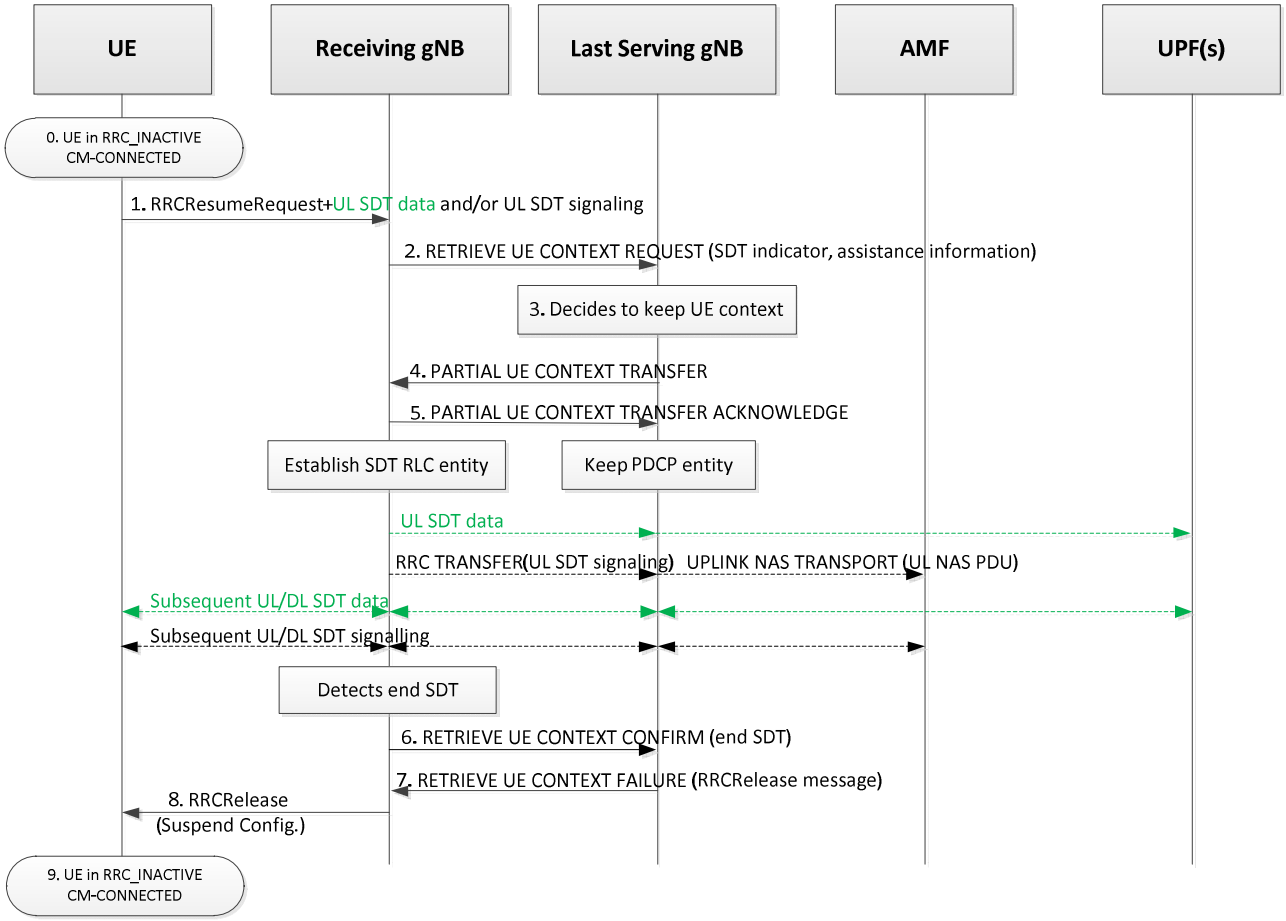


Figure 18.3-1. RA-based SDT without UE context relocation

1/2. The steps 1/2 are as defined in steps 1/2 in Figure 18.2-1.

3. The last serving gNB decides not to relocate the full UE context for SDT. In case that the Last Serving gNB has requested AMF for CN Buffering as part of step 0 for the UE in RRC INACTIVE state with eDRX cycle longer than 10.24 seconds, reachability of the UE is indicated to the AMF by the last serving gNB using the MT Communication Handling procedure as described in TS 23.501 [3] and TS 38.413 [26].

4. The last serving gNB transfers a partial UE context including the SDT related RLC context.

5. The receiving gNB acknowledges receiving the partial UE context and provides associated DL TNL address. The UE context is kept at the last serving gNB and the SDT related RLC context is established at the receiving gNB. Then UL/DL GTP-U tunnels are established for DRBs configured for SDT, if any, and the UL SDT data and/or signalling, if any, are forwarded to the last serving gNB, and then delivered to the core network.

NOTE 1: The DL signalling from the last serving gNB, if any, is forwarded to the receiving gNB via the RRC TRANSFER message, for which the receiving gNB delivers it to the UE.

NOTE 1a: In case DL non-SDT data or DL non-SDT signalling arrives, or UE assistance information (i.e. UL non-SDT data arrival indication) is received from the UE, the last serving gNB terminates the SDT procedure by sending the *RRCRelease* message.

NOTE 1b: The last serving gNB may terminate the SDT procedure by sending the *RRCRelease* message based on (e.g. large size of) DL SDT data or DL SDT signalling.

6. The receiving gNB detects the end of SDT session and sends the RETRIEVE UE CONTEXT CONFIRM message including whether this is a "normal" end of SDT transaction or a radio link problem, or large SDT volume from BSR.

7. Upon receiving the RETRIEVE UE CONTEXT CONFIRM message and deciding to terminate the SDT, the last serving gNB responds to the receiving gNB with the RETRIEVE UE CONTEXT FAILURE message including an encapsulated *RRCRelease* message. The receiving gNB shall release the established partial UE context.

NOTE 2: Void.

NOTE 3: Void.

8. The receiving gNB sends the *RRCRelease* message to the UE.

NOTE 4: Void.

NOTE 5: The last serving gNB may terminate the SDT procedure by sending the *RRCRelease* message upon receiving the indication about large uplink SDT data from the BSR from the receiving gNB in step 6.

NOTE 6: The Last Serving gNB may send the NGAP MT Communication Handling Request message to the AMF to trigger CN buffering when the UE is put again into RRC_INACTIVE state with eDRX cycle longer than 10.24 seconds.

9. The UE moves to RRC_INACTIVE state if the suspend indication is included in the *RRCRelease* message, or the UE may initiate RRC resume procedure to transition to RRC_CONNECTED state if the resume indication is included in the *RRCRelease* message. Or else, the UE moves to RRC_IDLE state.

18.4 MT-SDT with/without UE context relocation

The overall procedure for MT-SDT procedure with/without UE context relocation is illustrated in the figure 18.4-1.

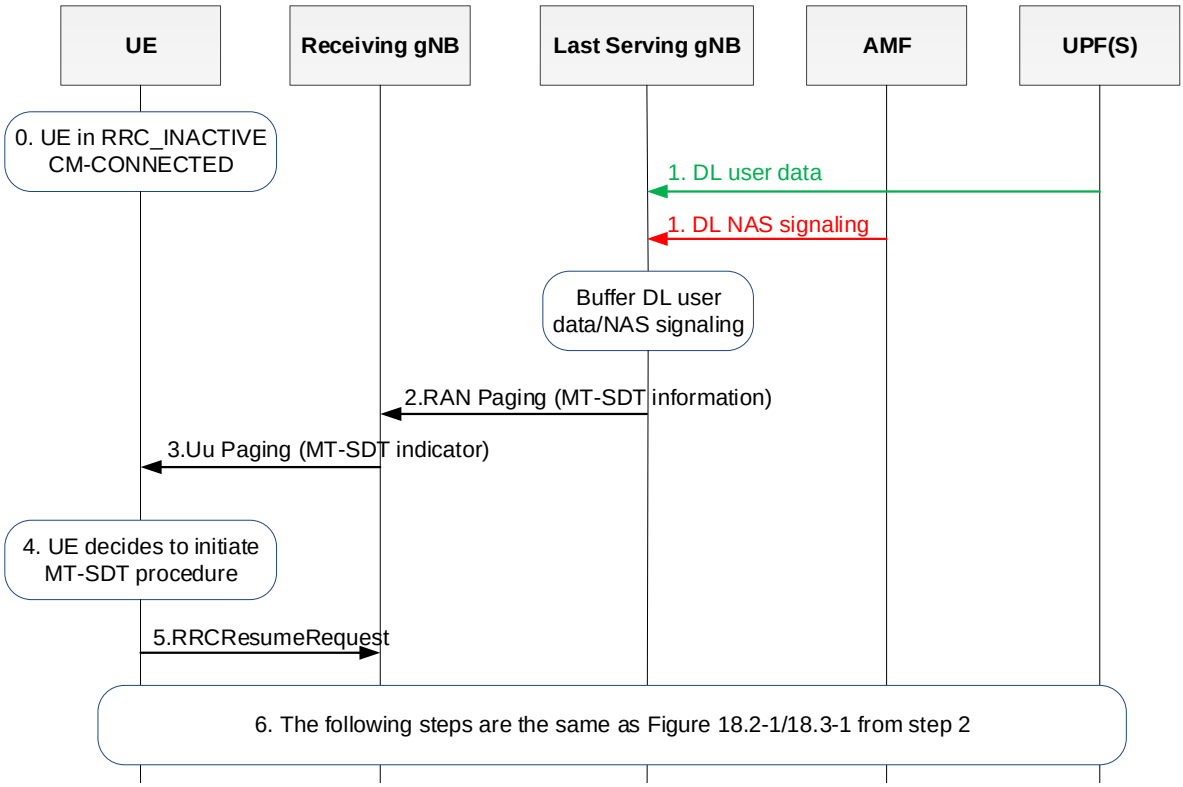


Figure 18.4-1: MT-SDT with/without UE context relocation

1. DL user data and/or DL NAS signalling are received at the Last Serving gNB for the UE in RRC_INACTIVE state, or RAN Paging request message is received at the Last Serving gNB for the UE in RRC_INACTIVE state with long eDRX(cycle) beyond 10.24 seconds.

2. The Last Serving gNB may send MT-SDT information to the neighbour gNBs within the RNA, via XnAP RAN PAGING message.

3. The gNB that receives MT-SDT information within the RNA, takes into account the MT-SDT information received in the XnAP RAN PAGING message to decide whether to trigger MT-SDT Paging. The gNB which ultimately reaches the UE via the Uu Paging becomes the Receiving gNB.

NOTE 1: In case that the Receiving gNB decides not to trigger MT-SDT paging, the above step 3 and subsequent steps are the same as Figure 9.2.2.4.2 from step 3.

4/5. The UE may decide to initiate MT-SDT procedure and in this case sends an RRCResumeRequest message with an MT-SDT resume cause to the Receiving gNB.

6. The following steps are the same as Figure 18.2-1/18.3-1 from step 2, except that the first SDT user data and/or NAS signalling is DL SDT data and/or DL SDT NAS signalling.

NOTE 2: In case DL non-SDT data or DL non-SDT signalling has arrived between step 2 and step 6, the Last Serving gNB should relocate the UE context to the Receiving gNB and forward the received data to the Receiving gNB.

19 Support for NR coverage enhancements

To improve NR uplink coverage for both FR1 and FR2, the following enhancements on PUSCH, PUCCH, PRACH and MSG3 PUSCH are supported:

- Enhanced aggregation of multiple slots with TB repetition is supported for both PUSCH transmission with dynamic and configured grant. In addition, counting based on available slots is supported. The maximum number of aggregated slots for counting based on available slots and counting based on physical slots are both 32.

- TB processing over multiple slots with and without repetition is supported for both PUSCH transmission with dynamic grant and configured grant. For a single transmission of TB processing over multiple slots PUSCH, the TB size is determined based on multiple slots.

- DMRS bundling where the UE maintains phase continuity and power consistency across PUSCH transmissions or PUCCH repetitions to enable improved channel estimation is supported. Inter-slot frequency hopping with DMRS bundling is supported.

- Dynamic PUCCH repetition factor indication configured per PUCCH resource is introduced, applicable to all PUCCH formats.

- Aggregation of multiple slots with TB repetition for MSG3 transmission is supported on both NUL and SUL, applicable to CBRA with 4-step RA type. If configured, the UE requests MSG3 repetition via separate RACH resources when the RSRP of DL path-loss reference is lower than a configured threshold. BWP configured with RACH resources solely for MSG3 repetition is also supported without the need to consider the RSRP of DL path-loss reference by the UE.

- MSG1 repetition with same beam is supported on both NUL and SUL for 4-step RA type. For CBRA, network broadcasts separate RSRP thresholds for different repetition numbers. UE performs MSG1 repetition via RACH resources that are different from RACH resources without MSG1 repetition. CFRA for MSG1 repetition for *ReconfigurationWithSync* is supported and the network signals the MSG1 repetition number explicitly. Fallback from lower number to higher number of MSG1 repetition is supported among the set(s) of RACH resources associated with same feature(s). Fallback from lower number to higher number of MSG1 repetition is not supported for MSG1-based SI request or if UE has performed fallback from CFRA to CBRA. Fallback from CFRA with MSG1 repetition to 4-step CBRA with MSG1 repetition using the same MSG1 repetition number as the one used for CFRA is supported.

- Dynamic switching between DFT-S-OFDM and CP-OFDM for PUSCH is supported. The indication for switching between DFT-S-OFDM and CP-OFDM for PUSCH is contained in DCI format 0_1/0_2, which is configured separately for each BWP. PHR can be reported for current transmission of PUSCH using one of the DFT-S-OFDM or CP-OFDM waveform and an assumed transmission of PUSCH using the other waveform than the current one.

- Frequency domain spectrum shaping without frequency extension is supported for MPR/PAR reduction on the PUSCH transmission, and the change value of UE power class is reported in the PHR.

To improve NR downlink coverage for FR1, the repetitions of PDCCH in common search space and of PDSCH carrying SIB1 within 20 ms are supported in TN as specified in TS 38.213 [38] and TS 38.214 [56].

20 Support for Multi-USIM devices

20.1 General

NG-RAN may support one or more of the following enhancements for MUSIM device operation:

- Paging Collision Avoidance, as described in clause 20.2;

- UE notification on Network Switching, as described in clause 20.3;

- Temporary UE capability restriction and removal of restriction, as described in clause 20.4.

20.2 Paging Collision Avoidance

The purpose of paging collision avoidance is to address the overlap of paging occasions on both USIMs when a MUSIM device (e.g. dual USIM device) is in RRC_IDLE/RRC_INACTIVE state in both the networks (e.g. Network A and Network B) associated with respective USIMs. Network A is NR and Network B is E-UTRA or NR.

A MUSIM device may determine potential paging collision on two networks and may trigger actions to prevent potential paging collision on NR network as specified in TS 23.501 [3].

NOTE: It is left to UE implementation as to how it selects one of the two RATs/networks for paging collision avoidance.

20.3 UE notification on Network Switching

For MUSIM operation, a MUSIM device in RRC_CONNECTED state in Network A may have to switch from Network A to Network B. Network A is NR and Network B can either be E-UTRA or NR. Before switching from Network A, a MUSIM device should notify Network A to either leave RRC_CONNECTED state, or be kept in RRC_CONNECTED state in Network A while temporarily switching to Network B.

When configured to do so, a MUSIM device can signal to the Network A a preference to leave RRC_CONNECTED state by using RRC (see TS 38.331 [12]) or NAS signalling (see TS 23.501 [3]). After sending a preference to leave RRC_CONNECTED state by using RRC signalling, if the MUSIM device does not receive an *RRCRelease* message from the Network A within a certain time period (configured by the Network A, see TS 38.331 [12]), the MUSIM device can enter RRC_IDLE state in Network A.

When configured to do so, a MUSIM device can signal to the Network A a preference to be temporarily switching to Network B while remaining in RRC_CONNECTED state in Network A. This is indicated by scheduling gaps preference. This preference can include information for setup or release of gap(s). The Network A can configure at most 4 gap patterns for MUSIM purpose: three periodic gaps and a single aperiodic gap. The Network A should always provide at least one of the requested gap pattern or no gaps. Network providing an alternative gap pattern instead of the one requested by the UE is not supported in this release.

