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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.

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[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 23.041: "Technical realization of Cell Broadcast Service (CBS)".

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
A-CSI	Aperiodic CSI
AKA	Authentication and Key Agreement
AMBR	Aggregate Maximum Bit Rate
AMC	Adaptive Modulation and Coding
AMF	Access and Mobility Management Function
ARP	Allocation and Retention Priority
BA	Bandwidth Adaptation
BCH	Broadcast Channel
BH	Backhaul
BL	Bandwidth reduced Low complexity
BPSK	Binary Phase Shift Keying
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
CFRA	Contention Free Random Access
CHO	Conditional Handover
CIoT	Cellular Internet of Things
CLI	Cross Link interference
CMAS	Commercial Mobile Alert Service
CORESET	Control Resource Set
CP	Cyclic Prefix
CPC	Conditional PSCell Change
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
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
E-CID	Enhanced Cell-ID (positioning method)
EHC	Ethernet Header Compression
ePWS	enhancements of Public Warning System
ETWS	Earthquake and Tsunami Warning System
FS	Feature Set
GFBR	Guaranteed Flow Bit Rate
HRNN	Human-Readable Network Name
IAB	Integrated Access and Backhaul
I-RNTI	Inactive RNTI
INT-RNTI	Interruption RNTI
KPAS	Korean Public Alarm System
LDPC	Low Density Parity Check
MDBV	Maximum Data Burst Volume
MIB	Master Information Block

MICO	Mobile Initiated Connection Only
MFBR	Maximum Flow Bit Rate
MMTEL	Multimedia telephony
MNO	Mobile Network Operator
MPE	Maximum Permissible Exposure
MT	Mobile Termination
MU-MIMO	Multi User MIMO
Multi-RTT	Multi-Round Trip Time
NB-IoT	Narrow Band Internet of Things
NCGI	NR Cell Global Identifier
NCR	Neighbour Cell Relation
NCRT	Neighbour Cell Relation Table
NGAP	NG Application Protocol
NID	Network Identifier
NPN	Non-Public Network
NR	NR Radio Access
P-MPR	Power Management Maximum Power Reduction
P-RNTI	Paging RNTI
PCH	Paging Channel
PCI	Physical Cell Identifier
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PLMN	Public Land Mobile Network
PNI-NPN	Public Network Integrated NPN
PO	Paging Occasion
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PRG	Precoding Resource block Group
PS-RNTI	Power Saving RNTI
PSS	Primary Synchronisation Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
PWS	Public Warning System
QAM	Quadrature Amplitude Modulation
QFI	QoS Flow ID
QPSK	Quadrature Phase Shift Keying
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
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
SCS	SubCarrier Spacing
SD	Slice Differentiator
SDAP	Service Data Adaptation Protocol
SFI-RNTI	Slot Format Indication RNTI
SIB	System Information Block
SI-RNTI	System Information RNTI
SLA	Service Level Agreement
SMC	Security Mode Command
SMF	Session Management Function

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
SPS	Semi-Persistent Scheduling
SR	Scheduling Request
SRS	Sounding Reference Signal
SRVCC	Single Radio Voice Call Continuity
SS	Synchronization Signal
SSB	SS/PBCH block
SSS	Secondary Synchronisation Signal
SST	Slice/Service Type
SU-MIMO	Single User MIMO
SUL	Supplementary Uplink
TA	Timing Advance
TPC	Transmit Power Control
TRP	Transmit/Receive Point
UCI	Uplink Control Information
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
V2X	Vehicle-to-Everything
Xn-C	Xn-Control plane
Xn-U	Xn-User plane
XnAP	Xn Application Protocol

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].

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

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.

Conditional Handover (CHO): a handover 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.

Downstream: Direction toward child node or UE in IAB-topology.

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

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

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.

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).

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.

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.

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

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.

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], between two or more nearby UEs, using NR technology but not traversing any network node.

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.

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

PLMN Cell: a cell of the PLMN.

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.

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.

Upstream: Direction toward parent node in IAB-topology.

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.

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.

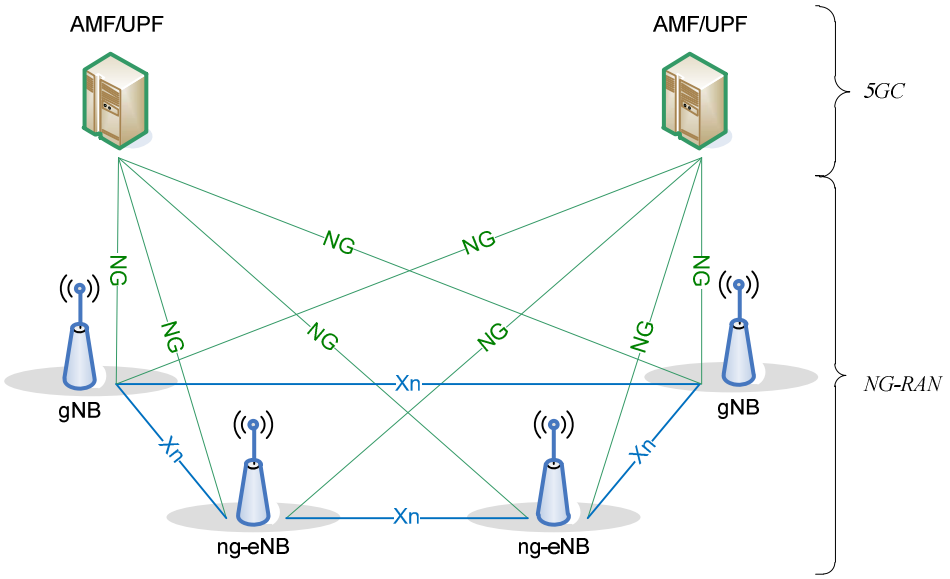


Figure 4.1-1: Overall Architecture

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, 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.

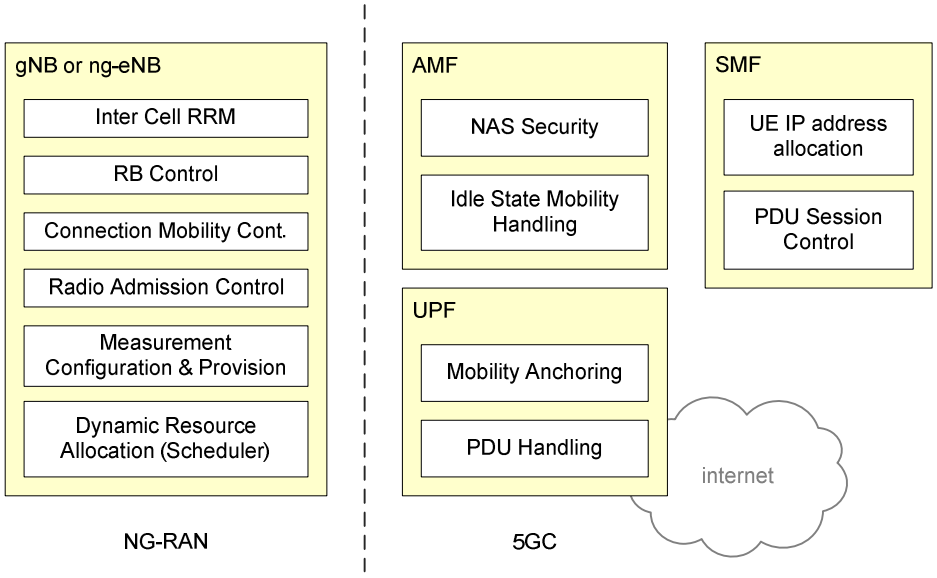


Figure 4.2-1: Functional Split between NG-RAN and 5GC

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.

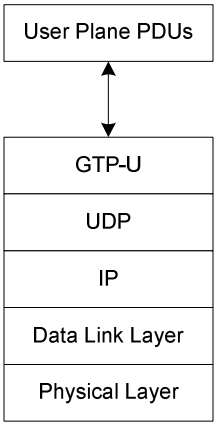


Figure 4.3.1.1-1: NG-U Protocol Stack

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. 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.

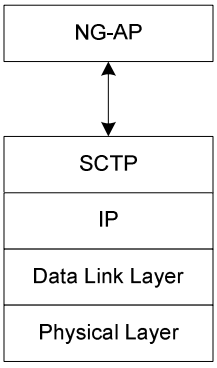


Figure 4.3.1.2-1: NG-C Protocol Stack

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.

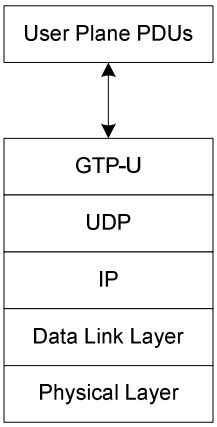


Figure 4.3.2.1-1: Xn-U Protocol Stack

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.