When configured to do so, a MUSIM device can include priority of periodic gap(s) in addition to scheduling gaps preference, and the priority preference should be indicated for all periodic gap(s). If the MUSIM device indicates gap priority preference, it can also indicate its preference on using *keep solution* (defined in TS 38.133 [13]).

20.4 Temporary UE capability restriction and removal of restriction

For MUSIM operation, a MUSIM device in RRC_CONNECTED state in Network A may indicate its preference on temporary UE capability restriction or removal of restriction via UE assistance information with Network A when the MUSIM device needs transmission or reception in Network B (e.g., including start/stop connection to Network B). Network A is NR and Network B can either be E-UTRA or NR. The MUSIM device may request a temporary capability restriction only after the Network signals via RRC that this is allowed.

When configured to do so, a MUSIM device can indicate one or more of the following temporary capability restriction or removal of restriction to the Network A:

- A MUSIM device can explicitly request SCell(s) or SCG to be released;
- A MUSIM device can indicate its preference on temporary maximum MIMO layers and/or supported channel bandwidth for specific serving cells for both UL/DL;
- A MUSIM device can indicate its preference on the temporary maximum number of CCs per UL/DL;
- A MUSIM device can indicate its preference on the concerned band(s) or band combination(s) (e.g. avoided and/or affected band(s) or band combination(s)) based on a band-filter list configured by network. For affected band(s) and band combination(s), this preference can include temporary maximum MIMO layers and/or supported channel bandwidth for both UL/DL;
- A MUSIM device can indicate the measurement gap requirement changes.

When it is allowed by Network A in SIB1, a MUSIM device can indicate in *RRCSetupComplete/RRCResumeComplete/RRCReestablishmentComplete* message to the Network A that its capabilities are temporarily restricted due to ongoing transmission/reception in Network B. This indication allows Network A to know whether UE capabilities without restrictions can be used by Network A, or if Network A needs to configure the UE to indicate its temporary capability restrictions, as described above. When configured to do so, a MUSIM device can also indicate to the Network A there is no temporary capability restriction via UE assistance information.

When a MUSIM device is in RRC_CONNECTED state in both Network A and Network B, if Network B is NR, it is up to UE implementation to select which network to request temporary UE capability restriction; if Network B is E-UTRA, the request for temporary UE capability restriction can only be performed on Network A.

21 Application Layer Measurement Collection

21.1 Overview

The QoE Measurement Collection function enables collection of application layer measurements from the UE. QoE measurement collection is supported for the following service types in NR cells:

- QoE Measurement Collection for DASH streaming services;
- QoE Measurement Collection for MTSI services;
- QoE Measurement Collection for VR services.

The QoE Measurement Collection function also supports collection of QoE measurements for any of the supported service types carried by the MBS communication service. The QoE Measurement Collection is supported for the following two communication service types:

- MBS broadcast;
- MBS multicast.

For DASH streaming, MTSI and VR, QMC is supported in RRC_CONNECTED state only, unless the application data is delivered via the MBS broadcast communication service.

For application sessions delivered via MBS broadcast, QMC is supported in RRC_CONNECTED, RRC_INACTIVE, and RRC_IDLE states. QMC for the application sessions delivered via MBS multicast is supported in RRC_CONNECTED state only. Both signalling based and management based QoE measurement collection are supported in NR SA and NR-DC. Further details of NR-DC operation can be found in TS 37.340 [21].

NOTE: The naming "QoE Measurement" is used in NG, Xn, and interfaces between the OAM and the gNB. In the Uu interface, the naming "application layer measurement" is used and it is equivalent to "QoE Measurement".

21.2 QoE Measurement Configuration

21.2.1 QoE Measurement Collection Activation and Reporting

The feature is activated in the gNB either by direct configuration from the OAM system (management-based activation), or by signalling from the OAM via the 5GC (signalling-based activation), containing UE-associated QoE configuration. One or more QoE measurement collection configurations can be activated at a UE per service type, and each QoE measurement configuration is uniquely identified by a QoE reference.

For signalling-based QoE measurements, the OAM initiates the QMC activation for a specific UE via the 5GC, and the gNB receives one or more QoE measurement configurations by means of UE-associated signalling. The QoE measurement configuration for signalling-based QMC activation includes an application layer measurement configuration list and the corresponding information for QoE measurement collection, e.g., QoE reference, service type, MCE IP address, slice scope, area scope, MDT alignment information, the indication of available RAN visible QoE metrics and assistance information.

For management-based QMC activation, the OAM sends one or more QoE measurement configurations directly to the gNB. The QoE measurement configuration for management-based QMC activation also includes an application layer measurement configuration list and the corresponding information for QoE measurement collection. The gNB selects UE(s) that have the required QoE measurement capability, and that meet the measurement collection criteria related to area scope and slice scope.

An application layer measurement configuration received by the gNB from the OAM or from the 5GC is encapsulated in a transparent container, which is forwarded to a UE as *measConfigAppLayerContainer* in the *RRCReconfiguration* message (there can be multiple configurations in the same message). Application layer measurement reports received from UE's application layer are encapsulated in a transparent container and sent to the network in the *MeasurementReportAppLayer* message, as specified in TS 38.331 [12]. The UE can send multiple application layer measurement reports to the gNB in one *MeasurementReportAppLayer* message. In order to allow the transmission of application layer measurement reports which exceed the maximum PDCP SDU size, segmentation of the *MeasurementReportAppLayer* message may be enabled by the gNB. A measurement configuration application layer ID conveyed in the RRC signalling is used to identify the application layer measurement configuration and report between the gNB and the UE. The measurement configuration application layer ID is mapped to the QoE reference in the gNB, and the gNB forwards the application layer measurement report to MCE together with the QoE reference. The gNB can release one or multiple application layer measurement configurations from the UE in one *RRCReconfiguration* message at any time. The UE may additionally be configured by the gNB to indicate to the gNB when a QoE measurement session starts or stops for a certain application layer measurement configuration.

For a QoE measurement configuration, assistance information provided by OAM can be considered by the gNB for configuring a UE with a priority value. The priority value can be used by the UE to discard QoE measurement reports, as specified in TS 38.331 [12].

21.2.2 QoE Measurement Collection Deactivation

The QoE Measurement Collection deactivation permanently stops all or some of the QoE measurement collection configurations at a UE, resulting in the release of the corresponding QoE measurement configuration(s) in the UE. QoE Measurement Collection deactivation is initiated by the OAM towards the gNB (via the core network in case of a signalling-based QoE measurement configuration). For a signalling-based QoE measurement configuration, the deactivation of QoE measurement collection is supported by using UE-associated NGAP signalling. A list of QoE references is used to deactivate the corresponding QoE measurement collection(s).

Upon reception of the QoE release message for an application layer measurement configuration, the UE deletes the application layer measurement configuration at the application layer and the associated parameters in the UE Access Stratum and discards any unsent application layer measurement reports corresponding to the released application layer configuration. The UE discards the reports received from the application layer when it has no associated application layer measurement configuration configured.

The network can replace a QoE measurement configuration with another one by releasing an existing QoE measurement configuration and configuring another QoE measurement configuration. The network is not expected to release a signalling-based QoE measurement configuration for the sake of configuring a new management-based QoE measurement configuration.

21.2.3 Handling of QMC during RAN Overload

The QoE measurement reporting pause/resume procedure is used to pause/resume reporting of one or multiple QoE measurement configurations in a UE in RAN overload situation.

The gNB can use the *RRCReconfiguration* message to temporarily stop the UE from sending application layer measurement reports associated with one or multiple application layer measurement configurations. When the UE receives the QoE measurement reporting pause indication, the UE temporarily stores application layer measurement reports in the AS layer. When the UE receives the QoE measurement reporting resume indication, the UE sends the stored application layer measurement reports to the gNB.

For a QoE measurement configuration, the assistance information provided by the OAM may be considered by the gNB for deciding whether to pause/resume the QoE measurement reporting for certain QoE measurement configurations in case of RAN overload.

21.2.4 QoE Measurement Handling in RRC_IDLE and RRC_INACTIVE States

If the UE enters RRC_INACTIVE, the UE AS configuration for the QoE is stored in the UE Inactive AS context.

If the UE enters RRC_IDLE state, the UE releases all application layer measurement configurations except the application layer configurations explicitly indicated by the gNB as applicable in RRC_IDLE and RRC_INACTIVE states.

For QoE measurement sessions pertaining to data flows received via MBS broadcast, QoE measurement collection may continue during the RRC_INACTIVE and RRC_IDLE.

Upon UE's transition from RRC_IDLE to RRC_CONNECTED, the gNB serving the UE should ensure that it does not release an already configured signalling-based QoE measurement configuration for the sake of configuring a new management-based QoE measurement configuration.

QoE measurements for ongoing sessions should be continued when switching between 5GC Shared MBS traffic delivery and 5GC Individual MBS traffic delivery modes for MBS multicast.

When the UE resumes the connection with a gNB that does not support QMC, the UE releases all configured application layer measurement configurations.

For application measurement configurations applicable in RRC_IDLE and RRC_INACTIVE states, the UE continues on-going QoE measurement collection when entering RRC_IDLE or RRC_INACTIVE state, and also when returning to RRC_CONNECTED state. The UE may also start QoE collection according to the stored QoE configuration while in RRC_IDLE or RRC_INACTIVE state. The UE keeps the application layer measurement configurations but does not start new QoE measurement sessions when it is outside of the area scope for QoE configurations in RRC_IDLE and/or RRC_INACTIVE state. The UE stores the application layer measurement reports generated while in RRC_IDLE and/or RRC_INACTIVE state in the AS layer. The gNB can retrieve the application layer measurement reports/configurations and session status indication by configuring SRB4 or SRB5 after it receives an indication of application layer measurement report/configuration availability. The UE can send to the gNB the application layer measurement reports buffered when in RRC_IDLE and/or RRC_INACTIVE state, only when the UE has moved to RRC_CONNECTED state due to other reasons. The UE should not transit from RRC_IDLE or RRC_INACTIVE state to RRC_CONNECTED state for the sole purpose of sending stored application layer measurement reports.

For the application measurement configurations applicable in RRC_IDLE state (i.e. for MBS broadcast service), the gNB that configures the QoE measurement collection also indicates to the UE the QoE reference, MCE ID, service type, area scope, QMC assistance information (i.e., *appLayerMeasPriority* in TS 38.331 [12]), QoE measurement type (signalling-based or management-based measurement), and available RVQoE metrics, per QoE reference. The UE stores the received information including the QoE reference, measurement configuration application layer ID, MCE ID, service type, area scope, QMC assistance information (i.e., *appLayerMeasPriority* in TS 38.331 [12]), QoE measurement type, and available RVQoE metrics, per QoE reference when entering RRC_IDLE. Upon UE's transition from RRC_IDLE to RRC_CONNECTED, the UE indicates the stored information to the new serving gNB, and the new serving gNB can use the information when managing the QoE configurations including configuring, releasing, updating the QoE configuration, and receiving and forwarding the QoE reports buffered in RRC_IDLE.

21.2.5 Per-slice QoE Measurement

When a service is provided within a configured slice, the QoE Measurement for this service type can also be configured together with the corresponding slice scope, so that the user experience of this service can also be evaluated on a per-slice basis. Multiple QoE measurement configurations can be configured for the same service type, and each configuration can pertain to different slices, where each QoE measurement configuration is identified with a QoE reference.

The UE includes the network slice identifier inside the QoE measurement report container when sending the QoE measurement reports.

21.3 QoE Measurement Continuity for Mobility

QoE measurement collection continuity for intra-system intra-RAT/inter-RAT handover is supported, with the Area Scope parameters configured by the OAM, where the network is responsible for keeping track of whether the UE is inside or outside the area scope. A UE continues an ongoing QoE measurement even if it leaves the area scope, unless the network indicates to the UE to release the application layer measurement configuration.

For handover, the source gNB may transmit the information related to one or more application layer measurement configurations of the UE to the target gNB via XnAP or NGAP. For signalling-based QoE, the service type indication, the QoE reference, and, optionally, the container for application layer measurement configuration, MCE IP address,

measurement configuration application layer ID, MDT alignment information, area scope, slice support list for QMC, available RAN visible QoE metrics, QoE measurement session status, MBS communication service type, and assistance information for QoE measurement are passed to the target gNB. For management-based QoE, the QoE reference, service type indication, and, optionally, the measurement configuration application layer ID, the MCE IP address, area scope, slice support list for QMC, MBS communication service type, assistance information for QoE measurement and QoE measurement session status are passed to the target gNB. For RRC_INACTIVE state mobility, QoE measurement configuration(s) of a specific UE can be retrieved from the gNB hosting the UE context when the UE resumes to the RRC_CONNECTED state.

For signalling-based QoE, at handover to a target gNB that supports QoE measurement collection, the target gNB decides which of the application layer measurement configurations should be kept and which should be released, e.g., based on application layer measurement configuration information received from the source gNB in Xn/NG signalling.

When the UE is handed over to a target gNB that does not support QMC, the UE releases all configured application layer measurement configurations.

The continuity of QoE measurement configuration and reporting in NR-DC scenario is supported as specified in TS 37.340 [21].

QoE measurement collection continuity for intra-system inter-RAT handover is supported.

For intra-5GC handover from a source gNB to a target ng-eNB, measurements continuity for only one QoE measurement configuration can be supported when the UE connects to the target ng-eNB. The source gNB decides which QoE measurement to keep and sends the information about this QoE measurement to the target ng-eNB. The UE releases all NR QoE configuration(s) and it applies the LTE QoE configuration, if received from the target ng-eNB.

For intra-5GC handover from a source ng-eNB to a target gNB, the UE releases the LTE QoE configuration and it applies the NR QoE configuration(s), if received from the target gNB.

21.4 RAN Visible QoE Measurements

RAN visible QoE measurements are configured at the UE by the gNB, where a subset of configured QoE metrics is reported from the UE to the gNB as an explicit IE readable by the gNB. The RAN visible QoE measurements can be used by the gNB for network optimization. The RAN visible QoE measurements are supported for the DASH streaming and VR services. The gNB configures the RAN visible QoE measurement of all or some of the available RAN visible QoE metrics, where the indication of metric availability is received by the gNB as part of the management-based or the signalling-based QoE configuration. The set of available RAN visible QoE metrics is a subset of the metrics configured as part of QoE measurement configuration encapsulated in the application layer measurement configuration container. RAN visible QoE measurements and encapsulated QoE measurements can be configured together or separately. RAN visible QoE measurements can only be configured if there is a corresponding QoE measurement configuration for the same service type configured at the UE. The gNB may modify a RAN visible QoE configuration by releasing it and configuring the UE with a new RAN visible QoE configuration pertaining to the same QoE reference. In this case, the new RAN visible QoE configuration applies immediately, i.e., even during the same application session.

Multiple simultaneous RAN visible QoE measurement configurations and reports can be supported for RAN visible QoE measurements, and each RAN visible QoE measurement configuration and report is identified by the same measurement configuration application layer ID as the corresponding QoE measurement configuration and measurement report. After receiving the RAN visible QoE measurement configuration, the UE AS layer forwards the configuration to the application layer, indicating the service type, the measurement configuration application layer ID and, optionally, the reporting periodicity for RAN visible QoE. The application layer sends the RAN visible QoE measurement report associated with the measurement configuration application layer ID to the UE's AS layer. The PDU session ID(s) and QoS Flow ID(s) per PDU session ID corresponding to the service that is subject to QoE measurements can also be reported by the UE along with the RAN visible QoE measurement results.

The RAN visible QoE measurements can be reported with a reporting periodicity different from the one of the corresponding encapsulated QoE measurements, when a dedicated RAN visible QoE reporting periodicity is configured by the gNB. The UE application layer can measure the RAN visible QoE metrics based on this reporting periodicity. If there is no reporting periodicity defined in the RAN visible QoE configuration, the UE sends both RAN visible QoE measurement reports and the QoE measurement reports to the gNB in the same *MeasurementReportAppLayer* message, except when QoE measurement reporting pause indication is received (e.g., in case of RAN overload). When a QoE measurement reporting is paused, if there is no reporting periodicity defined in the RAN visible QoE configuration, the

encapsulated QoE reports are stored at the UE's AS layer, but the RAN visible QoE reports continue to be reported to the gNB with the reporting periodicity configured for encapsulated QoE reporting.

The gNB can release one or multiple RAN visible QoE measurement configurations from the UE in one *RRCReconfiguration* message at any time. If the encapsulated QoE configuration is released, the corresponding RAN visible QoE configuration is released as well.

The RAN visible QoE configuration can be transferred from the source gNB to the target gNB upon mobility and from the old gNB to the new gNB during context retrieval. The target gNB or the new gNB can generate a new RAN visible QoE configuration based on the available RAN visible QoE metrics received and it can send the new RAN visible QoE configuration to the UE during handover or the RRC resume procedure.

21.5 Alignment of MDT and QoE Measurements

The radio-related measurements may be collected via immediate MDT for all types of supported services for the purpose of QoE analysis. The MCE/TCE performs the correlation of the immediate MDT measurement results and the QoE measurement results collected at the same UE.

The following is supported:

- Alignment between a signalling-based QoE measurement and a signalling-based MDT measurement. In this case, the signalling-based QoE configuration sent to the gNB includes the NG-RAN Trace ID of the signalling-based MDT measurement.
- Alignment between a management-based QoE measurement and a management-based MDT measurement.

The UE configured with QoE measurements sends an indication to inform the gNB about the start or the stop of a QoE measurement session of configured QoE measurements. The gNB can activate the MDT measurements that are to be aligned with the QoE measurements performed by the UE upon/after receiving the QoE measurement session start indication from the UE. The gNB may activate the MDT measurements upon/after receiving the MDT activation message from the OAM. The gNB can deactivate the aligned MDT measurements according to an OAM command which may, e.g., be triggered by the session stop indication.

The gNB includes time stamp information to the QoE measurement reports to enable the correlation of corresponding measurement results of MDT and QoE at the MCE/TCE. In addition, the gNB includes the MDT session identifiers (Trace Reference and Trace Recording Session Reference) in the corresponding QoE measurement report.

21.6 QoE Measurement Collection in High Mobility Scenarios

QoE measurements can be confined to high mobility state of the UE and/or to HSDN cells.

21.7 Void

22 Support of AI/ML for NR Air Interface

22.1 Overview

The objective of AI/ML for NR air interface is to improve network performance and user experience, through AI/ML-enabled enhancements to the following features: beam management, CSI prediction and positioning.

22.2 AI/ML-based Beam Management

22.2.1 Introduction

AI/ML-based beam management utilizes intra-cell downlink beam prediction of the serving cell to reduce measurement/RS overhead and to improve the accuracy of beam selection. Two types of beam prediction are supported:

- Spatial-domain downlink transmission beam prediction for one set of beams based on measurement results of another set of beams where the set of beams for prediction can be SSB or CSI-RS beams and another set of beams for measurement can be SSB or CSI-RS beams; and
- Temporal-domain downlink transmission beam prediction for one set of beams based on historic measurement results of another set of beams (these two sets may be different).

For AI/ML-based beam management, both Network-side model and UE-side model are supported.

22.2.2 Void

22.2.3 Applicability Reporting

For UE-side model, the gNB provides inference configuration or inference related parameters based on UE supported functionalities. The UE reports its applicable functionalities, inapplicable functionalities with its preference to release the configuration and subsequent changes of applicability status of functionalities to gNB. The basic procedure of applicability reporting is described in Figure 22.2.3-1.

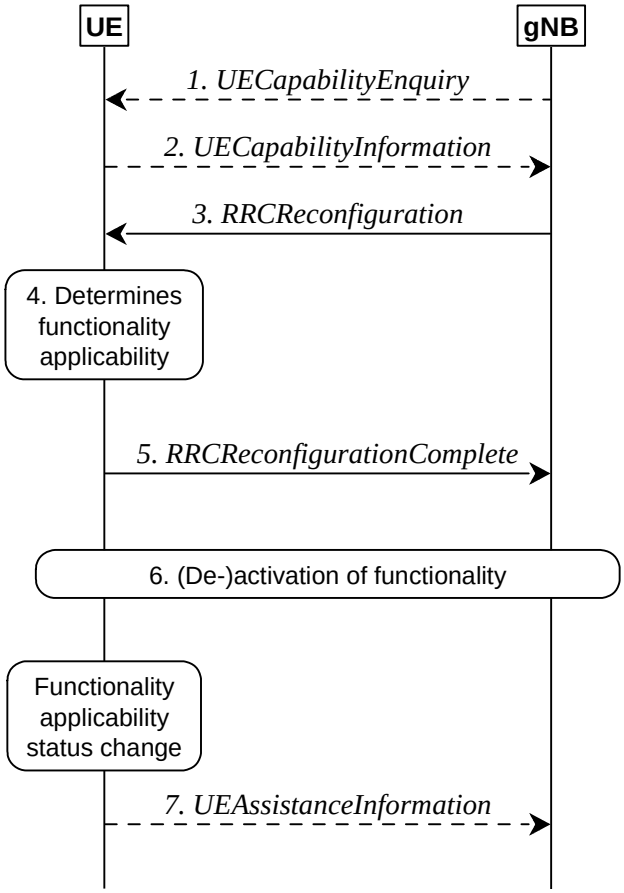


Figure 22.2.3-1: Initial applicability and applicability status change reporting

1. The gNB may inquire about the UE capability information.

2. If the gNB inquires the UE capability information then the UE indicates its supported AI/ML functionalities to the gNB via *UECapabilityInformation* message.

3. The gNB may provide inference configuration with Network-side additional conditions (i.e., associated ID) to UE via CSI report configuration or inference related parameters configuration.

4. The UE determines the applicable AI/ML functionalities based on Network-side additional conditions (if provided), UE-side additional conditions (internally known by UE) and model availability in the UE.

NOTE 1: If the gNB does not provide the associated ID, it is up to UE implementation how to determine the applicability.

5. The UE reports its functionality applicability in *RRCReconfigurationComplete* message.

6. When the inference configuration consists of periodic CSI report configuration, upon reporting the applicable functionalities, the UE autonomously activates the applicable AI/ML functionalities. When the inference configuration consists of semi-persistent CSI reporting and/or aperiodic CSI report configuration, upon reporting the applicable AI/ML functionalities, semi-persistent CSI reporting can be activated by MAC CE/DCI and aperiodic CSI reporting can be activated by DCI.

7. When applicability of the functionality changes, the UE can report updated functionality applicability status in *UEAssistanceInformation* message. When an activated AI/ML functionality becomes inapplicable, the UE does not autonomously deactivate it, but the UE indicates to the gNB the change in the applicability. Upon reception of UE indication of the functionality becoming inapplicable, the gNB should deactivate or release this activated functionality.

NOTE 2: Upon receiving one or more inference configuration(s), UE maintains all the inference configuration(s) no matter the inference configuration is applicable or inapplicable until the gNB releases it.

During handover, the UE may receive the inference configuration related to the target gNB via handover command. Then the UE reports its applicable/inapplicable AI/ML functionalities to the target gNB after the handover completion.

NOTE 3: UAI can be sent from the source gNB to the target gNB to exchange applicability reporting referring to the configurations from the source gNB. The source gNB can send to the target gNB applicability information referring to the configurations from the source gNB, via handover preparation information message.

UE can also report functionality applicability during RRC connection resume procedure.

22.2.4 Inference, Monitoring and Management

For Network-side model, the CSI measurement and reporting is used to acquire input data for inference.

NOTE: For Network-side model, network side additional conditions are considered known via network implementation.

For Network-side model, the gNB is responsible for performance monitoring (i.e., calculates performance metrics). There are no additional impacts on the UE for monitoring and management, except for being configured to provide the required measurement/data. Additionally, the UE is not informed about any gNB-side management decision.

For UE-side model, the gNB initiates performance monitoring, and makes management decisions based on the performance monitoring results. The UE can be configured to send either the measurement reports or the calculated performance metrics.

22.3 AI/ML-based CSI prediction

AI/ML-based CSI prediction is supported with similar principles and procedures as described in 22.2 for AI/ML-based beam management with the following differences:

- Only temporal-domain CSI prediction with UE-side model is supported.

- During the applicability reporting procedure, there is no inference related parameters configuration provided from gNB to UE for CSI prediction.

22.4 AI/ML-based Positioning

AI/ML-based Positioning is described in TS 38.305 [42].

For the deployment of AI/ML assisted positioning with gNB-side AI/ML model, AI/ML Model Training and AI/ML Model Inference are both located in the gNB. The gNB also does performance monitoring of its own AI/ML Model. The other principles for support of AI/ML for NG-RAN described in clause 16.20.2 apply for AI/ML assisted positioning with gNB-side AI/ML model.

22.5 Data Collection for Offline Model Training

22.5.1 Network-side data collection

Network-side data collection applies only to AI/ML beam management feature.

Network-side data collection for Network-side model training can be initiated by OAM or by gNB. In case of NR-DC, the data collection can only be configured for MCG. The following enablers are introduced for Network-side data collection for Network-side model over air interface:

- The UE can be configured by gNB to log L1 measurements in the AS layer memory and report them via a RRC message(s).
- Both periodic and L3 measurement event-triggered data collection are supported. The UE stores the logged data at the AS layer memory. When the AS layer memory for storing logged data becomes full, the UE stops measurement and logging for data collection. When the AS layer memory reserved for storing logged data becomes full or reaches an absolute threshold (if configured), the UE indicates data availability to the gNB, as specified in TS 38.331[12].
- When low power state is detected, the UE can indicate the low power state to the gNB. Upon reception of the low power state indication, the gNB should release the UE data collection configuration for Network-side model.

NOTE: It is up to UE implementation how to determine the AS layer memory threshold is reached and how to determine low power state.

- The gNB can indicate UE whether the logged data should be kept or not during handover. When indicated to keep the logged data, UE retains it during handover and indicates its availability after handover.

22.5.2 UE-side data collection

UE-side data collection applies to AI/ML Beam management and CSI prediction features.

For UE-side data collection for UE-side model training, the gNB can configure whether UE is allowed to initiate a request for data collection configuration (e.g., UE's preference to start or to stop data collection, preferred configuration from a list of candidate configurations provided by network). The gNB can also provide UE with data collection configuration or release the data collection configuration at any point in time, with or without UE request.

23 SBFD

23.1 General

Sub-Band Full Duplex (SBFD) operation is supported for a TDD carrier, enabling simultaneous downlink transmission and uplink reception at the gNB on their non-overlapping respective sub-bands. From UE perspective, full duplex is not supported. The configurations of cell-specific SBFD time and frequency resources are provided through SIB1 or dedicated signalling.

A UE can be semi-statically configured with SBFD sub-bands in downlink symbols and flexible symbols provided by *tdd-UL-DL-ConfigurationCommon* and this UE is referred to as an SBFD aware UE. The maximum number of UL sub-bands for SBFD operation in an SBFD symbol within a TDD carrier is one. The maximum number of DL sub-bands for

SBFD operation in an SBFD symbol within a TDD carrier is two. A UE can be configured with SBFD sub-bands in at most one TDD carrier in multi-carrier scenario.

In an SBFD symbol, except for cross-link interference measurements, a UE transmits or receives only in RBs that are both in the active UL BWP and in the UL sub-band, or both in the active DL BWP and the DL sub-band(s), respectively.

A UE can be configured to transmit or receive only in non-SBFD symbols, only in SBFD symbols, or across both SBFD symbols and non-SBFD symbols for multiple transmission or reception occasions.

23.2 SBFD Random Access

Random access procedure in SBFD symbols is supported for all existing RACH trigger events as described in clause 9.2.6, except for the event of Request for Other SI and Early UL synchronization with an LTM candidate cell. Random access procedure in SBFD symbols is not supported in RACH associated with additional PCIs for one serving cell. For the event of RACH-based LTM cell switch, random access procedure in SBFD symbols is only supported for intra-DU case.

Both CBRA and CFRA can be supported on SBFD sub-bands. Only the 4-step RA type using SBFD RACH resources can be supported.

Two RACH configuration options are specified for SBFD RA operation in TS 38.331 [12]. A cell can configure only one SBFD RACH configuration option. This can be either: 1) A single RACH configuration that supports both non-SBFD RA operation and SBFD RA operation, or 2) A dual RACH configuration where a RACH configuration is used for non-SBFD RA operation and an additional RACH configuration is designated for SBFD RA operation, as specified in TS 38.331 [12]. An SBFD aware UE that supports the SBFD RACH configuration option configured in the cell applies the corresponding RACH configuration. Otherwise, the SBFD aware UE applies the non-SBFD RA operation.

For CFRA, an SBFD aware UE can be explicitly indicated in the PDCCH order, the (Enhanced) LTM Cell Switch Command MAC CE or dedicated RRC signalling whether to use either the first PRACH occasions or the second PRACH occasions as specified in TS 38.213 [38], for the PRACH transmission. For CBRA, the network can configure a cell specific indication in SI whether to use either the first PRACH occasions or the second PRACH occasions. If there is no cell specific indication, an SBFD aware UE selects the PRACH occasions based on an SSB RSRP threshold provided in SI. If none of cell specification indication nor SSB RSRP threshold is provided, the SBFD aware UE selects the PRACH occasions based on its implementation.

For CBRA, an SBFD aware UE is permitted to switch from the first PRACH occasions to the second PRACH occasions and vice versa during a random access procedure. However, no further switch of PRACH occasions type (the first or second PRACH occasions) is allowed in the same random access procedure.

If a fall-back from CFRA to CBRA occurs, an SBFD aware UE uses the CBRA resource associated with the same PRACH occasions type.

Annex A (informative): QoS Handling in RAN

A.1 PDU Session Establishment

The following figure shows an example message flow for a PDU session establishment. NAS procedures details between gNB and 5GC can be found in TS 23.501 [3], TS 23.502 [22] and TS 38.413 [26].

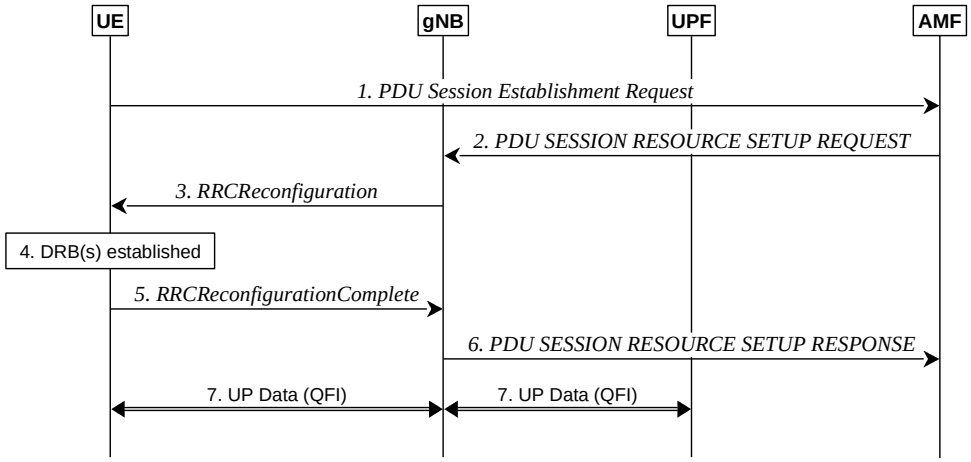


Figure A.1-1: PDU session establishment

1. UE requests a PDU session establishment to AMF.
2. AMF sends a PDU SESSION RESOURCE SETUP REQUEST message to gNB, which includes the NAS message to be sent to the UE with NAS QoS related information.
3. gNB sends an *RRCReconfiguration* message to UE including the configuration of at least one DRB and the NAS message received at Step 2.
4. UE establishes the DRB(s) for the new PDU session and creates the QFI to DRB mapping rules.
5. UE sends an *RRCReconfiguration Complete* message to gNB.
6. gNB sends a PDU SESSION RESOURCE SETUP RESPONSE message to AMF.
7. User Plane Data can then be exchanged between UE and gNB over DRB(s) according to the mapping rules and between UPF and gNB over the tunnel for the PDU session. QFI marking over Uu is optional (see clause 12) while QFI marking over NG-U is always present.

A.2 New QoS Flow with RQoS

The following figure shows an example message flow when RQoS is used for a new QoS flow. In this example, the gNB receives from UPF a first downlink packet associated with a QFI for which the QoS parameters are known from the PDU session establishment, but for which there is no association to any DRB yet in AS.