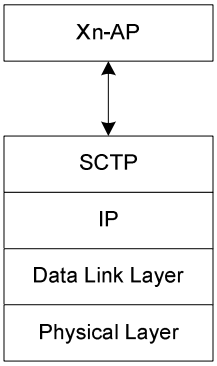


Figure 4.3.2.2-1: Xn-C Protocol Stack

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.

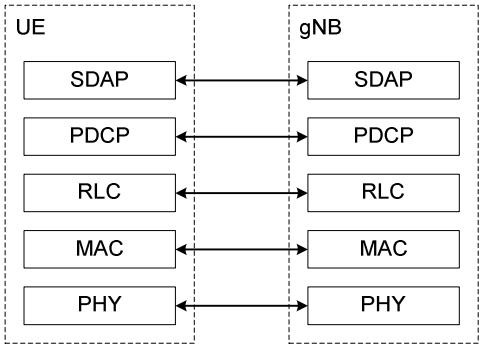


Figure 4.4.1-1: User Plane Protocol Stack

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…

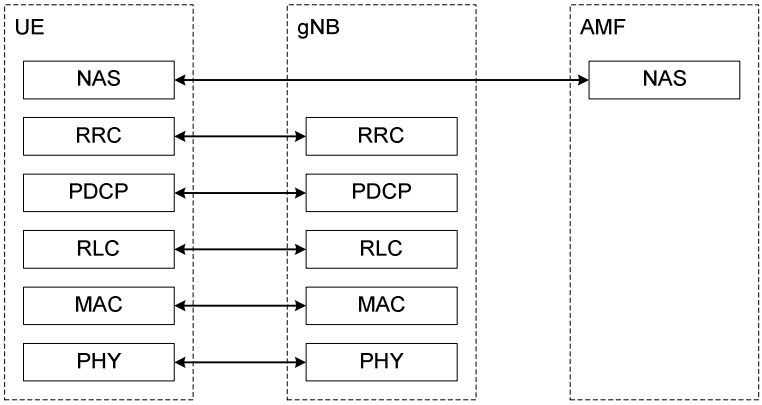


Figure 4.4.2-1: Control Plane Protocol Stack

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 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 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]).

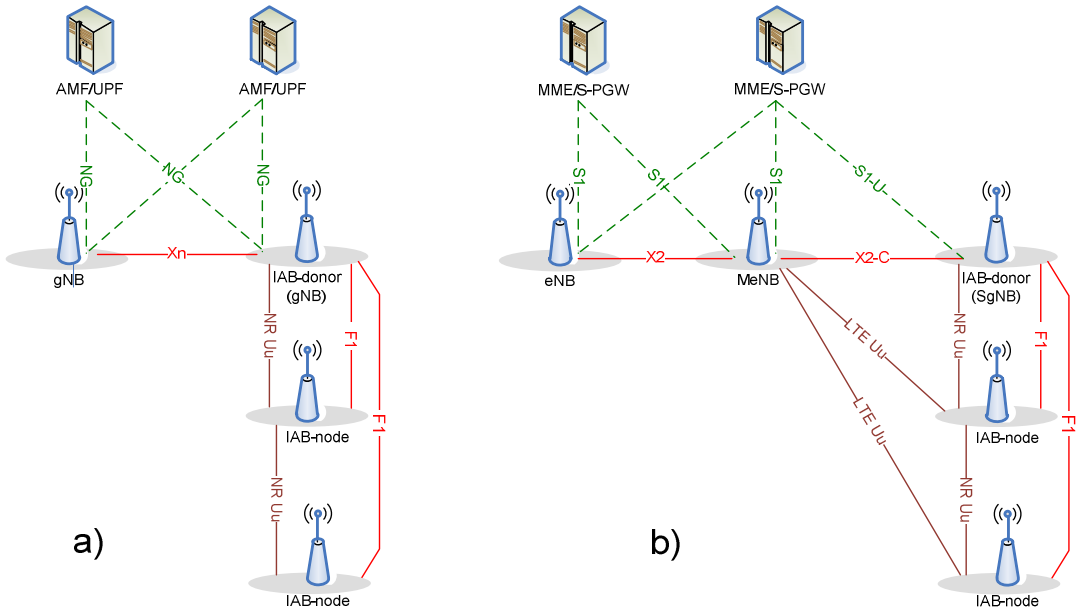


Figure 4.7.1-1: IAB architecture; a) IAB-node using SA mode with 5GC; b) IAB-node using EN-DC

All IAB-nodes that are connected to an IAB-donor via one or multiple hops form a directed acyclic graph (DAG) topology with the IAB-donor as its root (Fig. 4.7.1-2). In this DAG topology, the neighbour node of the IAB-DU or the IAB-donor-DU is referred to as *child* node and the neighbour node of the IAB-MT is referred to as *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 the IAB topology.

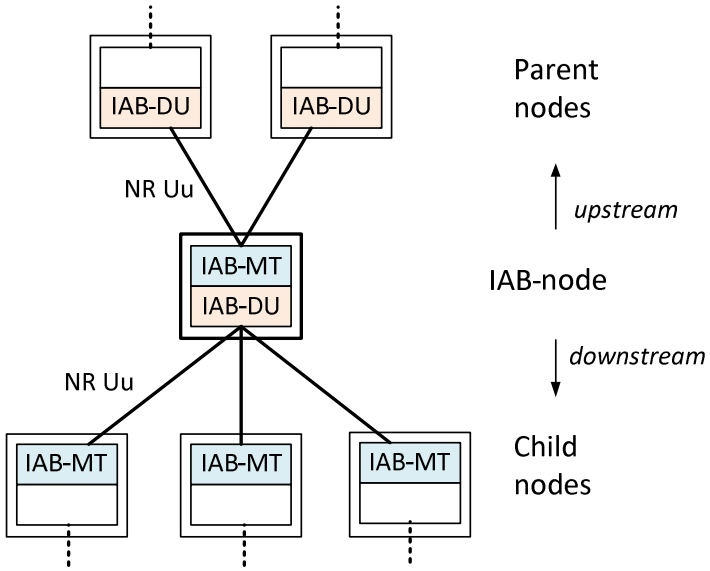


Figure 4.7.1-2: Parent- and child-node relationship for IAB-node

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].

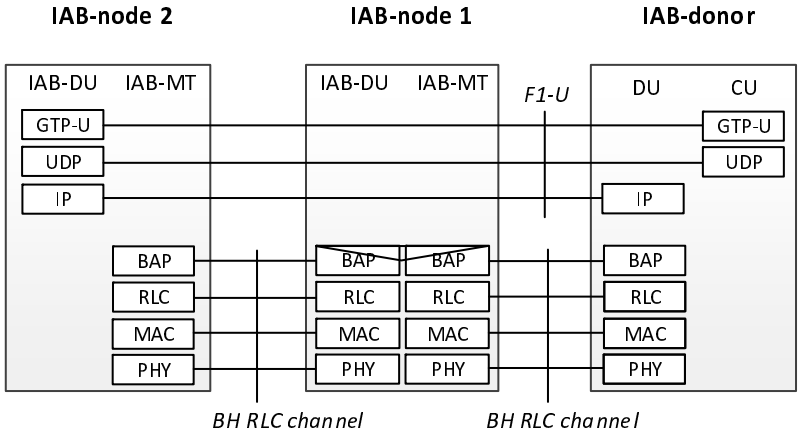


Fig. 4.7.2-1: Protocol stack for the support of F1-U protocol

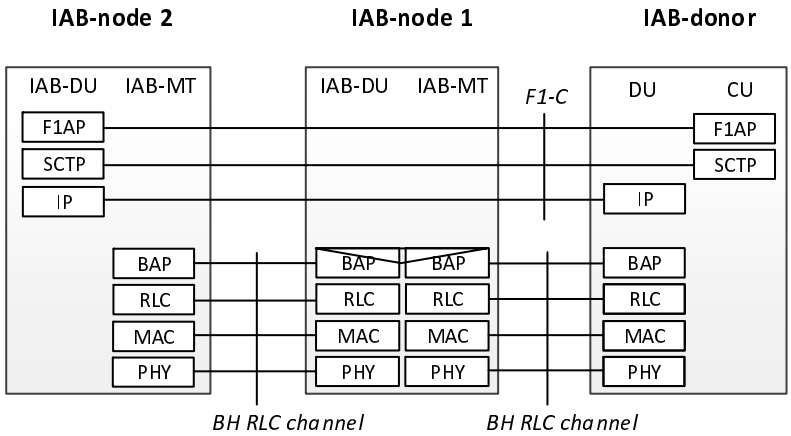


Fig. 4.7.2-2: Protocol stack for the support of F1-C protocol

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.

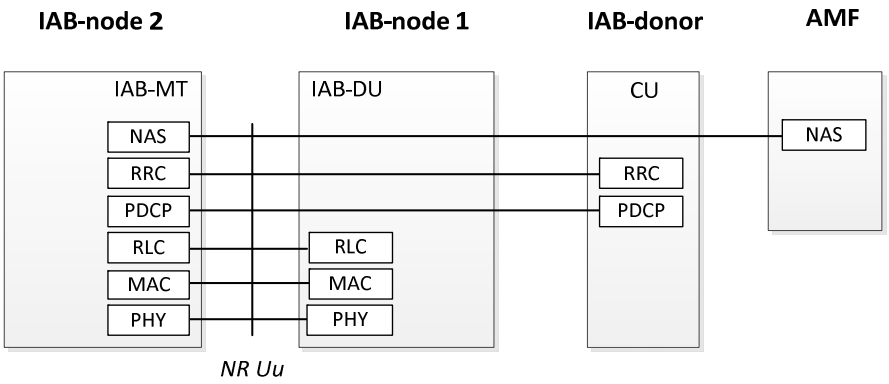


Figure 4.7.2-3: Protocol stack for the support of IAB-MT's RRC and NAS connections

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 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.

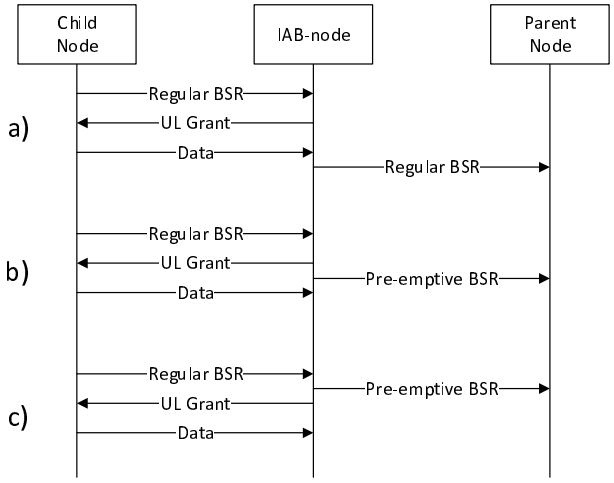


Figure 4.7.3.3-1: Scheduling of BSR in IAB:
a) regular BSR based on buffered data,
b) Pre-emptive BSR based on UL grant,
c) Pre-emptive BSR based on reception of regular BSR

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-node migration procedure is captured in TS 38.401 [4].

4.7.4.3 Topological Redundancy

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

For IAB-nodes operating in SA-mode, NR DC is 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 have to be connected to the same IAB-donor-CU, which controls the establishment and release of redundant routes via these two parent nodes. The parent nodes' gNB-DU functionality together with the IAB-donor-CU obtains 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].

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 MeNB and IAB-donor.

The procedure for establishment of redundant transport of F1-C for IAB-nodes using EN-DC is captured in 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 migrate to another parent node. The BH RLF recovery procedure to a parent node underneath the same IAB-donor-CU is captured in TS 38.401 [4]. BH RLF declaration for IAB is handled in clause 9.2.7.

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 signalled 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 neighboring IAB-nodes. The configuration is not expected to create a conflict between IAB-DU SSB transmission and IAB-MT SSB measurement windows.

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.

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, the uplink transmission waveform subcarrier mapping can map to subcarriers in one or more PRB interlaces.

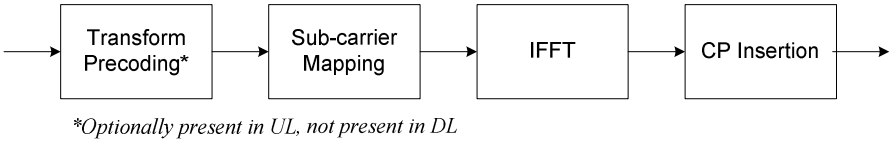


Figure 5.1-1: Transmitter block diagram for CP-OFDM with optional DFT-spreading

The numerology is based on exponentially scalable sub-carrier spacing $\Delta f = 2^{\mu} \times 15$ kHz with μ={0,1,3,4} for PSS, SSS and PBCH and μ={0,1,2,3} 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

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.

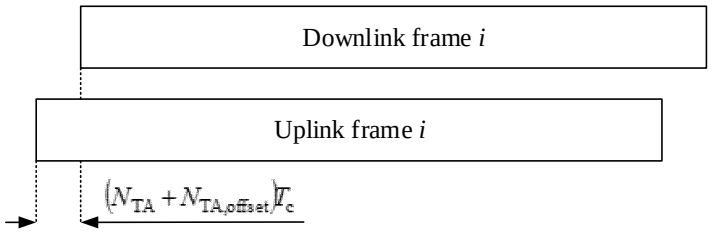


Figure 5.1-2: Uplink-downlink timing relation

Operation on both paired and unpaired spectrum is supported.

5.2 Downlink

5.2.1 Downlink transmission scheme

A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and 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 and 256QAM;
- 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.

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. 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.

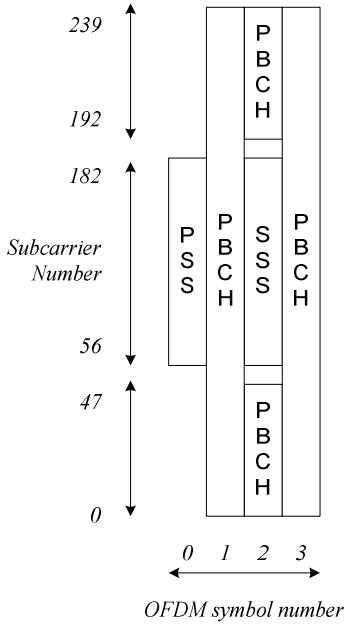


Figure 5.2.4-1: Time-frequency structure of SSB

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 all configured CCs and HARQ processes in the PUCCH group.

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.

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, and UE Rx-Tx time difference respectively 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.

A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. 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) is 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. Long PUCCH formats can be repeated over multiple slots.

For operation with shared spectrum channel access, 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.

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).

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):

- 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.

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 and 120 kHz, and sequence lengths of 571 and 1151 are applied with subcarrier spacings of 30 kHz and 15 kHz respectively. 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. Sequence lengths of 571 and 1151 can be used only for operation with shared spectrum channel access.

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 determines the desired Timing Advance setting and provides that to the UE. The UE uses the provided TA to determine its uplink transmit timing relative to the UE's observed downlink receive timing.

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.

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-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].

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 dynamically switched from one uplink carrier to another uplink carrier for enabling 2Tx UL transmission on that carrier.

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.

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:

- 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

Two sidelink resource allocation modes are supported: mode 1 and mode 2. In mode 1, the sidelink resource allocation is provided by the network. In mode 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.

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).

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;
- *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.