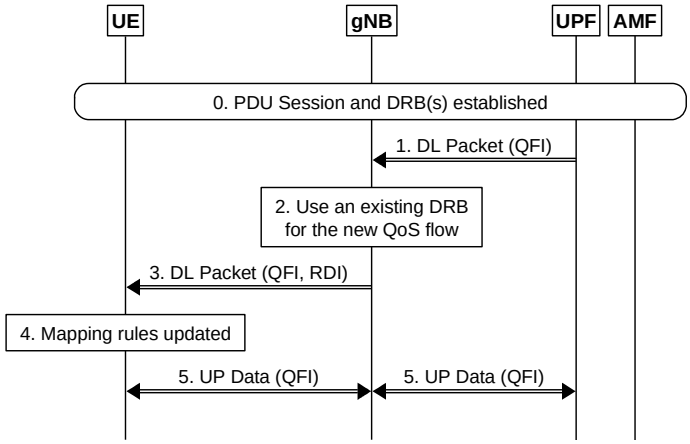


Figure A.2-1: DL data with new QFI sent over existing DRB

0. PDU session and DRB(s) have been already established.
1. gNB receives a downlink packet with a new QFI from UPF.
2. gNB decides to send the new QoS flow over an existing DRB.

NOTE: If gNB decides to send it over a new DRB, it needs to establish the DRB first.

3. gNB sends the DL packet over the selected DRB with the new QFI and RDI set in the SDAP header.
4. UE identifies the QFI and RDI in the received DL packet and the DRB on which the packet was received. The AS mapping rules are then updated accordingly.
5. User Plane Data for the new QoS flow can then be exchanged between UE and gNB over the DRB according to the updated mapping rules and between UPF and gNB over the tunnel for the PDU session.

A.3 New QoS Flow with Explicit RRC Signalling

The following figure shows an example message flow when explicit RRC signalling is used for a new QoS flow. In this example, the gNB receives from UPF a first downlink packet associated with a QFI, for which the QoS parameters are already known from the PDU session establishment, but for which there is no association to any DRB yet in AS.

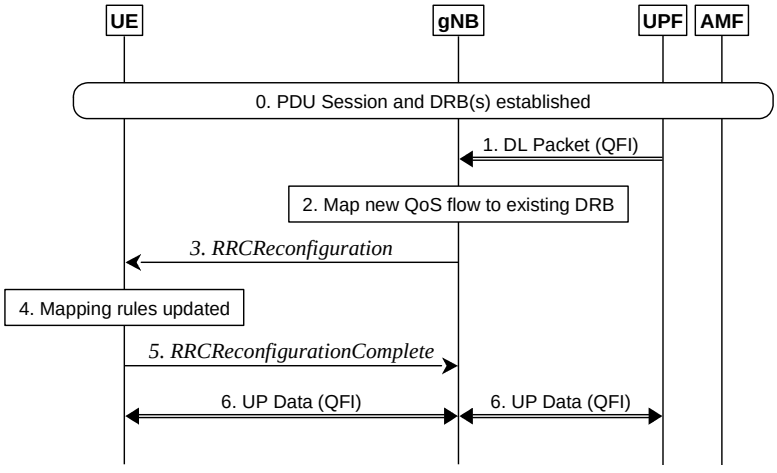


Figure A.3-1: DL data with new QFI sent over existing DRB

0. PDU session and DRB(s) have been already established.
1. gNB receives a downlink packet with a new QFI from UPF.

2. gNB decides to send the new QoS flow over an existing DRB using explicit RRC signalling for updating the AS mapping rules.
3. gNB sends an *RRCReconfiguration* message to UE with the new QFI to DRB mapping rule. gNB may also decide to update the DRB configuration if required to meet the QoS requirements for the new QoS Flow.
4. UE updates the QFI to DRB mapping rules and configuration (if received).
5. UE sends an *RRCReconfigurationComplete* message to gNB.
6. User Plane Data for the new QoS flow can then be exchanged between UE and gNB over the DRB according to the updated mapping rules and between UPF and gNB over the tunnel for the PDU session.

A.4 New QoS Flow with Explicit NAS Signalling

The following figure shows an example message flow when the gNB receives a new QoS flow establishment request from CN that involves NAS explicit signalling. The QoS flow establishment request provides the gNB and UE with the QoS parameters for the QFI. In this example, the gNB decides to establish a new DRB (rather than re-use an existing one) for this QoS flow and provides the mapping rule over RRC signalling. NAS procedures details between gNB and 5GC can be found in TS 23.501 [3], TS 23.502 [22] and TS 38.413 [26].

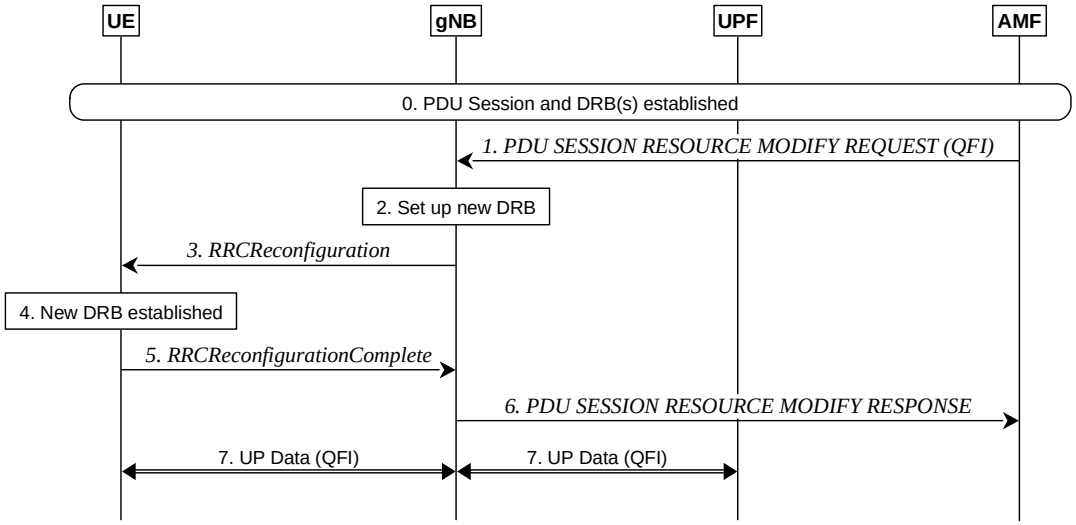


Figure A.4-1: DL data with new QoS Flow ID sent over new DRB with explicit signalling

0. PDU session DRB(s) have been already established.
1. gNB receives a PDU SESSION RESOURCE MODIFY REQUEST message from AMF for a new QoS flow.
2. If gNB cannot find an existing DRB to map this new QoS flow, it decides to establish a new DRB.
3. gNB sends an *RRCReconfiguration* message to UE including the DRB configuration with the new QFI to DRB mapping rule and the NAS message received at step 1.
4. UE establishes the DRB for the new QoS flow associated with this PDU session and updates the mapping rules.
5. UE sends an *RRCReconfigurationComplete* message to gNB.
6. gNB sends a PDU SESSION RESOURCE MODIFY RESPONSE message to AMF.
7. User Plane Data can then be exchanged between UE and gNB over DRB(s) according to the mapping rules and between UPF and gNB over the tunnel for the PDU session.

A.5 Release of QoS Flow with Explicit Signalling

The following figure shows an example message flow when the gNB receives a request to release a QoS flow from CN that involves explicit NAS signalling. NAS procedures details between gNB and 5GC can be found in TS 23.501 [3], TS 23.502 [22] and TS 38.413 [26].

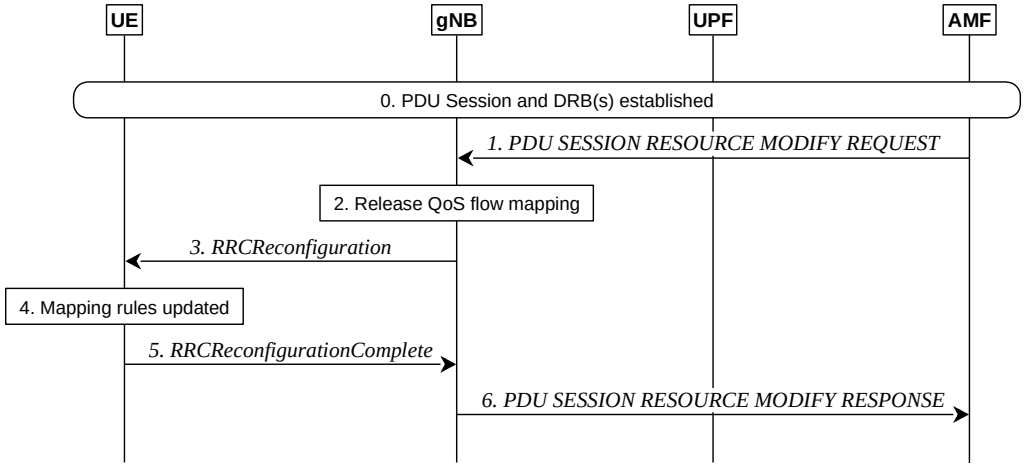


Figure A.5-1: Release of QoS Flow with Explicit Signalling

0. PDU session and DRB(s) have been already established.
1. gNB receives a PDU SESSION RESOURCE MODIFY REQUEST message from AMF to release a QoS flow.
2. The gNB decides to release corresponding the QFI to DRB mapping rule. Since the DRB also carries other QoS flows, the DRB is not released.
3. gNB sends an *RRCReconfiguration* message to UE to release the QFI to DRB mapping rule.
4. UE updates the AS QFI to DRB mapping rules to release this QFI to DRB mapping rule.
5. UE sends an *RRCReconfigurationC*omplete message to gNB.
6. gNB sends a PDU SESSION RESOURCE MODIFY RESPONSE message to AMF.

A.6 UE Initiated UL QoS Flow

The following figure shows an example message flow when the UE AS receives an UL packet for a new QoS flow for which a QFI to DRB mapping rule does not exist.

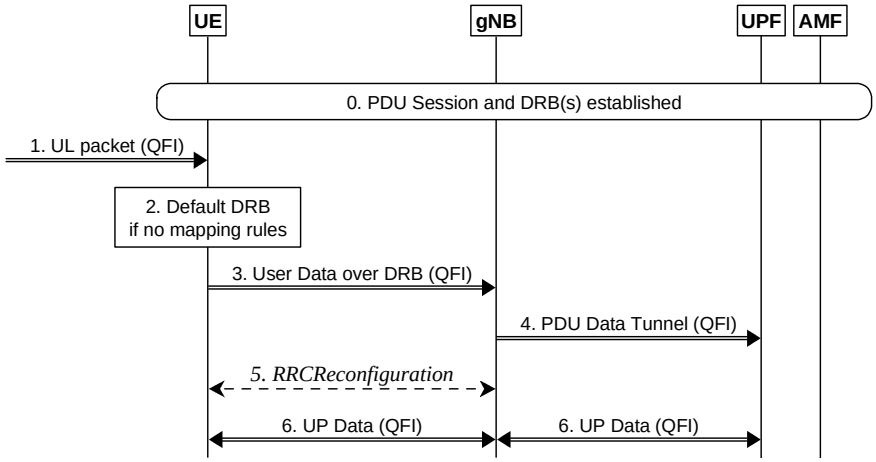


Figure A.6-1: UL packet with a new QoS flow for which a mapping does not exist in UE

0. PDU session and DRBs (including a default DRB) have been already established.
1. UE AS receives a packet with a new QFI from UE NAS.
2. UE uses the QFI of the packet to map it to a DRB. If there is no mapping of the QFI to a DRB in the AS mapping rules for this PDU session, then the packet is assigned to the default DRB.
3. UE sends the UL packet on the default DRB. The UE includes the QFI in the SDAP header.
4. gNB sends UL packets to UPF and includes the corresponding QFI.
5. If gNB wants to use a new DRB for this QoS flow, it sets up one. It can also choose to move the QoS flow to an existing DRB using RQoS or RRC signalling (see clauses A.2 and A.3).
6. User Plane Data for the new QoS flow can then be exchanged between UE and gNB over the DRB according to the updated mapping rules and between UPF and gNB over the tunnel for the PDU session.

Annex B (informative): Deployment Scenarios

B.1 Supplementary Uplink

To improve UL coverage for high frequency scenarios, SUL can be configured (see TS 38.101-1 [18]). With SUL, the UE is configured with 2 ULs for one DL of the same cell as depicted on Figure B.1-1 below:

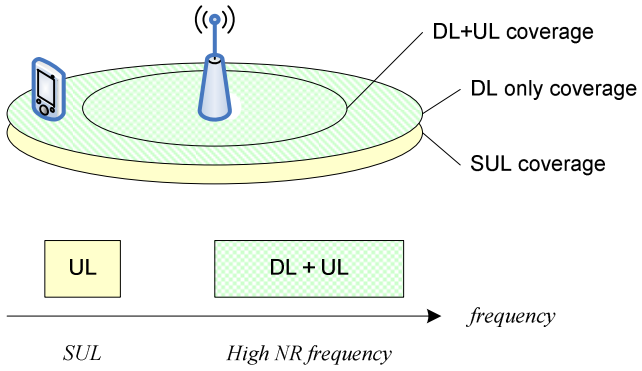


Figure B.1-1: Example of Supplementary Uplink

B.2 Multiple SSBs in a carrier

For a UE in RRC_CONNECTED, the BWPs configured by a serving cell may overlap in the frequency domain with the BWPs configured for other UEs by other cells within a carrier. Multiple SSBs may also be transmitted within the frequency span of a carrier used by the serving cell. However, from the UE perspective, each serving cell is associated to at most a single SSB. Figure B.2-1 below describes a scenario with multiple SSBs in a carrier, identifying two different cells (NCGI = 5, associated to SSB1, and NCGI = 6, associated to SSB3) with overlapping BWPs, and where RRM measurements can be configured to be performed by the UE on each of the available SSBs, i.e. SSB1, SSB2, SSB3 and SSB4.

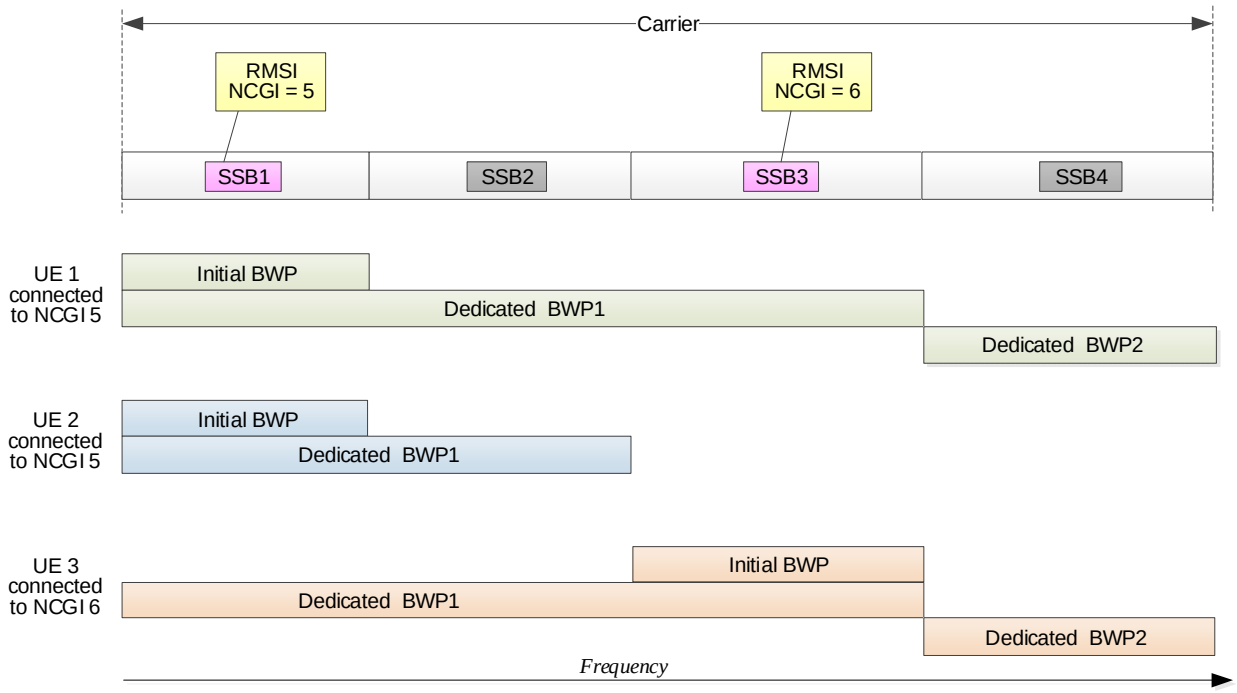


Figure B.2-1: Example of multiple SSBs in a carrier

B.3 NR Operation with Shared Spectrum

NR Radio Access operating with shared spectrum channel access can support the following deployment scenarios:

- Scenario A: Carrier aggregation between NR in licensed spectrum (SpCell) and NR in shared spectrum (SCell);
  - Scenario A.1: SCell is not configured with uplink (DL only);
  - Scenario A.2: SCell is configured with uplink (DL+UL).
- Scenario B: Dual connectivity between LTE in licensed spectrum and NR in shared spectrum (PSCell);
- Scenario C: NR in shared spectrum (PCell);
- Scenario D: NR cell in shared spectrum and uplink in licensed spectrum;
- Scenario E: Dual connectivity between NR in licensed spectrum (PCell) and NR in shared spectrum (PSCell).