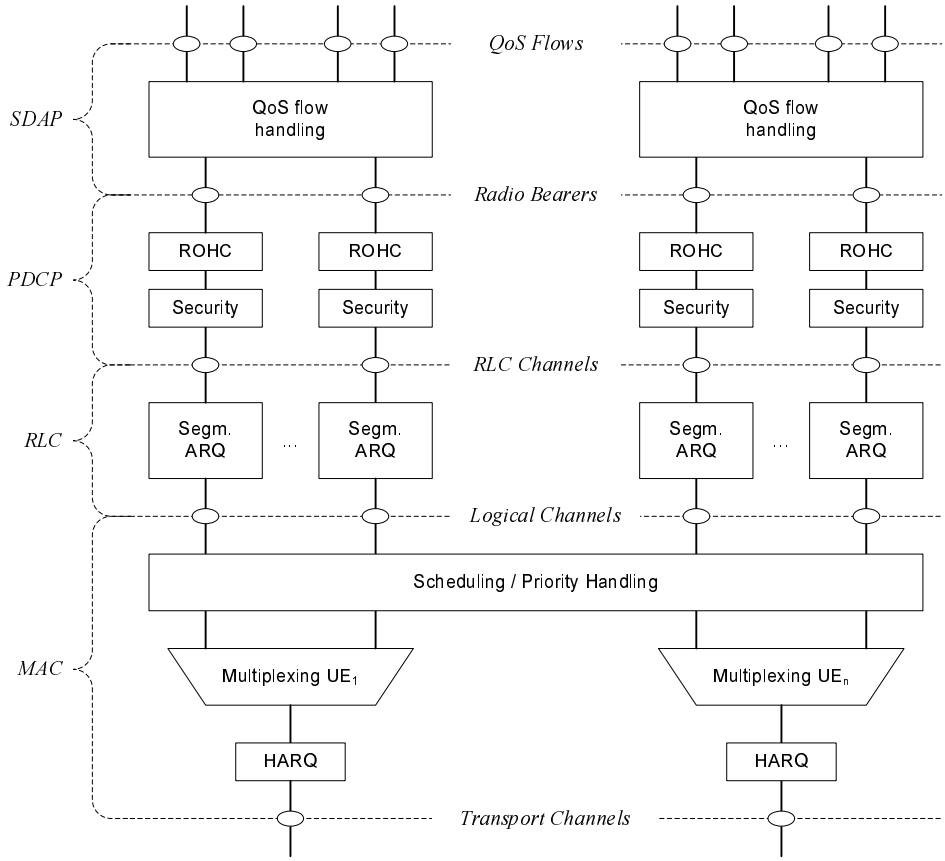


Figure 6.1-1: Downlink Layer 2 Structure

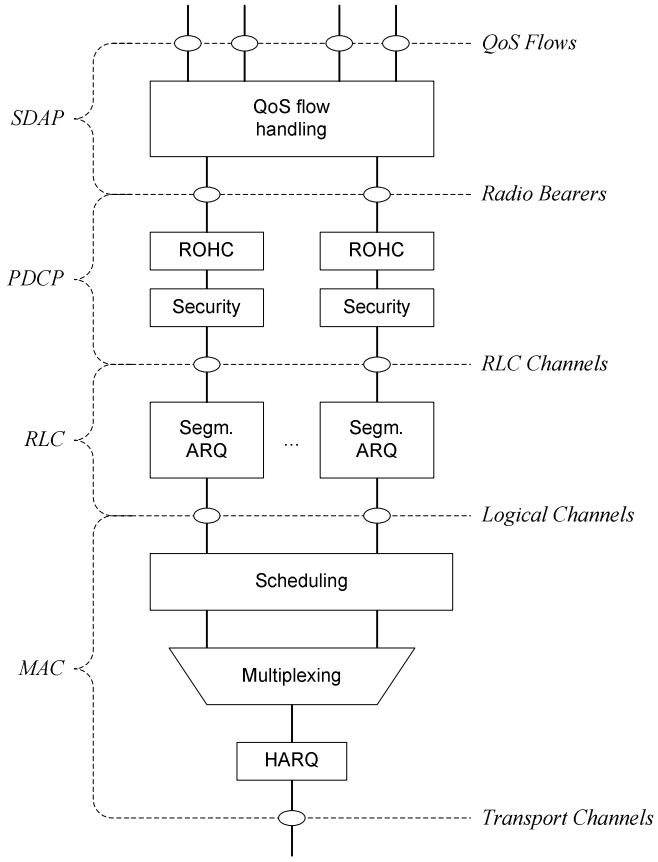


Figure 6.1-2: Uplink Layer 2 Structure

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. Figure 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.

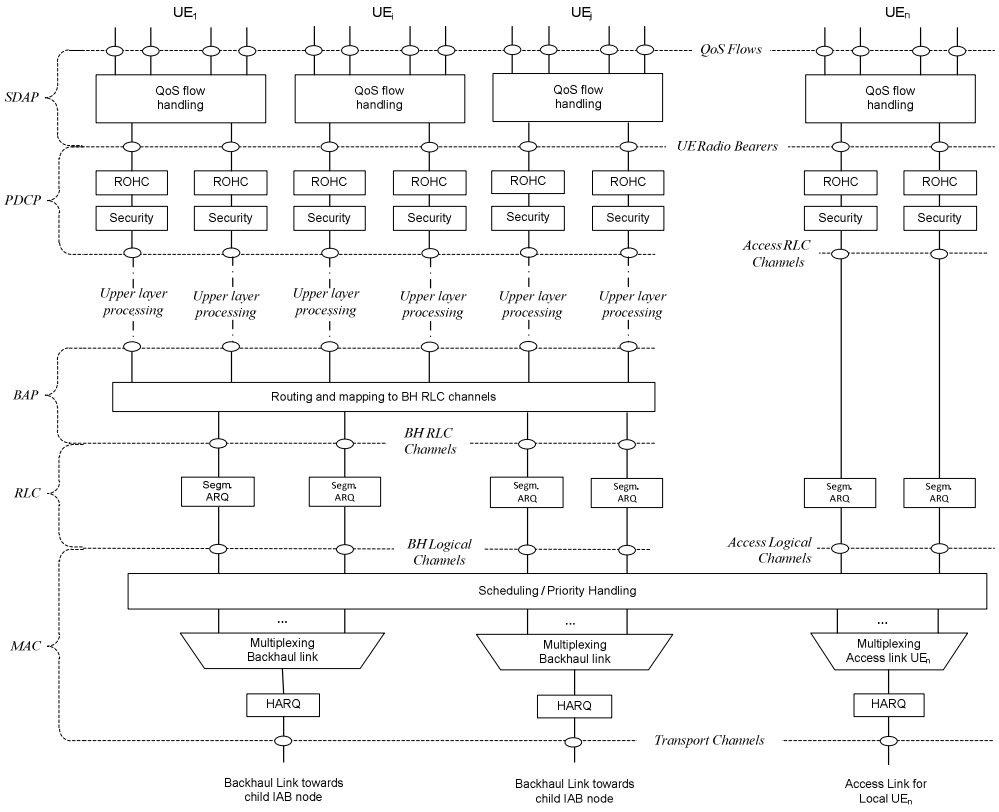


Figure 6.1-3: DL L2-structure for user plane at IAB-donor

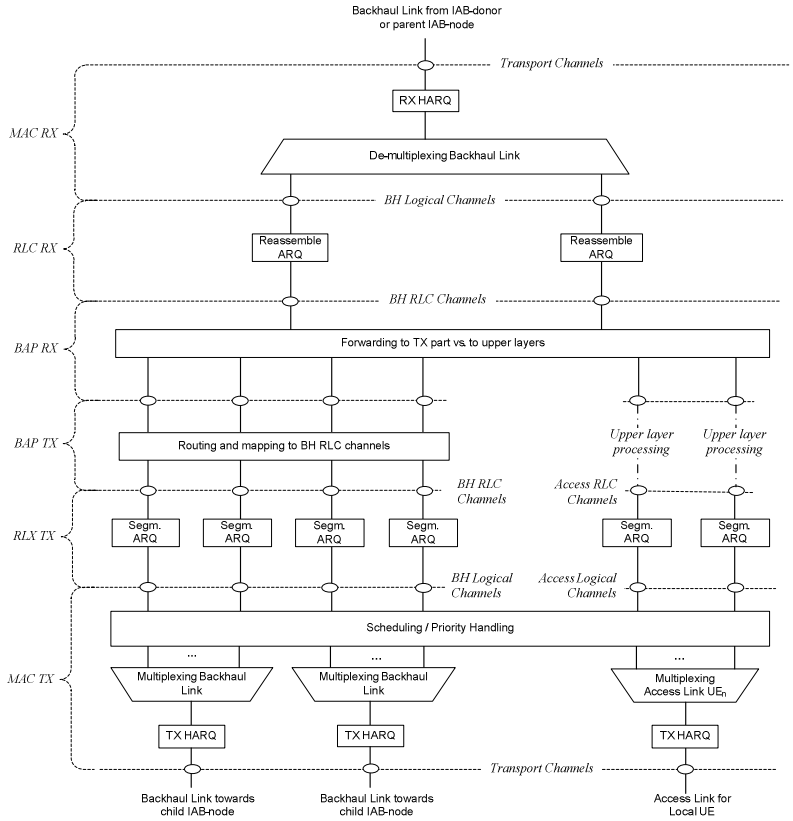


Figure 6.1-4: DL L2-structure at IAB-node

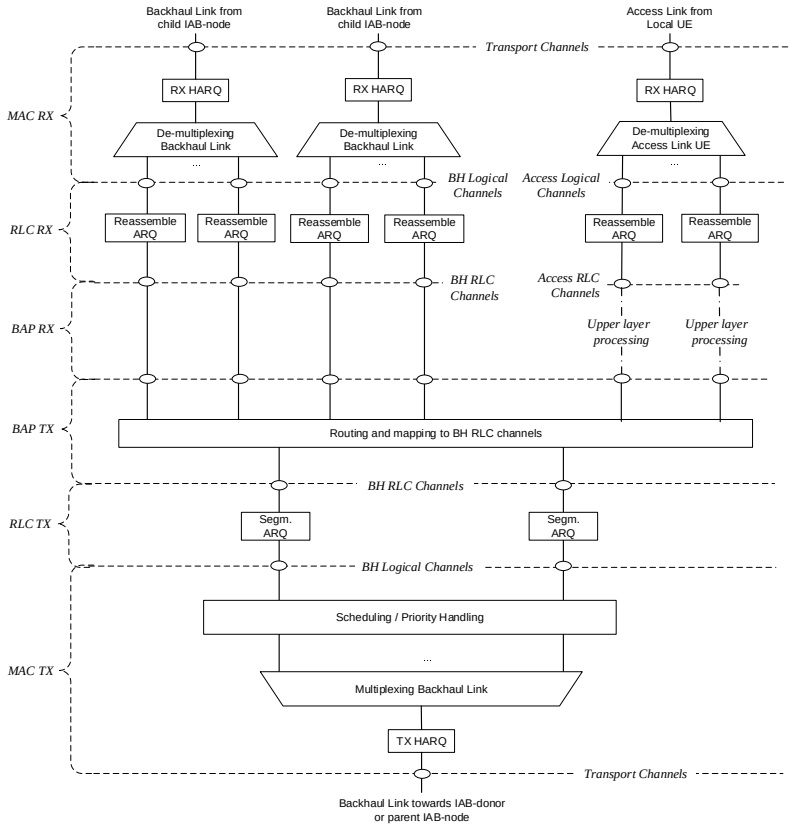


Figure 6.1-5: UL L2-structure at IAB-node

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;
- 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;
- 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.

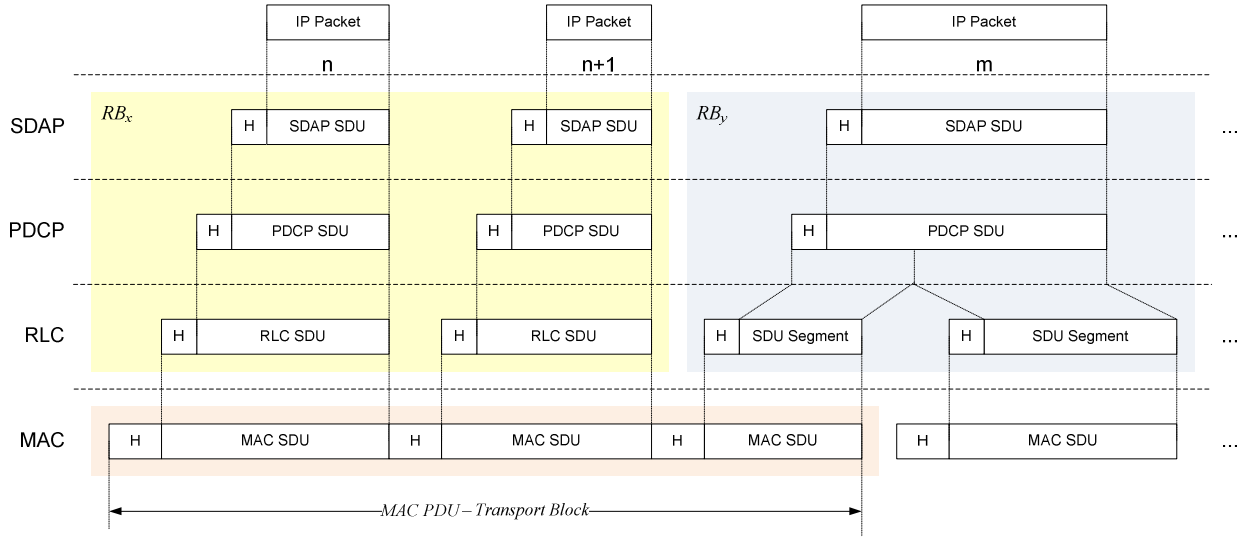


Figure 6.6-1: Data Flow Example

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.

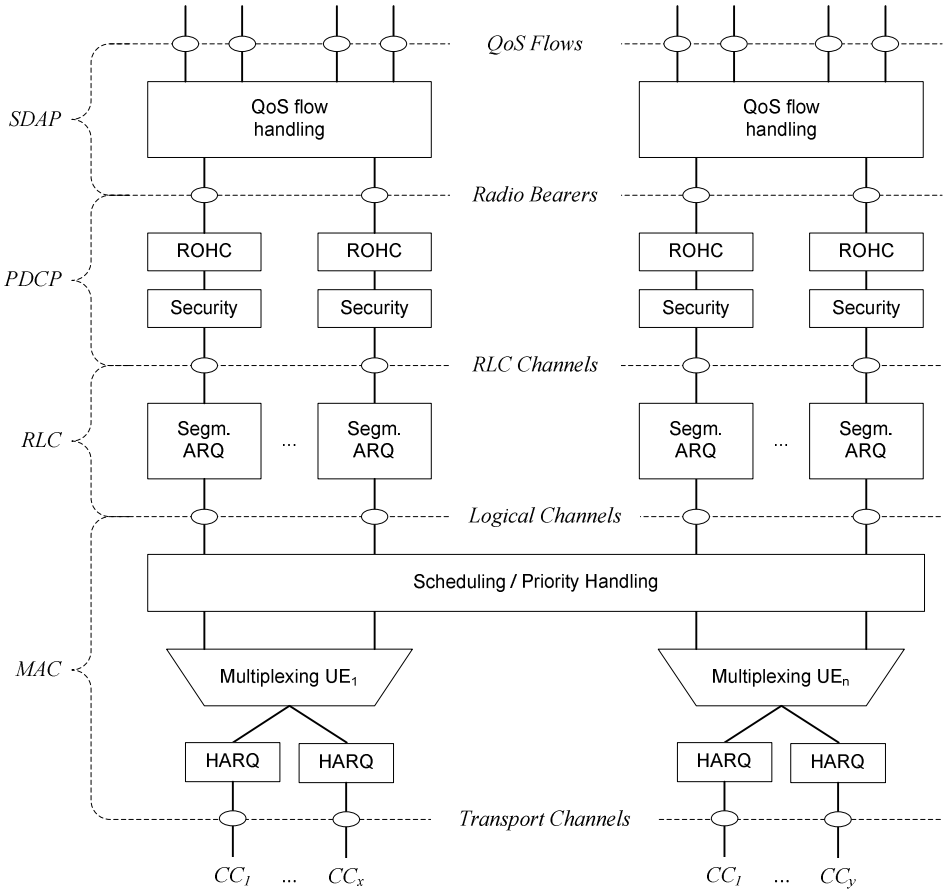


Figure 6.7-1: Layer 2 Structure for DL with CA configured

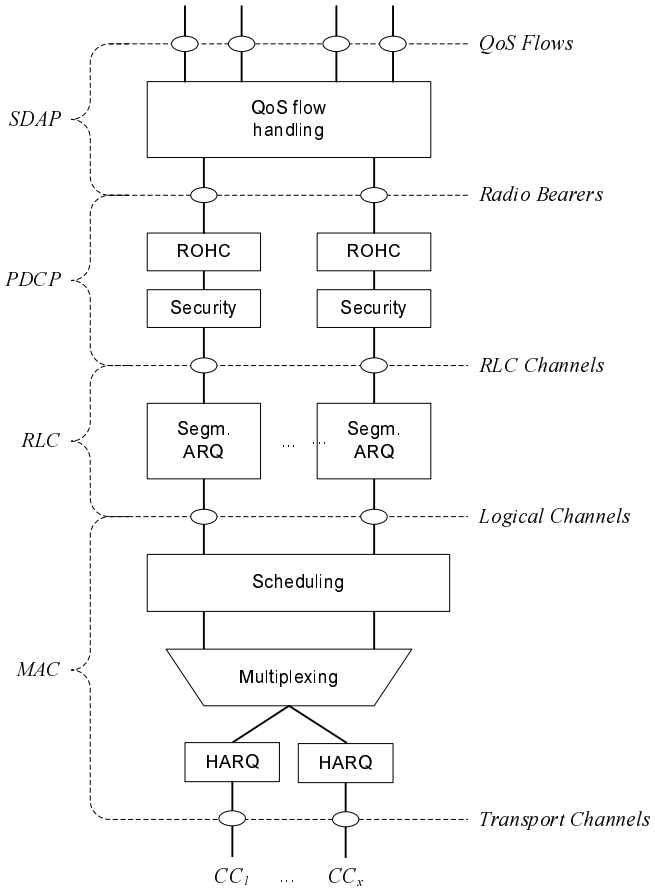


Figure 6.7-2: Layer 2 Structure for UL with CA configured

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.