Carrier aggregation of cells in shared spectrum is applicable to all deployment scenarios.

B.4 Example implementation of Non-Terrestrial Networks

The following figure illustrates an example implementation of a Non-Terrestrial Network for transparent NTN payload:

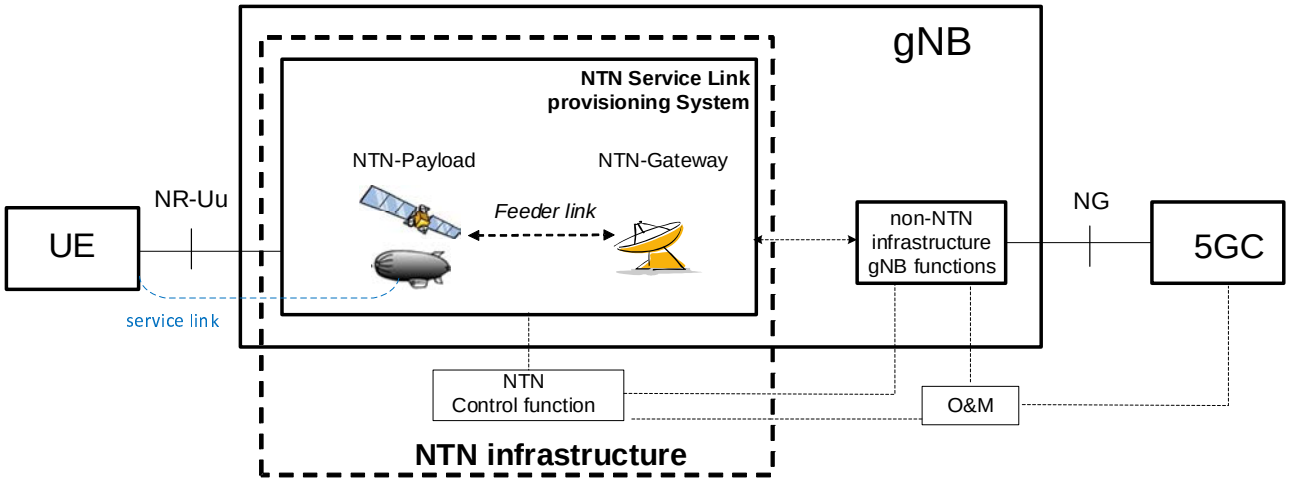


Figure B.4-1: NTN based NG-RAN with transparent NTN payload

The gNB depicted in Figure B.4-1 may be subdivided into non-NTN infrastructure gNB functions and the NTN Service Link provisioning system. The NTN infrastructure may be thought of being subdivided into the NTN Service Link provisioning system and the NTN Control function. The NTN Service Link provisioning system may consist of one or more NTN payloads and NTN Gateways.

The NTN payload is embarked on a spaceborne (or airborne) vehicle, providing a structure, power, commanding, telemetry, attitude control for the satellite (resp. HAPS) and possibly an appropriate thermal environment, radiation shielding.

The NTN Service Link provisioning system maps the NR-Uu radio protocol over radio resources of the NTN infrastructure (e.g. beams, channels, Tx power).

The NTN control function controls the spaceborne (or airborne) vehicles as well as the radio resources of the NTN infrastructure (NTN payload(s) & NTN Gateway(s)). It provides control data, e.g. Ephemeris, to the non-NTN infrastructure gNB functions of the gNB.

Provision of NTN control data to the gNB is out of 3GPP scope.

NOTE: The transport of NR-Uu protocol between the NTN Service Link provisioning system and the non-NTN infrastructure gNB functions is out of 3GPP scope.

At least the following NTN related parameters are expected to be provided by O&M to the gNB for its operation:

a) Earth-fixed beams: for each beam provided by a given NTN-payload:

- The Cell identifier (NG and Uu) mapped to the beam;
- The Cell's reference location (e.g. cell's center and range).

b) Quasi-Earth-fixed: for each beam provided by a given NTN payload:

- The Cell identifier (NG and Uu) and time window mapped to a beam;
- The Cell's/beam's reference location (e.g. cell's center and range);
- The time window of the successive switch overs (feeder link, service link);
- The identifier and time window of all serving satellites (resp. HAPS) and NTN Gateways.

c) Earth moving beams: for each beam provided by a given NTN payload:

- The Uu Cell identifier mapped to a beam and mapping information to fixed geographical areas reported on NG, including information about the beams direction and motion of the beam's foot print on Earth;
- Its elevation wrt NTN payload;
- Schedule of successive serving NTN Gateways/gNBs;

- Schedule of successive switch overs (feeder link, service link).

The NTN related parameters provided by O&M to the CN for UE location verification is specified in TS 38.305 [42].

Annex C (informative): I-RNTI Reference Profiles

The I-RNTI provides the new NG-RAN node a reference to the UE context in the old NG-RAN node. How the new NG-RAN node is able to resolve the old NG-RAN ID from the I-RNTI is a matter of proper configuration in the old and new NG-RAN node.

Table C-1 below provides some typical partitioning of a 40bit I-RNTI, assuming the following content:

- **UE specific reference**: reference to the UE context within a logical NG-RAN node;
- **NG-RAN node address index**: information to identify the NG-RAN node that has allocated the UE specific part;

NOTE: **RAT-specific information** may be introduced in a later release, containing information to identify the RAT of the cell within which the UE was sent to RRC_INACTIVE. This version of the specification only supports intra-RAT mobility of UEs in RRC_INACTIVE.

- **PLMN-specific information**: information supporting network sharing deployments, providing an index to the PLMN ID part of the Global NG-RAN node identifier.

Table C-1: I-RNTI reference profiles

Profile ID	UE specific reference	NG-RAN node address index (e.g., gNB ID, eNB ID)	RAT-specific information	PLMN-specific information	Comment
1	20 bits (~1 million values)	20 bits (~1 million values)	N/A	N/A	NG-RAN node address index may be very well represented by the LSBs of the gNB ID. This profile may be applicable for any NG-RAN RAT.
2	20 bits (~1 million values)	16 bits (65.000 nodes)	N/A	4 bits (Max 16 PLMNs)	Max number of PLMN IDs broadcast in NR is 12. This profile may be applicable for any NG-RAN RAT.
3	24 bits (16 million values)	16 bits (65.000 nodes)	N/A	N/A	Reduced node address to maximise addressable UE contexts. This profile may be applicable for any NG-RAN RAT.

Annex D (informative): SPID ranges and mapping of SPID values to cell reselection and inter-RAT/inter frequency handover priorities

The Subscriber Profile ID for RAT/Frequency Priority (SPID) values are defined in Annex I of TS 36.300 [2].

From these SPID reference values, the SPID=253 also applies for 5GC.

In addition, the SPID values defined below applies for 5GC.

SPID = 252

Table D-1: gNB local configuration in idle and connected mode for SPID = 252

Configuration parameter	Value	Meaning
2Rx XR device subscriber	true	The selection provides information that subscriber is an XR device and is permitted to utilise a minimum of two Rx antenna ports for the NR bands where four Rx antenna ports are baseline as given in TS 38.101-1 [18].

Annex E (informative): NG-RAN Architecture for Radio Access Network Sharing with multiple cell ID broadcast

Each NG-RAN node serving a cell identified by a Cell Identity associated with either a subset of PLMNs, or a subset of SNPNs, or a subset of PNI-NPNs is connected to another NG-RAN node via a single Xn-C interface instance.

Each Xn-C interface instance is setup and removed individually.

Xn-C interface instances terminating at NG-RAN nodes which share the same physical radio resources may share the same signalling transport resources. If this option is applied:

- Non-UE associated signalling is associated to an Xn-C interface instance by including an Interface Instance Indication in the XnAP message;

- Node related, non-UE associated Xn-C interface signalling may provide information destined for multiple logical nodes in a single XnAP procedure instance once the Xn-C interface instance is setup;

NOTE 1: If the Interface Instance Indication corresponds to more than one interface instance, the respective XnAP message carries information destined for multiple logical nodes.

- A UE associated signalling connection is associated to an Xn-C interface instance by allocating values for the corresponding NG-RAN node UE XnAP IDs so that they can be mapped to that Xn-C interface instance.

NOTE 2: One possible implementation is to partition the value ranges of the NG-RAN node UE XnAP IDs and associate each value range with an Xn-C interface instance.

Annex F (normative): Use and structure of the I-RNTI

The I-RNTI provides an NG-RAN node with a reference to the UE context and a reference to the NG-RAN node that allocated the UE context.

To support an NG-RAN node in resolving the Local NG-RAN ID of the NG-RAN node that allocated the UE context, the I-RNTI structure is as follows:

- the first part (starting from the MSB of the I-RNTI) identifies the I-RNTI profile. It is 2 bits long for a Full I-RNTI or 1 bit long for a short I-RNTI, and it indicates the length of a Local NG-RAN Node Identifier of the NG-RAN Node that allocated the I-RNTI;
- the second part, immediately following the first part, is a Local NG-RAN Node Identifier;
- the third part, immediately following the second part, identifies the UE context stored in the NG-RAN node that allocated the I-RNTI.

In case a NG-RAN node takes an additional Local NG-RAN Node identifier into use or removes a Local NG-RAN Node identifier currently in use it informs its neighbour NG-RAN nodes about this change.

The I-RNTI profiles for Full I-RNTI are described in table F-1.

Table F-1: I-RNTI profiles for Full I-RNTI

I-RNTI Profile Identity	I-RNTI profile value (binary encoding)
0	0b00
1	0b01
2	0b10
3	0b11

The I-RNTI profiles for Short I-RNTI are described in table F-2.

Table F-2: I-RNTI profiles for Short I-RNTI

I-RNTI Profile Identity	I-RNTI profile value (binary encoding)
0	0b0
1	0b1

Annex G (informative): Components of Mobility Latency

Mobility interruption time for L1/L2 Triggered Mobility (LTM) is the time from UE receives the cell switch command to UE performs the first DL/UL reception/transmission on the indicated beam of the target cell.

The latency of the mobility procedure for LTM is characterized by the terms illustrated in Figure G-1.

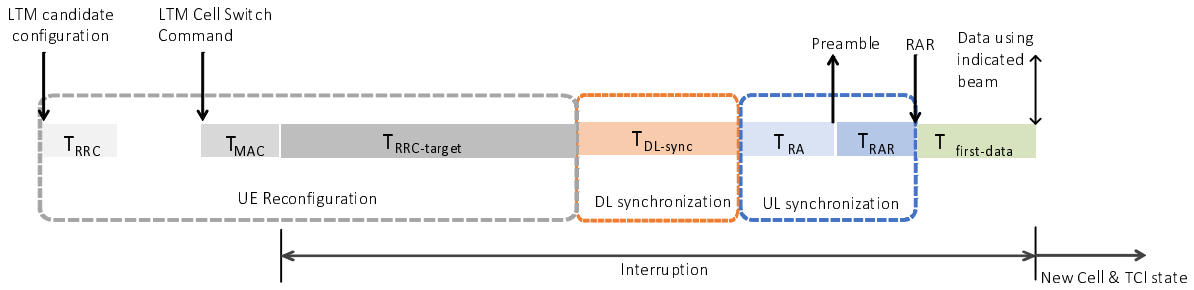


Figure G-1: Components of Mobility Latency for LTM

Each component of mobility latency is described in the table below. The value of T_{RRC} is specified in clause 12 of TS 38.331 [12].

Table G-1: Components of Mobility Latency

Component	Meaning
T_{RRC}	Processing time for *RRCReconfiguration* carrying candidate configurations
T_{MAC}	Time for processing the LTM cell switch command MAC CE
$T_{RRC-target}$	Time for processing and applying the target configuration
$T_{DL-sync}$	Time for DL synchronization
T_{RA}	Time until RA transmission
T_{RAR}	Time until RAR reception
$T_{first-data}$	Time for UE performs the first DL/UL reception/ transmission on the indicated beam of the target cell, after RAR

The latency of the RACH-based and RACH-less LTM procedure is characterized by the terms illustrated in Figure G-2 and Figure G-3. In particular, Figure G-2 shows the LTM procedure where the UE performs DL synchronization toward an LTM candidate cell before performing an LTM cell switch which involves a random access procedure. Further, Figure G-3 shows the LTM procedure where the UE performs the UL and DL synchronization before performing an LTM cell switch which does not involve a random access procedure. In both figures, it is highlighted how the overall mobility latency of LTM can be reduced by early synchronization procedure. Interruption time requirements (not represented by this annex) are specified in clause 6.3 of TS 38.133[13].

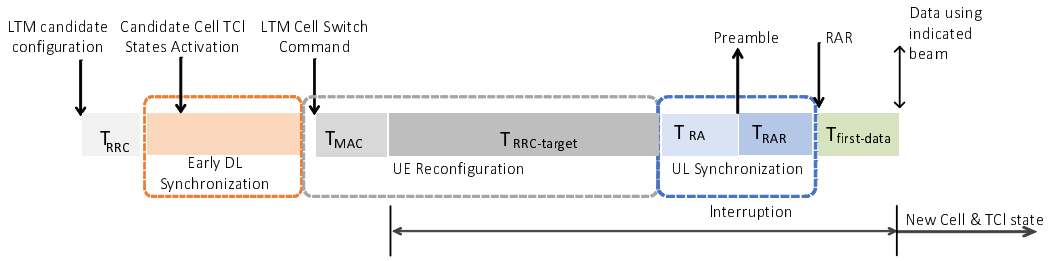


Figure G-2: Mobility Latency for RACH-based LTM

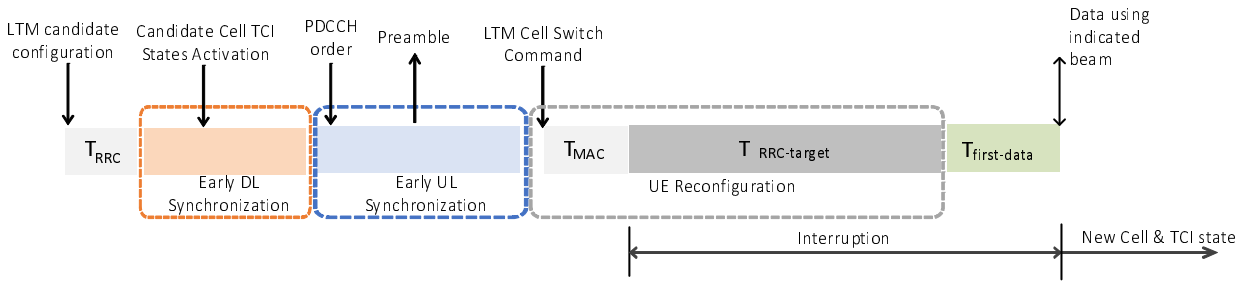


Figure G-3: Mobility Latency for RACH-less LTM

Annex H (informative): Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New Version**
2017.03	RAN2 97bis	R2-1702627	-	-	-	First version.	0.1.0
2017.04	RAN2 97bis	R2-1703825	-	-	-	Editorial Updates: - Stage 2 Details of ARQ operation marked as FFS - Placeholder for CU/DU Split overview added - Outdated editor notes removed - Protocol Architecture updated - NG-RAN terminology aligned - Header placement in the L2 overview put as FFS	0.1.1
2017.04	RAN2 97bis	R2-1703952	-	-	-	Editorial Updates: - description of measurements for mobility clarified - some cell reselection details put FFS - outdated references removed	0.1.2
2017.04	RAN2 98	R2-1704296	-	-	-	Editorial updates: - NG interfaces naming aligned to RAN3 - 5GC used consistently - Statement on lossless delivery removed from 9.3.2 - Overview of PDCP function for CP detailed	0.1.3
2017.05	RAN2 98	R2-1704298	-	-	-	Agreements of RAN2#97bis captured: - overview of duplication operation - RLC modes for DRBs and SRBs - Condition for lossless mobility - L2 handling at handover - RLF triggers - Measurement details (filtering, beams, quality…) - QoS flow handling in DC - RACH procedure message usage for on-demand SI - Random Access Procedure triggers - DRX baseline	0.2.0
2017.05	RAN2 98	R2-1704452	-	-	-	RAN3 agreements captured (R3-171329) 5G logo and specification title updated	0.2.1
2017.05	RAN2 98	R2-1705994	-	-	-	RLC failure for RLF generalized.	0.3.0
2017.06	RAN2 98	R2-1706204	-	-	-	Agreements of RAN2#98 captured: - Duplication Control - RLC mode for SRB0 and System Info - Provision of Assistance Info for AMF Selection - QoS Handling from R2-1706011 - Beam measurements combining - MSG1 request details for on-demand SI - RNA and RLAU terminology introduced for INACTIVE - Skipping of SPS resources when nothing to transmit - Duplication detection at RLC only for AM - Provision of access category by NAS for connection control Editorial updates in addition: - QFI used consistently	0.3.1
2017.06	RAN2 98	R2-1706205	-	-	-	RAN3 agreements captured (R3-171932)	0.4.0
2017.06	RAN2 98	R2-1706206	-	-	-	Corrections: - provision of AC in INACTIVE is FFS - agreements on measurement moved from 9.2.1.1 to 9.2.4	0.4.1
2017.06	NR Adhoc 2	R2-1706540	-	-	-	Editorial corrections Agreement on RLC Segmentation captured Duplicated statement in 9.2.1.1. and 7.3 removed	0.5.0
2017.08	RAN2 99	R2-1707748	-	-	-	Agreements of RAN2 NR June Adhoc captured: - TP on Security in R2-1707466 - TP on Measurement Model in R2-1707480 - NCR Acronym addition - Duplication control details - UE capabilities and band combinations - Disabling of PDPC reordering as PDCP function - On-Demand SI and RACH details - Measurement Report Characteristics - Mapping rules update handling - UE Capabilities and Band Combination handling In addition: - ARQ overview aligned with Stage 3 agreements	0.6.0

						- L2 Data Flow aligned with Stage 3 agreements - References updated RAN3 TP incorporated (R3-172610)	
2017.08	RAN2 99	R2-1709937	-	-	-	Agreements of RAN2 99 captured: - QoS update in R2-1709830 - Description of the RRC states in R2-1707690 - Correction on RRC_INACTIVE state in R2-1709833 - LCP description in R2-1709829 - Baseline HO procedure update in R2-1709850 with corrections - UE identities in R2-1709868 - Radio Link Failure handling in R2-1709870 - RAN3 agreements on roaming restrictions in R3-172655 - Integrity protection configurable on a per DRB basis - Various Acronyms added - Slicing details - PWS basic principles - UE capability restrictions	0.7.0
2017.09	RAN 77	RP-171730	-	-	-	Provided for information to RAN	1.0.0
2017.10	RAN2 99bis	R2-1710693	-	-	-	Editorial Updates and Corrections: - inter RAT mobility in 9.3.2 restructured - SON promoted to top clause level (as it is not a vertical) - Obsolete clauses 14 and 15 removed. - Description of paging in idle aligned with 23.501 - I-RNTI suggested for INACTIVE - Missing agreement from RAN2 99 on INACTIVE captured	1.0.1
2017.10	RAN2 99bis	R2-1711936	-	-	-	Clean version	1.1.0
2017.10	RAN2 99bis	R2-1711972	-	-	-	Corrections: - Container for mobility in 9.2.3.2.1 - "HO" changed to "handover" for consistency Agreements from RAN2 99bis captured: - URLLC text in R2-1710253 - Clarification on RRC States in R2-1710074 - Resume ID terminology in R2-1711778 - Slicing clarifications in R2-1712034 - Usage of SRB0 and SRB1 in INACTIVE - Prioritisation of RACH resources for handover - SPS configuration per SCell in CA - Enabling / Disabling IP on DRB via handover only - First agreements on Supplementary Uplink - Maximum supported data rate calculation RAN3 agreements: - R3-173639 on Rapporteur updates to RAN3-related clauses - R3-174162 on AMF discovery by NG-RAN - R3-174187 on RAN paging failure handling in RRC_INACTIVE - R3-174188 on Unreachability in RAN Inactive State - R3-174225 on Inter System Handover - R3-174230 on RRC Inactive Assistant Information RAN agreement: - RP-172113 on UE categories.	1.1.1
2017.11	RAN2 100	R2-1712266	-	-	-	Clean version	1.2.0
2017.11	RAN2 100	R2-1712355	-	-	-	Editorial Clean Up: - Editor's Notes & relevant FFS moved to R2-17112357 - Protocol stack figures for NG interface updated - Dual Connectivity changed to Multi-RAT connectivity - Details about SI handling added to tackle RMSI - Access Control updated and reference to 22.261 added - DC specific details removed (37.340 is used instead) - Notes numbered wherever required	1.2.1
2017.12	RAN2 100	R2-174079	-	-	-	Agreements from RAN2 100 captured: - QoS update in R2-1714230 - Updates to stage 2 QoS flow in R2-1712687 - BWP Description in R2-172360 - Transition from INACTIVE to CONNECTED in R2-173937 - SUL overview - Removal of DC related definitions - BWP agreements - SPS terminology changed to CS to cover both types RAN3 agreements in R3-175011 RAN1 agreements in R1-1721728	1.2.2
2017.12	RAN2 100	R2-1714252	-	-	-	Clean version	1.3.0
2017.12	RP-78	RP-172496	-	-	-	Provided for approval to RAN	2.0.0
2017/12	RP-78					Upgraded to Rel-15 (MCC)	15.0.0
2018/03	RP-79	RP-180440	0009	1	F	Miscellaneous Corrections & Additions	15.1.0

2018/06	RP-80	RP-181214	0010	1	F	Clarification on NR Carrier Aggregation	15.2.0
	RP-80	RP-181214	0011	2	F	Miscellaneous Corrections	15.2.0
	RP-80	RP-181214	0012	1	F	Paging Mechanisms	15.2.0
	RP-80	RP-181214	0013	2	F	Security Update	15.2.0
	RP-80	RP-181214	0014	1	F	UE Identities	15.2.0
	RP-80	RP-181214	0015	1	F	Corrections on deactivation of PUCCH SCell	15.2.0
	RP-80	RP-181214	0022	2	F	Clarification on count wrap around	15.2.0
	RP-80	RP-181214	0024	1	F	Slicing assistance information	15.2.0
	RP-80	RP-181214	0025	-	F	Physical Layer Update	15.2.0
	RP-80	RP-181214	0026	1	F	Default DRB & QoS Remapping	15.2.0
	RP-80	RP-181214	0027	1	F	SSB Clarifications	15.2.0
	RP-80	RP-181217	0029	2	B	CR on U-plane handling for handover	15.2.0
	RP-80	RP-181217	0030	2	B	CR on message content in inter-RAT handover	15.2.0
	RP-80	RP-181215	0032	1	F	Clarifications on (de)activation of Duplication and (de)activation of SCells	15.2.0
	RP-80	RP-181216	0033	2	B	Introduce ANR in NR	15.2.0
	RP-80	RP-181215	0036	1	F	Corrections to Unified Access Control	15.2.0
	RP-80	RP-181215	0040	-	F	Correction to TS 38.300 on Open Issues for Handover	15.2.0
	RP-80	RP-181216	0041	-	B	Baseline CR for June version of RAN2 TS 38.300 (RAN3 part) covering agreements of RAN3#100	15.2.0
	RP-80	RP-181216	0042	-	B	Delay budget report and MAC CE adaptation for NR for TS 38.300	15.2.0
2018/09	RP-81	RP-181941	0035	3	B	ECN support in NR	15.3.0
	RP-81	RP-181938	0043	2	D	Miscellaneous Clean Up and Corrections	15.3.0
	RP-81	RP-181938	0045	1	F	Mobility Call Flows	15.3.0
	RP-81	RP-181938	0046	2	F	QoS Handling Corrections	15.3.0
	RP-81	RP-181938	0047	4	F	MDBV Enforcement	15.3.0
	RP-81	RP-181939	0050	1	F	Completion of description of power saving	15.3.0
	RP-81	RP-181940	0051	1	F	Correction to description of bandwidth adaptation	15.3.0
	RP-81	RP-181939	0053	1	F	Clarification of PDCP functionality	15.3.0
	RP-81	RP-181939	0062	2	F	Clarification on number of CC for NR CA	15.3.0
	RP-81	RP-181938	0070	1	F	Beam management, failure detection and recovery	15.3.0
	RP-81	RP-181941	0071	-	F	System Information Handling in TS38.300	15.3.0
	RP-81	RP-181941	0072	1	F	Correction on RRC Resume procedure	15.3.0
	RP-81	RP-181940	0077	-	F	CR on RACH configuration during HO	15.3.0
	RP-81	RP-181941	0078	1	F	Missing Call Flows	15.3.0
	RP-81	RP-181942	0079	1	F	CN type indication for Redirection from NR to E-UTRA	15.3.0
	RP-81	RP-181942	0080	1	F	QoS Flow to DRB Remapping during Handover	15.3.0
	RP-81	RP-181941	0081	1	F	NR Corrections (38.300 Baseline CR covering RAN3-101 agreements)	15.3.0
2018/10	-	-	-	-	-	Changes of CR0035 rev 3 were undone since this CR was actually not approved by RAN #81 as it was not submitted to RAN #81	15.3.1
2018/12	RP-82	RP-182656	0028	5	F	Slice Aware Access Control	15.4.0
	RP-82	RP-182649	0035	4	B	ECN support in NR	15.4.0
	RP-82	RP-182653	0074	2	F	Corrections to System Information	15.4.0
	RP-82	RP-182655	0075	2	F	Stage2 Corrections on UE capability	15.4.0
	RP-82	RP-182657	0083	3	F	Clarifications on dynamic scheduling	15.4.0
	RP-82	RP-182658	0084	2	F	Clarification of AMF Switch in RRC_INACTIVE	15.4.0
	RP-82	RP-182657	0086	2	F	Correction to the system information in Handover Request message	15.4.0
	RP-82	RP-182654	0087	2	F	Capture signalling flows where the last serving gNB moves the UE to RRC_IDLE	15.4.0
	RP-82	RP-182649	0088	2	F	Scheduling Request Overview	15.4.0
	RP-82	RP-182649	0089	1	F	System Information Provisioning	15.4.0
	RP-82	RP-182657	0090	3	F	Transport of NAS Messages	15.4.0
	RP-82	RP-182649	0091	2	F	SON Overview	15.4.0
	RP-82	RP-182649	0093	2	F	RDI handling for data forwarding at handover	15.4.0
	RP-82	RP-182656	0095	2	F	Clarification on basic voice support	15.4.0
	RP-82	RP-182659	0096	2	F	Relation between SSB and SS-Burst	15.4.0
	RP-82	RP-182659	0097	3	F	Defining inter-system and intra-system handover	15.4.0
	RP-82	RP-182659	0099	3	F	Correction regarding key deletion at state transition to RRC_IDLE	15.4.0
	RP-82	RP-182656	0102	2	F	Clarification on SSB-based BM, RLM and BFD	15.4.0
	RP-82	RP-182653	0103	1	F	Correction to beam failure detection in Stage-2	15.4.0
	RP-82	RP-182655	0106	2	F	Random Access Triggers	15.4.0
	RP-82	RP-182649	0107	-	F	Correction of BWP adaptation	15.4.0
	RP-82	RP-182657	0108	1	F	Notification Control	15.4.0
	RP-82	RP-182665	0109	1	F	PDU Session AMBR	15.4.0
	RP-82	RP-182649	0110	-	F	Logical channel restrictions clarifications and correction	15.4.0
	RP-82	RP-182666	0111	2	F	CORESET#0	15.4.0
	RP-82	RP-182659	0115	2	F	Corrections to activation of SCells	15.4.0
	RP-82	RP-182657	0116	1	F	Description of RLM aspects	15.4.0
	RP-82	RP-182651	0120	-	F	Minor corrections to paging	15.4.0
	RP-82	RP-182659	0125	1	F	Clarification on power ramping counter	15.4.0
	RP-82	RP-182658	0127	1	F	Corrections on the descriptions of active BWP	15.4.0
	RP-82	RP-182653	0131	-	F	Stage 2 Correction on Mobility in RRC_IDLE	15.4.0