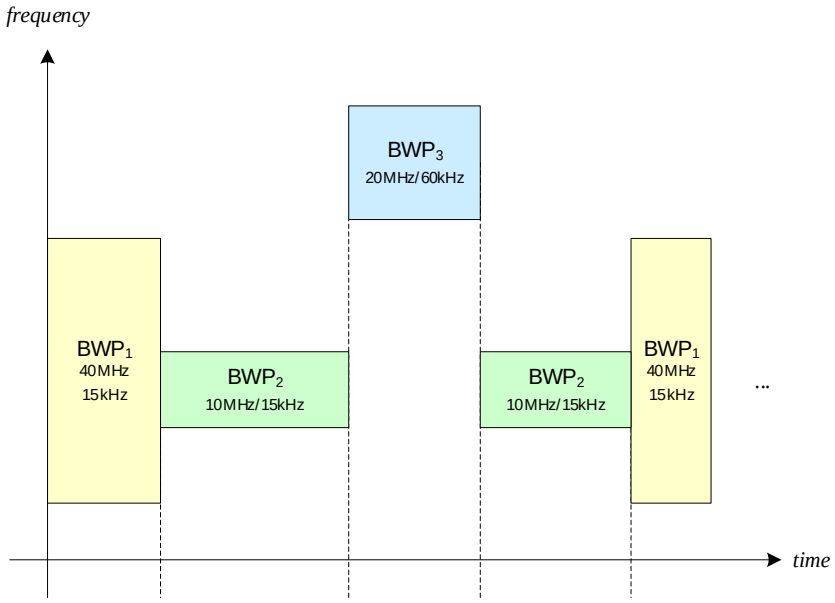


Figure 6.10-1: BA Example

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 indication.

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. 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 and BH-RLC-channel mapping on BAP sublayer

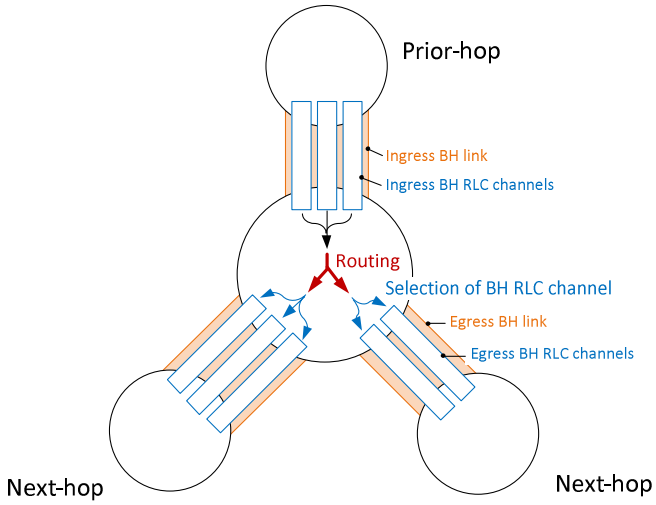


Figure 6.11.3-1: Routing and BH RLC channel selection on BAP sublayer

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.

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 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.

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 has

RLF, the IAB-node may select another BH link based on routing entries with the same destination BAP address, i.e., by disregarding the BAP path ID. In this manner, a packet can be delivered via an alternative path in case the indicated path is not available.

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 link	Derived from packet's ingress BH RLC channel	BH RLC channel on egress link to forward packet

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

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

There are two different operation modes for multi-TRP: 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, UE is scheduled by the same DCI for both TRPs and in multi-DCI mode, UE is scheduled by independent DCIs from each TRP.

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;
  - 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.
- **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;
  - 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 is periodically broadcast on DL-SCH or sent in a dedicated manner on DL-SCH to UEs in RRC_CONNECTED.
- **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). 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;
  - *SIBpos* contains positioning assistance data as defined in TS 37.355 [43] and TS 38.331 [12].

For sidelink, Other SI also includes:

- *SIB12* contains information related to NR sidelink communication;
- *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].

Figure 7.3-1 below summarises System Information provisioning.

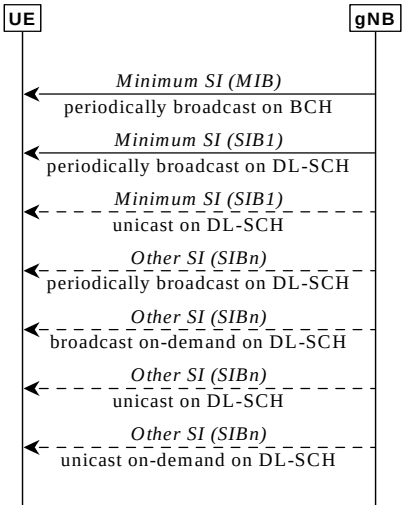


Figure 7.3-1: System Information Provisioning

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.

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, 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_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.

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;
- The list of frequencies affected by IDC problems (see clause 23.4 of TS 36.300 [2]).

NOTE: Only the Frequency Division Multiplexing (FDM) solution as defined for E-UTRA in clause 23.4 of TS 36.300 [2] is used in NR. 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.

In this version of the specification, segmentation applies only to the *UECapabilityInformation*, *RRCReconfiguration*, and *RRCResume* messages.

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;
- 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 identities are used at NG-RAN level:

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

For UE power saving purpose during DRX, the following identity is used:

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

For IAB the following identity is used:

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

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.

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 Identifier (NID): identifies an SNPN in combination with a PLMN ID.
- Closed Access Group Identifier: identifies a CAG within a PLMN.

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 and V2X sidelink communication related identities

The following identities are used for NR sidelink communication:

- Source Layer-2 ID: Identifies the sender of the data in NR sidelink communication. 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 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. For NR sidelink communication, 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 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].

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 and the cell is not part of a tracking area which is in the list of "forbidden tracking areas for roaming";
  - 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 applies the cell selection procedure as described for the UE with the following differences:
  - The IAB-MT ignores 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.

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;
  - An NCL can be provided by the serving cell to handle specific cases for intra- and inter-frequency neighbouring cells;
  - Black lists can be provided to prevent the UE from reselecting to specific intra- and inter-frequency neighbouring cells;
  - White 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.

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]):

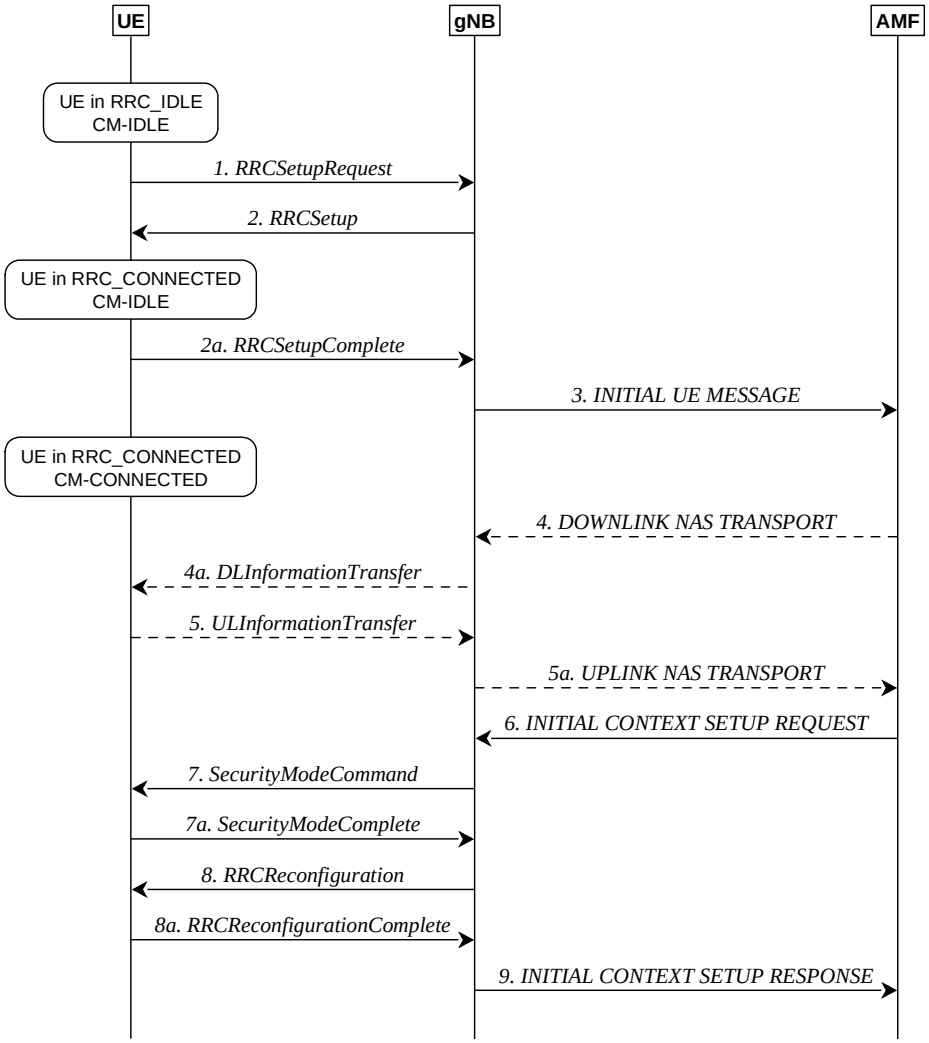


Figure 9.2.1.3-1: UE triggered transition from RRC_IDLE to RRC_CONNECTED

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

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

NOTE: 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:

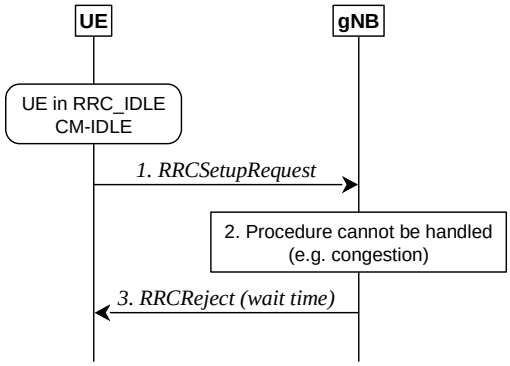


Figure 9.2.1.3-2: Rejection of UE triggered transition from RRC_IDLE

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.

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 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 registration area configured for the UE, the Periodic Registration Update timer, and the UE Identity Index value, and may include the UE specific DRX, an indication if the UE is configured with Mobile Initiated Connection Only (MICO) mode by the AMF, the Expected UE Behaviour, and the UE Radio Capability for Paging. The UE registration area is taken into account by the NG-RAN node when configuring the RNA. The UE specific DRX and UE Identity Index value are used by the NG-RAN node for RAN paging. The Periodic Registration Update timer is taken into account by the NG-RAN node to configure Periodic RNA Update timer. The NG-RAN node takes into account the Expected UE Behaviour to assist the UE RRC state transition decision. The NG-RAN node may use the UE Radio Capability for Paging during RAN Paging.

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:

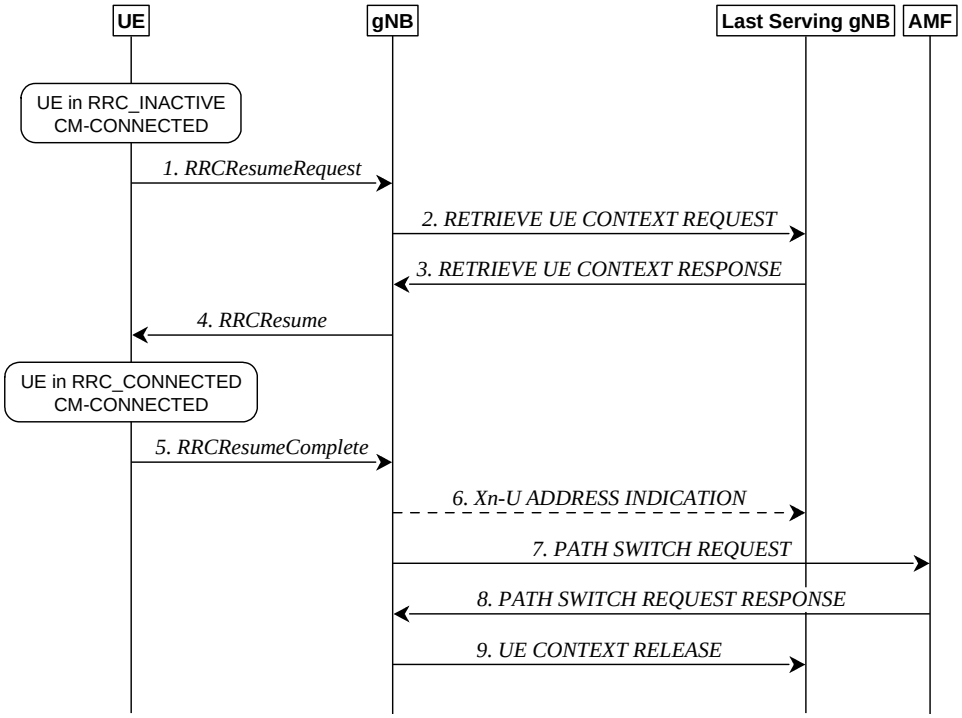


Figure 9.2.2.4.1-1: UE triggered transition from RRC_INACTIVE to RRC_CONNECTED (UE context retrieval success)

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: 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: 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:

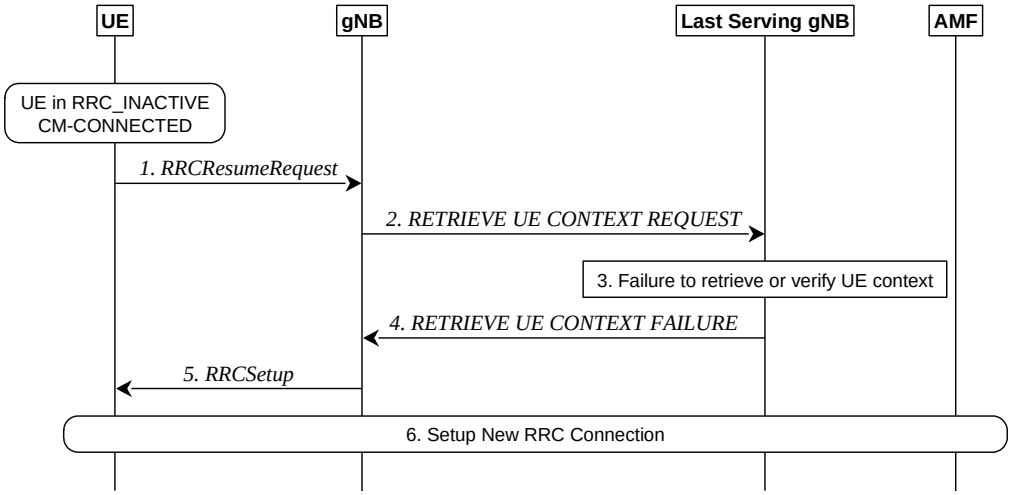


Figure 9.2.2.4.1-2: UE triggered transition from RRC_INACTIVE to RRC_CONNECTED (UE context retrieval failure)

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:

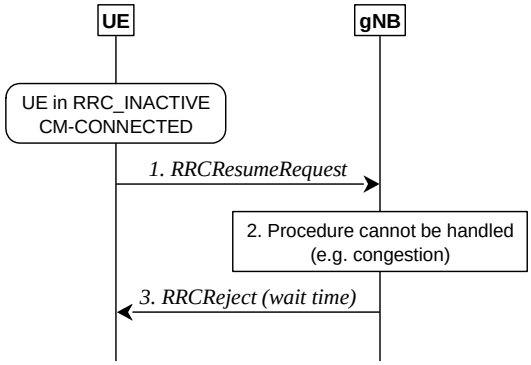


Figure 9.2.2.4.1-3: Reject from the network, UE attempts to resume a connection

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:

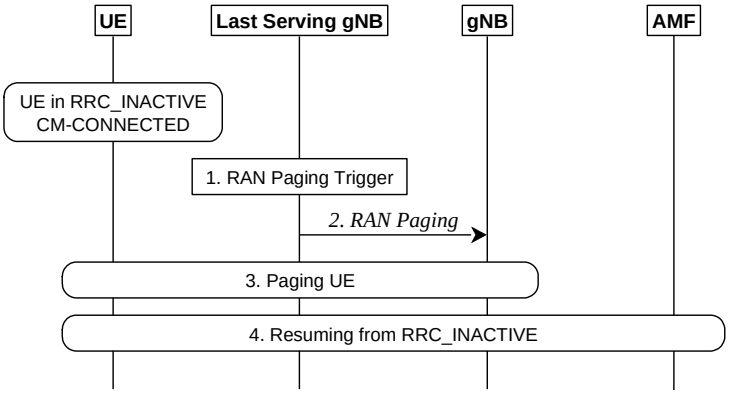


Figure 9.2.2.4.2-1: Network triggered transition from RRC_INACTIVE to RRC_CONNECTED

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.