	RP-82	RP-182660	0133	1	F	Stage 2 CR on Measurement gap configuration scenarios	15.4.0
	RP-82	RP-182659	0134	1	F	CR on the carrier selection for random access	15.4.0
	RP-82	RP-182659	0137	1	F	Corrections on Multi-Radio dual connectivity	15.4.0
	RP-82	RP-182670	0138	2	F	Inter-system HO	15.4.0
	RP-82	RP-182787	0139	-	F	Baseline CR for TS 38.300	15.4.0
	RP-82	RP-182799	0140	-	B	Addition of Annex X for SPID ranges	15.4.0
2019/03	RP-83	RP-190542	0142	2	F	RRC Reject Handling for MPS and MCS	15.5.0
	RP-83	RP-190540	0143	-	F	Misalignments with other Specifications	15.5.0
	RP-83	RP-190543	0146	2	F	RLF triggering when RLC reaches maximum number of retransmission	15.5.0
	RP-83	RP-190543	0147	1	F	Correction on RLC modes for duplication	15.5.0
	RP-83	RP-190545	0148	1	F	Correction of Data Forwarding over Xn	15.5.0
	RP-83	RP-190544	0149	-	F	Correction to RNAU without context relocation	15.5.0
	RP-83	RP-190544	0150	-	F	Correction of handling of PDCP SN during Data Forwarding	15.5.0
	RP-83	RP-190545	0151	1	F	Correction of stage 2 for slicing	15.5.0
	RP-83	RP-190544	0152	-	F	Energy Saving Support in R15	15.5.0
2019/06	RP-84	RP-191373	0154	-	F	CQI and MCS for URLLC	15.6.0
	RP-84	RP-191373	0155	1	F	Miscellaneous Corrections	15.6.0
	RP-84	RP-191373	0156	1	F	CA Clarifications - RACH and Timing Advance	15.6.0
	RP-84	RP-191373	0157	-	F	Cross Carrier Scheduling	15.6.0
	RP-84	RP-191379	0159	1	F	CR on 38.300 for SRB cell mapping for CA duplication	15.6.0
	RP-84	RP-191380	0160	1	F	Support of ongoing re-mapping on source side during SDAP mobility	15.6.0
	RP-84	RP-191379	0161	-	F	Correction of data forwarding	15.6.0
	RP-84	RP-191379	0162	-	F	Slicing information during handover	15.6.0
	RP-84	RP-191380	0163	-	F	Corrections for support of data forwarding for reestablishment UE	15.6.0
	RP-84	RP-191380	0164	-	F	Correction of QoS flow re-mapping before handover	15.6.0
	RP-84	RP-191380	0165	-	F	Correction of NAS PDU	15.6.0
	RP-84	RP-191380	0168	-	F	Support for network sharing	15.6.0
2019/09	RP-85	RP-192191	0171	1	F	Correction on 5GC to EPC inter-RAT inter-system handover	15.7.0
2019/12	RP-86	RP-192934	0173	2	F	Clarification on measurement gap configuration in NR SA	15.8.0
	RP-86	RP-192934	0174	1	F	KgNB derivation upon mobility	15.8.0
	RP-86	RP-192934	0178	-	F	Correction on PUCCH transform precoding	15.8.0
	RP-86	RP-192935	0181	-	F	Correction on mini-slot scheduling	15.8.0
	RP-86	RP-192937	0182	-	F	Independent migration to IPv6 on NG-U	15.8.0
	RP-86	RP-192938	0183	-	F	Correction of QoS flow re-mapping before handover	15.8.0
	RP-86	RP-192944	0184	-	B	CR TS 38.300 Remote Interference Management	16.0.0
	RP-86	RP-192942	0185	-	B	Introduction of direct data forwarding for inter-system HO between EPS and 5GS	16.0.0
2020/03	RP-87	RP-200349	0153	8	B	CR to 38.300 on Integrated Access and Backhaul for NR	16.1.0
	RP-87	RP-200347	0172	3	B	Introduction of NR mobility enhancement	16.1.0
	RP-87	RP-200360	0175	3	B	Introduction of additional enhancements for eMTC	16.1.0
	RP-87	RP-200361	0176	3	B	Introduction of additional enhancements for NB-IoT	16.1.0
	RP-87	RP-200350	0186	2	B	Introduction of SRVCC from 5G to 3G	16.1.0
	RP-87	RP-200351	0187	1	B	Introduction of RACS and DL RRC segmentation	16.1.0
	RP-87	RP-200335	0189	2	A	Security and RRC Resume Request	16.1.0
	RP-87	RP-200357	0190	-	B	Introduction of NR IDC solution	16.1.0
	RP-87	RP-200344	0193	2	B	Introduction of UE Power Saving in NR	16.1.0
	RP-87	RP-200341	0194	2	B	Introduction of on-demand SI procedure in RRC_CONNECTED	16.1.0
	RP-87	RP-200353	0195	2	B	Non-Public Networks	16.1.0
	RP-87	RP-200342	0197	1	B	Introduction of 2-step RACH	16.1.0
	RP-87	RP-200348	0198	2	B	CR for 38.300 for CA/DC enhancements	16.1.0
	RP-87	RP-200341	0199	2	B	Introduction of NR operation with Shared Spectrum Access to Stage 2	16.1.0
	RP-87	RP-200343	0200	1	B	Introduction of NR eURLLC	16.1.0
	RP-87	RP-200340	0201	2	B	Introduction of cross link interference management	16.1.0
	RP-87	RP-200352	0203	-	B	Introduction of NR Industrial IoT features	16.1.0
	RP-87	RP-200346	0204	-	B	Introduction of 5G V2X with NR Sidelink	16.1.0
	RP-87	RP-200334	0207	-	A	Propagation of Roaming and Access Restriction information in NG-RAN in non-homogenous NG-RAN node deployments	16.1.0
	RP-87	RP-200345	0209	-	B	RAN1 stage 2 agreements related to positioning	16.1.0
2020/07	RP-88	RP-201165	0191	3	B	Introduction of NeedForGap capability for NR measurement	16.2.0
	RP-88	RP-201177	0211	2	F	Corrections to Mobility Enhancements	16.2.0
	RP-88	RP-201173	0214	1	F	4-step RA type figure description	16.2.0
	RP-88	RP-201181	0215	1	F	Stage-2 updates for IIOT	16.2.0
	RP-88	RP-201171	0217	4	F	CLI Corrections	16.2.0
	RP-88	RP-201179	0220	1	C	CR to 38.300 on Integrated Access and Backhaul for NR	16.2.0
	RP-88	RP-201161	0222	1	A	Clarification on pdcp-Duplication at RRC Reconfiguration	16.2.0
	RP-88	RP-201164	0224	1	A	Correction on bandwidth adaptation	16.2.0
	RP-88	RP-201182	0225	2	F	Miscellaneous corrections to NPN	16.2.0
	RP-88	RP-201175	0227	1	F	Missing SIB for positioning	16.2.0
	RP-88	RP-201172	0229	1	F	Miscellaneous corrections for NR operation with shared spectrum	16.2.0
	RP-88	RP-201177	0230	2	F	Corrections on NR mobility enhancements	16.2.0
	RP-88	RP-201178	0236	2	F	Clarification of DAPS configuration in MR-DC	16.2.0

	RP-88	RP-201176	0237	1	F	Introduction of on-demand SIB(s) procedure in RRC_CONNECTED	16.2.0
	RP-88	RP-201190	0239	-	C	Introduction of eCall over IMS for NR	16.2.0
	RP-88	RP-201176	0245	1	F	Correction for NR sidelink communication	16.2.0
	RP-88	RP-201165	0246	-	A	Global Cell Identities and Global NG-RAN Node Identities when NR access is shared	16.2.0
	RP-88	RP-201176	0248	1	B	Support for Alternative QoS profiles	16.2.0
	RP-88	RP-201211	0249	1	C	Introduction of Inter-gNB CSI-RS Based Mobility	16.2.0
	RP-88	RP-201165	0251	-	A	Correction of NAS NON Delivery	16.2.0
	RP-88	RP-201177	0252	1	B	Baseline CR for introducing Rel-16 NR mobility enhancement	16.2.0
	RP-88	RP-201181	0253	-	B	NRIIOT Higher Layer Multi-Connectivity	16.2.0
	RP-88	RP-201182	0254	1	B	Introduction of Non Public Networks	16.2.0
	RP-88	RP-201179	0255	-	B	Mapping of Uplink Traffic to Backhaul RLC Channels	16.2.0
	RP-88	RP-201354	0256	-	B	Addition of SON features	16.2.0
2020/09	RP-89	RP-201937	0232	1	A	Clarification for KPAS and EU-alert	16.3.0
	RP-89	RP-201931	0258	1	F	Drafting Rules in Subclause 15 on SON	16.3.0
	RP-89	RP-201928	0259	-	F	Missing RACH Figure	16.3.0
	RP-89	RP-201937	0260	-	F	Clarification on NCGI	16.3.0
	RP-89	RP-201963	0263	1	F	Stage-2 CR for clarifications of Rel-16 PDCP Duplication	16.3.0
	RP-89	RP-201926	0265	-	F	Correction on CSI-RS Based Intra-frequency and Inter-frequency Measurement Definition	16.3.0
	RP-89	RP-201930	0274	-	F	Various corrections to NR Mobility enhancements description	16.3.0
	RP-89	RP-201930	0278	-	F	DAPS handover corrections	16.3.0
	RP-89	RP-201922	0284	1	F	Misc corrections for Rel-16 DCCA	16.3.0
	RP-89	RP-201932	0285	1	F	Mandatory support of full rate user plane integrity protection	16.3.0
	RP-89	RP-201922	0286	1	F	Correction on UL behaviours in the dormant BWP	16.3.0
	RP-89	RP-201923	0293	1	F	CR to 38.300 on Integrated Access and Backhaul for NR	16.3.0
	RP-89	RP-201921	0294	1	F	Correction of CAPC for NR-U	16.3.0
	RP-89	RP-201929	0295	-	F	Correction on prioritization between DCP and RAR to C-RNTI for CFRA BFR	16.3.0
	RP-89	RP-201928	0296	-	F	Correction of NPN CAG cells and non-CAG cells	16.3.0
2020/12	RP-90	RP-202776	0299	1	F	Stage-2 description of MPE reporting	16.4.0
	RP-90	RP-202771	0300	3	F	Description of Multi-TRP operation	16.4.0
	RP-90	RP-202774	0305	1	F	Miscellaneous corrections to Mobility Enhancements	16.4.0
	RP-90	RP-202774	0307	1	F	Clarification on no support of CA, DC or multi-TRP with DAPS	16.4.0
	RP-90	RP-202771	0310	1	F	BFR on SCell	16.4.0
	RP-90	RP-202776	0317	3	F	Dynamic UMTS Radio Capability impact on SRVCC and RACS	16.4.0
	RP-90	RP-202772	0318	1	F	Corrections on non DRB operation for IAB-MT	16.4.0
	RP-90	RP-202774	0322	1	F	Correction to RLF in case of DAPS HO	16.4.0
	RP-90	RP-202769	0323	-	F	Stage-2 corrections for NR sidelink communication	16.4.0
	RP-90	RP-202771	0324	-	F	Clarifying the use of PNI-NPN term in RAN specifications	16.4.0
	RP-90	RP-202777	0325	1	F	Clarification on the indication of eCall over IMS	16.4.0
	RP-90	RP-202777	0326	1	F	Secondary DRX group description is missing	16.4.0
	RP-90	RP-202774	0327	-	F	CHO in stage-2	16.4.0
	RP-90	RP-202769	0328	-	F	Corrections on AQP for notification control	16.4.0
	RP-90	RP-202774	0330	-	F	Correction for NR CHO and Full Configuration	16.4.0
	RP-90	RP-202767	0331	-	F	Update the deployment scenarios in Annex B.3	16.4.0
2021/03	RP-91	RP-210701	0302	2	A	UE Capabilities Description	16.5.0
	RP-91	RP-210692	0333	1	F	Clarification on no support of SUL with DAPS	16.5.0
	RP-91	RP-210691	0337	1	F	Miscellaneous Stage-2 corrections of IAB in 38.300	16.5.0
	RP-91	RP-210695	0338	2	F	Release with Redirect for connection resume triggered by NAS	16.5.0
	RP-91	RP-210702	0339	1	A	Clarification of data forwarding upon intra-system HO using full configuration	16.5.0
	RP-91	RP-210692	0340	2	F	Addition of releasing the source part of DAPS DRBS upon DAPS release	16.5.0
	RP-91	RP-210689	0343	-	F	Correction on uplink transmission allowed without TA	16.5.0
	RP-91	RP-210689	0346	1	F	Clarification on DAPS HO configuration	16.5.0
	RP-91	RP-210694	0347	-	F	PDCP SN issue for EPC to 5GC handover	16.5.0
2021-06	RP-92	RP-211475	0352	2	F	Addition of size limitation for SRVCC	16.6.0
	RP-92	RP-211473	0353	2	F	Transmissions to the source that continue upon DAPS UL switching	16.6.0
	RP-92	RP-211473	0354	1	F	Removing ambiguous legacy and normal terms from handover descriptions	16.6.0
	RP-92	RP-211472	0359	1	F	Updated description of multi-TRP	16.6.0
	RP-92	RP-211484	0364	3	A	SRB PDCP handling upon handover	16.6.0
	RP-92	RP-211472	0366	3	F	Missing IAB SA mode for QoS description	16.6.0
	RP-92	RP-211473	0368	1	F	Clarification on RLF detection of source PCell	16.6.0
	RP-92	RP-211473	0370	1	F	Miscellaneous corrections to DAPS handover	16.6.0
	RP-92	RP-211480	0373	1	F	Miscellaneous Corrections	16.6.0
	RP-92	RP-211471	0379	-	F	Correction of MRO in stage 2	16.6.0
	RP-92	RP-211484	0380	-	F	Supporting use of UE Radio Capability for Paging in RRC_INACTIVE	16.6.0
2021-09	RP-93	RP-212443	0381	1	F	Correction to Rel-16 HARQ description	16.7.0
	RP-93	RP-212442	0387	1	F	Miscellaneous corrections to eURLLC for 38.300	16.7.0
	RP-93	RP-212440	0388	1	F	NAS PDU handling	16.7.0

2021-12	RP-94	RP-213343	0391	1	F	Miscellaneous Corrections	16.8.0
	RP-94	RP-213343	0398	-	F	Handling of mobility and dual connectivity in mixed PNI-NPN/PLMN cell scenarios	16.8.0
2022-03	RP-95	RP-220484	0342	10	B	Introduction of NR MBS	17.0.0
	RP-95	RP-220487	0357	7	B	Introduction of SDT	17.0.0
	RP-95	RP-220486	0389	4	B	Introduction of IAB enhancements	17.0.0
	RP-95	RP-220477	0400	1	B	Introduction of NR dynamic spectrum sharing	17.0.0
	RP-95	RP-220506	0401	1	D	Inclusive Language Review for TS 38.300	17.0.0
	RP-95	RP-220837	0402	1	B	Introduction of MINT [MINT]	17.0.0
	RP-95	RP-220491	0403	2	B	Introduction of Sidelink Relay	17.0.0
	RP-95	RP-220476	0405	1	B	Introduction of eSL in TS 38.300	17.0.0
	RP-95	RP-220837	0407	1	B	Introduction of RACH triggers for T_ADV in NR E-CID [NRTADV]	17.0.0
	RP-95	RP-220475	0408	1	B	Introduction of NR operation up to 71GHz	17.0.0
	RP-95	RP-220499	0411	1	B	Stage 2 CR for UL Tx switching enhancement	17.0.0
	RP-95	RP-220478	0412	1	B	Introduction of NR coverage enhancements	17.0.0
	RP-95	RP-220490	0413	1	B	RAN enhancements in the support of slicing	17.0.0
	RP-95	RP-220493	0414	2	B	Introducing NPN enhancements: Credential Holders, Onboarding, IMS emergency, and PWS support in SNPNs	17.0.0
	RP-95	RP-220489	0415	-	B	Introduction of the support for UDC in NR	17.0.0
	RP-95	RP-220481	0416	1	B	Introduction of Rel-17 IIoT/URLLC to TS 38.300	17.0.0
	RP-95	RP-220960	0417	2	B	Introduction of UE power saving enhancements In 38.300	17.0.0
	RP-95	RP-220496	0420	1	B	Introduction of DL 1024 QAM in NR	17.0.0
	RP-95	RP-220480	0421	2	B	Introduction of RedCap in TS 38.300	17.0.0
	RP-95	RP-220488	0422	1	B	Running CR to 38300 for Multi-USIM devices support	17.0.0
	RP-95	RP-220482	0423	2	B	Support of Non-Terrestrial Networks	17.0.0
	RP-95	RP-220494	0424	-	B	38.300 CR for Introduction of QoE measurements in NR	17.0.0
	RP-95	RP-220510	0426	-	B	Introduction of Local NG-RAN Node IDs for RRC_INACTIVE [RRCInactive]	17.0.0
	RP-95	RP-220510	0427	1	C	UE Security Capabilities signaling in NG-RAN [UE_Sec_Caps]	17.0.0
	RP-95	RP-220839	0431	-	B	Addition of SON features enhancement	17.0.0
	RP-95	RP-220474	0439	-	B	Introduction of feMIMO	17.0.0
2022-06	RP-96	RP-221728	0362	2	B	Introduction of further MRDC enhancements	17.1.0
	RP-96	RP-221732	0440	1	F	Correction on stage 2 for sidelink relay	17.1.0
	RP-96	RP-221735	0441	1	F	38.300 CR Correction for Introduction of QoE measurements in NR	17.1.0
	RP-96	RP-221715	0447	1	F	Stage-2 corrections for 71 GHz	17.1.0
	RP-96	RP-221727	0458	2	F	Corrections to UE power saving enhancements In 38.300	17.1.0
	RP-96	RP-221719	0462	-	C	Updates for RAN Slicing from RAN2#118	17.1.0
	RP-96	RP-221716	0464	1	F	Corrections on RedCap in TS 38.300	17.1.0
	RP-96	RP-221729	0465	1	F	Corrections on SDT	17.1.0
	RP-96	RP-221729	0466	2	F	Introduction of RACH partitioning	17.1.0
	RP-96	RP-221762	0469	2	F	Miscellaneous Corrections to eSL	17.1.0
	RP-96	RP-221724	0472	-	F	Correction for NR coverage enhancements	17.1.0
	RP-96	RP-221736	0474	1	B	Introduction of gNB ID length reporting in the NR CGI report [gNB_ID_Length]	17.1.0
	RP-96	RP-221718	0476	-	F	Various corrections to IAB enhancements	17.1.0
	RP-96	RP-221726	0477	-	F	Corrections for IIoT on simultaneous PUCCH and PUSCH transmission	17.1.0
	RP-96	RP-221717	0478	-	F	Corrections to stage 2 for NR NTN	17.1.0
	RP-96	RP-221714	0480	-	A	Inter-system direct data forwarding between source SgNB and target gNB	17.1.0
	RP-96	RP-221754	0483	-	F	Correction on NR MBS	17.1.0
	RP-96	RP-221754	0484	1	F	Correction of MBS data forwarding	17.1.0
	RP-96	RP-221729	0485	-	F	Correction on RA-SDT overall procedures	17.1.0
	RP-96	RP-221717	0486	-	F	Corrections for NR NTN	17.1.0
	RP-96	RP-221733	0487	-	F	Correction on R17 SON MDT for 38.300	17.1.0
	RP-96	RP-221727	0488	-	F	Correction of the "last used cell" in UE Context Release Complete	17.1.0
	RP-96	RP-221754	0490	-	F	Correction on NR MBS mobility for 38300	17.1.0
	RP-96	RP-221733	0491	-	F	TS 38.300 corrections for CCO	17.1.0
	RP-96	RP-221754	0492	-	F	Corrections on MBS	17.1.0
2022-09	RP-97	RP-222524	0509	2	F	Rel-17 NTN related Rapporteur's corrections to TS 38.300	17.2.0
	RP-97	RP-222516	0515	1	A	NR Correction related to RNA	17.2.0
	RP-97	RP-222525	0519	1	F	Corrections on SDT	17.2.0
	RP-97	RP-222523	0524	-	F	Clarification on PUCCH cell switching for TDD cells	17.2.0
	RP-97	RP-222525	0535	2	F	Corrections on RedCap in TS 38.300	17.2.0
	RP-97	RP-222524	0543	2	F	Stage-2 corrections to Rel-17 QoE	17.2.0
	RP-97	RP-222522	0546	1	F	Miscellaneous Corrections	17.2.0
	RP-97	RP-222524	0547	1	F	38.300 corrections for sidelink enhancements	17.2.0
	RP-97	RP-222522	0548	-	F	Stage-2 corrections on MUSIM	17.2.0
	RP-97	RP-222525	0549	1	F	Corrections on TS 38.300 for RAN Slicing	17.2.0
	RP-97	RP-222524	0550	2	F	Correction on stage 2 for sidelink relay	17.2.0
	RP-97	RP-222525	0552	-	F	Corrections to UE power saving enhancements in TS 38.300	17.2.0
	RP-97	RP-222523	0553	-	F	Correction to Rel-17 SON features	17.2.0
	RP-97	RP-222523	0555	-	F	Correction of MBS stage 2	17.2.0

	RP-97	RP-222519	0557	-	A	CAG access control without mobility restrictions	17.2.0
	RP-97	RP-222523	0558	-	F	Completion of the missing descripition of SCG MRO handling	17.2.0
	RP-97	RP-222525	0559	-	F	Correction on Slice Group Configuration	17.2.0
	RP-97	RP-222526	0561	-	F	Support for flexible gNB ID length [gNB_ID_Length]	17.2.0
2022-12	RP-98	RP-223406	0564	2	F	Corrections on MBS	17.3.0
	RP-98	RP-223411	0572	4	F	Corrections to TS 38.300 for Rel-17 NR NTN	17.3.0
	RP-98	RP-223412	0583	2	F	Miscellaneous corrections on TS 38.300 for NR sidelink	17.3.0
	RP-98	RP-223411	0587	2	F	Miscellaneous RedCap corrections in stage-2	17.3.0
	RP-98	RP-223413	0595	1	F	Clarifications for SDT Stage-2	17.3.0
	RP-98	RP-223410	0596	1	F	Clarification on BFD-RS set based BFR	17.3.0
	RP-98	RP-223412	0598	1	F	Correction on SL relay	17.3.0
	RP-98	RP-223413	0599	1	D	Clarification on PDCCH skipping	17.3.0
	RP-98	RP-223404	0601	1	A	Clarification for ePWS	17.3.0
	RP-98	RP-223410	0602	-	F	CR to TS 38.300 on IAB-topology definition	17.3.0
	RP-98	RP-223412	0603	-	F	Correction on NSAG	17.3.0
	RP-98	RP-223412	0604	-	F	NSAG for cell reselection and random access	17.3.0
	RP-98	RP-223406	0605	-	F	Minimization of data loss and duplication avoidance during mobility from MBS non upporting gNB to supporting gNB	17.3.0
	RP-98	RP-223410	0607	-	F	Correction of UE History Information for CHO	17.3.0
	RP-98	RP-223410	0608	-	F	SHR correction	17.3.0
	RP-98	RP-223411	0609	1	F	CR to TS 38.300 on RAN visible QoE	17.3.0
	RP-98	RP-223412	0610	-	F	Clarification on slice group information provided by NAS	17.3.0
2023-03	RP-99	RP-230690	0611	1	F	Correction on Stage-2 descriptions for NR NTN	17.4.0
	RP-99	RP-230690	0613	2	F	MBS corrections for multicast configuration and service continuity	17.4.0
	RP-99	RP-230691	0614	-	F	Corrections to description of RAN Visible QoE Measurements	17.4.0
	RP-99	RP-230691	0619	2	F	Clarification of UE Behaviour upon Pause of QoE Reporting	17.4.0
	RP-99	RP-230689	0621	1	F	Removal of editor's note on sequence length 1151 for PRACH usage	17.4.0
	RP-99	RP-230692	0627	-	F	Correction to 38.300 on SRAP operation	17.4.0
	RP-99	RP-230688	0628	2	F	Correction on RRCReject handling for SDT	17.4.0
	RP-99	RP-230685	0639	1	A	Clarification on the PDCCH Ordered RACH for SCell in 38.300	17.4.0
	RP-99	RP-230692	0642	2	F	Miscellaneous corrections on TS 38.300 for NR sidelink	17.4.0
	RP-99	RP-230686	0644	-	A	Corrections on PSBCH Symbols number for NR sidelink	17.4.0
2023-06	RP-100	RP-231418	0647	5	F	NTN stage-2 correction	17.5.0
	RP-100	RP-231416	0656	2	F	Miscellaneous corrections for Stage 2 NR sidelink relay	17.5,0
	RP-100	RP-231415	0666	1	F	Clarification on the application of slice-based RACH configuration	17.5.0
	RP-100	RP-231414	0672	-	F	Miscellaneous Corrections	17.5.0
	RP-100	RP-231416	0673	2	F	Miscellaneous corrections on TS 38.300 for NR sidelink	17.5.0
	RP-100	RP-231415	0678	1	F	Corrections on eDRX and RRM measurement relaxation for RedCap	17.5.0
	RP-100	RP-231415	0684	2	F	Corrections to Security Issues for MO-SDT	17.5.0
	RP-100	RP-231413	0686	-	F	Correction of QoE stage-2 description	17.5.0
	RP-100	RP-231415	0687	1	F	Introduction of Hashed UE Identity Index Value for RRC_INATIVE with eDRX	17.5.0
	RP-100	RP-231415	0688	-	F	Correction to Security Issues for MO-SDT	17.5.0
2023-09	RP-101	RP-232570	0691	3	F	Correction on SDT	17.6.0
	RP-101	RP-232667	0697	1	F	Correction on gap requirement for inter-RAT LTE measurement	17.6.0
	RP-101	RP-232566	0701	1	A	Miscellaneous stage 2 corrections for sidelink	17.6.0
	RP-101	RP-232566	0705	-	A	Stage2 correction on UE Identities	17.6.0
	RP-101	RP-232570	0707	-	F	Correction on SDT Triggering	17.6.0
	RP-101	RP-232667	0708	1	F	RedCap specific SDT configuration	17.6.0
	RP-101	RP-232667	0709	-	F	Rapporteur Miscellaneous Stage 2 Corrections	17.6.0
	RP-101	RP-232570	0710	-	F	Correction on R17 MO SDT termination	17.6.0
2023-12	RP-102	RP-233890	0726	1	F	Miscellaneous Corrections	17.7.0
	RP-102	RP-233890	0735	1	F	Clarification for Mission Critical UEs	17.7.0
	RP-102	RP-233885	0738	1	A	Correction on NR SL Stage 2	17.7.0
	RP-102	RP-233888	0744	1	F	Correction on the SidelinkUEInformationNR message	17.7.0
	RP-102	RP-233889	0747	-	F	Correction of Paging with PEI	17.7.0
	RP-102	RP-233887	0749	-	F	Correction on SHR for intra-NR mobility	17.7.0
2023-12	RP-102	RP-233905	0680	5	B	Introduction of In-Device Co-existence (IDC) enhancements for NR	18.0.0
	RP-102	RP-233898	0685	5	B	Introducing support for Network-Controlled Repeaters to 38.300	18.0.0
	RP-102	RP-233900	0689	7	B	Introduction of Network Energy Savings	18.0.0
	RP-102	RP-233902	0711	2	B	Introduction of MT-SDT in Stage-2	18.0.0
	RP-102	RP-233956	0721	1	B	Introduction of support for BWP operation without restriction	18.0.0
	RP-102	RP-233901	0722	2	B	Introduction of sidelink positioning in 38300	18.0.0
	RP-102	RP-233912	0723	1	B	Introduction of R18 eNPN for TS 38.300	18.0.0
	RP-102	RP-233908	0724	1	B	Introduction of XR Enhancements	18.0.0
	RP-102	RP-233933	0727	2	B	Introduction of Mobile IAB	18.0.0
	RP-102	RP-233897	0728	1	B	Introduction of NR Sidelink Evolution	18.0.0
	RP-102	RP-233899	0729	1	B	Introduction of eRedCap in TS 38.300	18.0.0
	RP-102	RP-233911	0730	2	B	Introduction of Timing Resiliency and URLLC enhancements	18.0.0
	RP-102	RP-233913	0731	-	B	Introduction on UE preference for multi-Rx operation in UAI	18.0.0
	RP-102	RP-233907	0732	2	B	Introduction of eMBS in TS 38.300	18.0.0

	RP-102	RP-233895	0733	1	B	Introduction of Further NR coverage enhancements to 38.300	18.0.0
	RP-102	RP-233906	0734	1	B	Introduction of NTN enhancements	18.0.0
	RP-102	RP-233932	0736	1	B	Introduction of NR Support for Uncrewed Aerial Vehicles	18.0.0
	RP-102	RP-233916	0740	1	B	Introduction of NR ATG in TS 38.300	18.0.0
	RP-102	RP-233903	0741	1	B	Introduction of NR MUSIM enhancements in TS 38.300	18.0.0
	RP-102	RP-233896	0742	1	B	Introduction of MIMO evolution for Downlink and Uplink	18.0.0
	RP-102	RP-233882	0743	1	B	Introduction of maximum time duration to initiate CG-SDT in Stage-2 [CG-SDT-Enh]	18.0.0
	RP-102	RP-233882	0748	-	B	Support of oversize UL SDT Data Arrival [Large SDT Uplink Data]	18.0.0
	RP-102	RP-233902	0751	-	B	Introduction on MT-SDT	18.0.0
	RP-102	RP-233882	0753	-	B	Introduction of RedCap UE MBS Broadcast reception [RedcapMBS]	18.0.0
	RP-102	RP-233935	0754	-	B	Enhancement of RAN Slicing for NR	18.0.0
	RP-102	RP-233934	0756	-	B	AI/ML for NG-RAN	18.0.0
	RP-102	RP-233909	0757	-	B	Addition of SON features enhancement	18.0.0
	RP-102	RP-233936	0766	1	B	Introduction of NR support for dedicated spectrum less than 5MHz for FR1	18.0.0
	RP-102	RP-233910	0768	1	B	Introduction of R18 QoE enhancement in TS 38.300	18.0.0
	RP-102	RP-233894	0769	-	B	Introduction of Multi-carier enhancements	18.0.0
	RP-102	RP-233930	0770	-	B	Introduction of NR further mobility enhancements in TS 38.300	18.0.0
	RP-102	RP-233904	0771	3	B	Introduction of NR sidelink relay enhancements	18.0.0
2024-03	RP-103	RP-240655	0773	1	A	Correction in TS 38.300 to support Simultaneous PUSCH and PUCCH transmissions of same priority on different inter-band cells [SimultaneousPUSCH-PUCCH]	18.1.0
	RP-103	RP-240697	0777	1	F	Stage-2 CR for Rel-18 NR QoE enhancement	18.1.0
	RP-103	RP-240666	0780	1	F	Miscellaneous corrections on TS 38.300 for BWP operation without restriction	18.1.0
	RP-103	RP-240698	0782	-	F	Handover for Reduced Capability	18.1.0
	RP-103	RP-240705	0783	-	F	Misellaneous Corrections	18.1.0
	RP-103	RP-240702	0784	2	F	Miscellaneous XR corrections	18.1.0
	RP-103	RP-240700	0785	3	F	Introduction of NR sidelink relay enhancements	18.1.0
	RP-103	RP-240701	0789	2	F	Corrections to NR Support for Uncrewed Aerial Vehicles	18.1.0
	RP-103	RP-240676	0793	1	F	Correction on UAI for URLLC	18.1.0
	RP-103	RP-240699	0795	1	F	Miscellaneous Stage 2 Corrections for NR Sidelink Evolution	18.1.0
	RP-103	RP-240655	0797	-	A	Correction on service link types for GSO	18.1.0
	RP-103	RP-240688	0798	4	F	Corrections to TS 38.300 for MBS	18.1.0
	RP-103	RP-240670	0801	1	F	Corrections to TS 38.300 for R18 MUSIM	18.1.0
	RP-103	RP-240694	0806	-	A	RACH resources while SDT procedure is ongoing	18.1.0
	RP-103	RP-240703	0807	1	F	Resume indication in RRCRelease [SDT_ReleaseEnh]	18.1.0
	RP-103	RP-240662	0811	-	F	Clarification of cell DTX/DRX operation with TRP	18.1.0
	RP-103	RP-240695	0812	2	F	38.300 NR NTN Corrections	18.1.0
	RP-103	RP-240707	0813	2	B	Introduction of 2Rx XR UEs [2Rx_XR_Device]	18.1.0
	RP-103	RP-240701	0814	1	F	Correction on TS 38300 for UAV	18.1.0
	RP-103	RP-240659	0816	-	F	Resource handling for Alternative S-NSSAIs	18.1.0
	RP-103	RP-240676	0817	-	F	Correction of network timing synchronization status monitoring	18.1.0
	RP-103	RP-240694	0820	-	F	Add a new tigger condition for MT-SDT in TS38.300	18.1.0
	RP-103	RP-240698	0821	-	F	Correction of Redcap RAN Paging Request	18.1.0
	RP-103	RP-240695	0822	1	F	Correction of timer-based conditional handover for NR NTN	18.1.0
	RP-103	RP-240674	0823	-	F	Correction on MRO	18.1.0
	RP-103	RP-240673	0824	2	B	Introduction of new SPID value for 2RX XR UE [2Rx_XR_Device]	18.1.0
	RP-103	RP-240674	0825	-	F	Stage 2 correction for NR-U	18.1.0
	RP-103	RP-240674	0826	-	F	Corrections on stage 2 descriptions for SON	18.1.0
	RP-103	RP-240664	0827	-	F	Corrections on AI for RAN stage 2	18.1.0
	RP-103	RP-240702	0828	-	F	Transfer PDU Set Information during data forwarding for Xn handover	18.1.0
	RP-103	RP-240702	0829	-	F	Support of mixed PDUs handling in Non-Homogeneous deployment	18.1.0
	RP-103	RP-240702	0830	-	F	Correction on ECN marking for L4S and data forwarding	18.1.0
	RP-103	RP-240697	0831	1	F	Corrections on R18 QoE enhancements	18.1.0
	RP-103	RP-240689	0832	1	B	Correction to 38.300 for multi-cell scheduling	18.1.0
	RP-103	RP-240692	0833	-	F	Stage-2 Corrections to LTM	18.1.0
2024-06	RP-104	RP-241544	0799	4	B	RACH-less support generalization [RACH-lessHO]	18.2.0
	RP-104	RP-241563	0808	3	F	Clarification to Network-Controlled Repeaters Stage-2 description	18.2.0
	RP-104	RP-241544	0836	3	F	Correction on TRS for idle and inactive UEs	18.2.0
	RP-104	RP-241583	0837	1	D	Miscellaneous corrections on TS 38.300 for BWP operation without restriction	18.2.0
	RP-104	RP-241562	0838	3	F	Miscellaneous Rapporteur Stage 2 Corrections for NR Sidelink Evolution	18.2.0
	RP-104	RP-241550	0841	2	A	Clarification on the combination of HST and RRM measurement relaxation	18.2.0
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