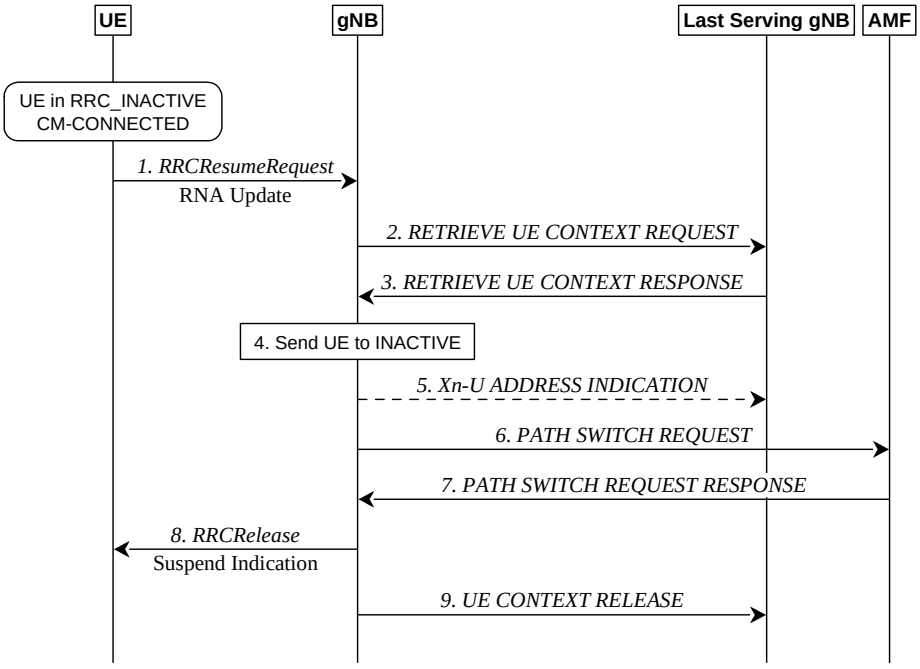


Figure 9.2.2.5-1: RNA update procedure with UE context relocation

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:

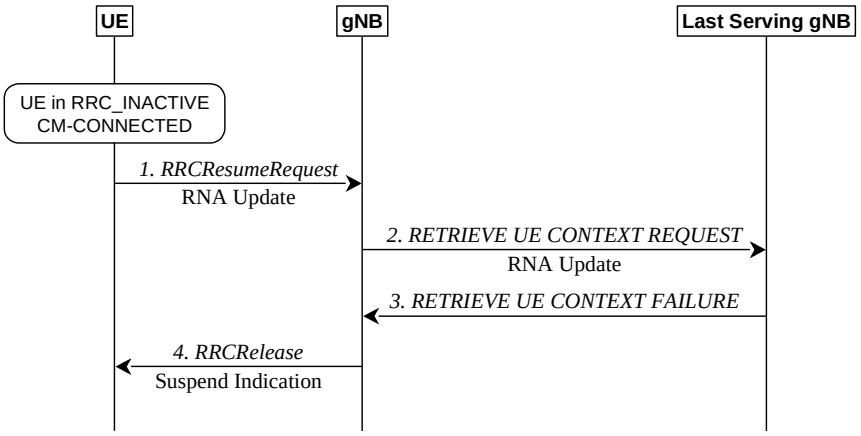


Figure 9.2.2.5-2: Periodic RNA update procedure without UE context relocation

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:

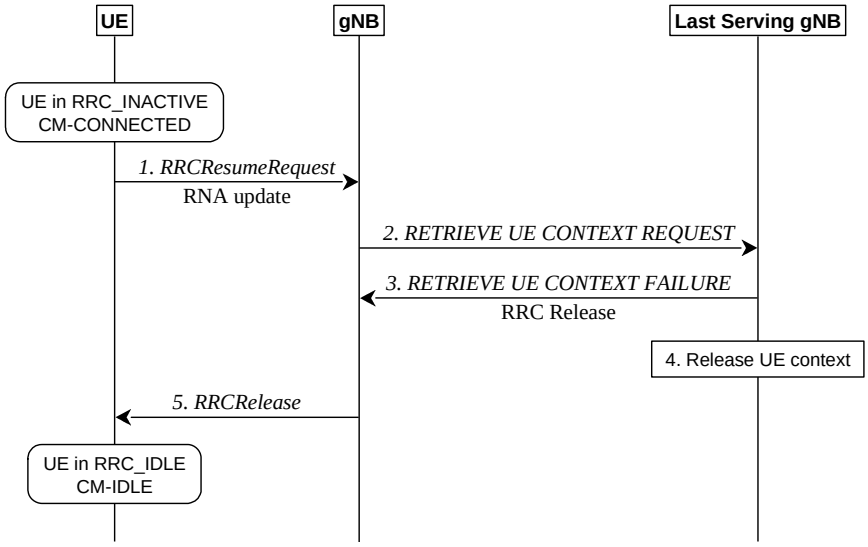


Figure 9.2.2.5-3: RNA update procedure with transition to RRC_IDLE

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.

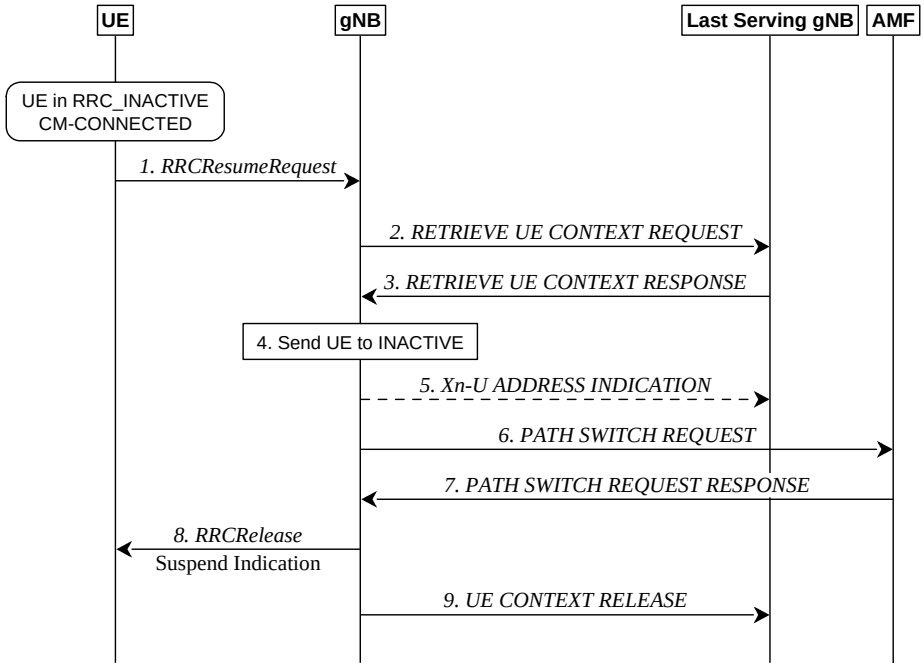


Figure 9.2.2.6-1: Resume request responded with Release with Redirect, with UE Context relocation

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.

NOTE1: 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.

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:

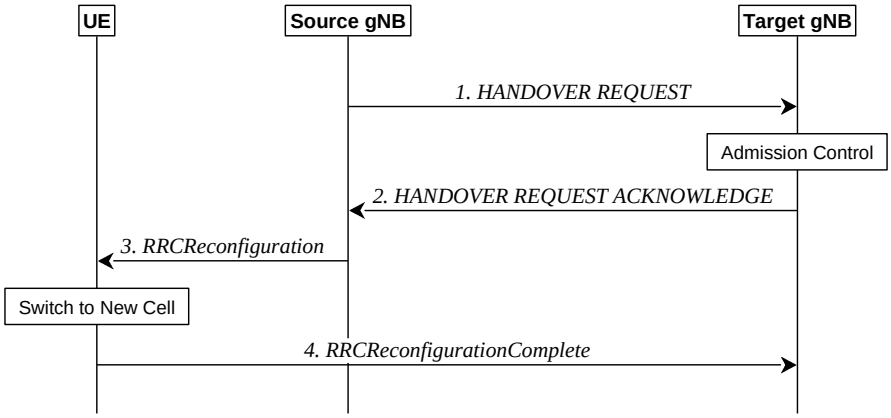


Figure 9.2.3.1-1: Inter-gNB handover procedures

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, 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.

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 or DAPS handover 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.

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 topology adaptation procedure 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].

Beam Level Mobility does not require explicit RRC signalling to be triggered. 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. 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 SSB associated to the initial DL BWP and can only be configured for the initial DL BWPs and for DL BWPs containing the SSB associated to the initial DL BWP. For other DL BWPs, Beam Level Mobility can only be performed based on CSI-RS.

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:

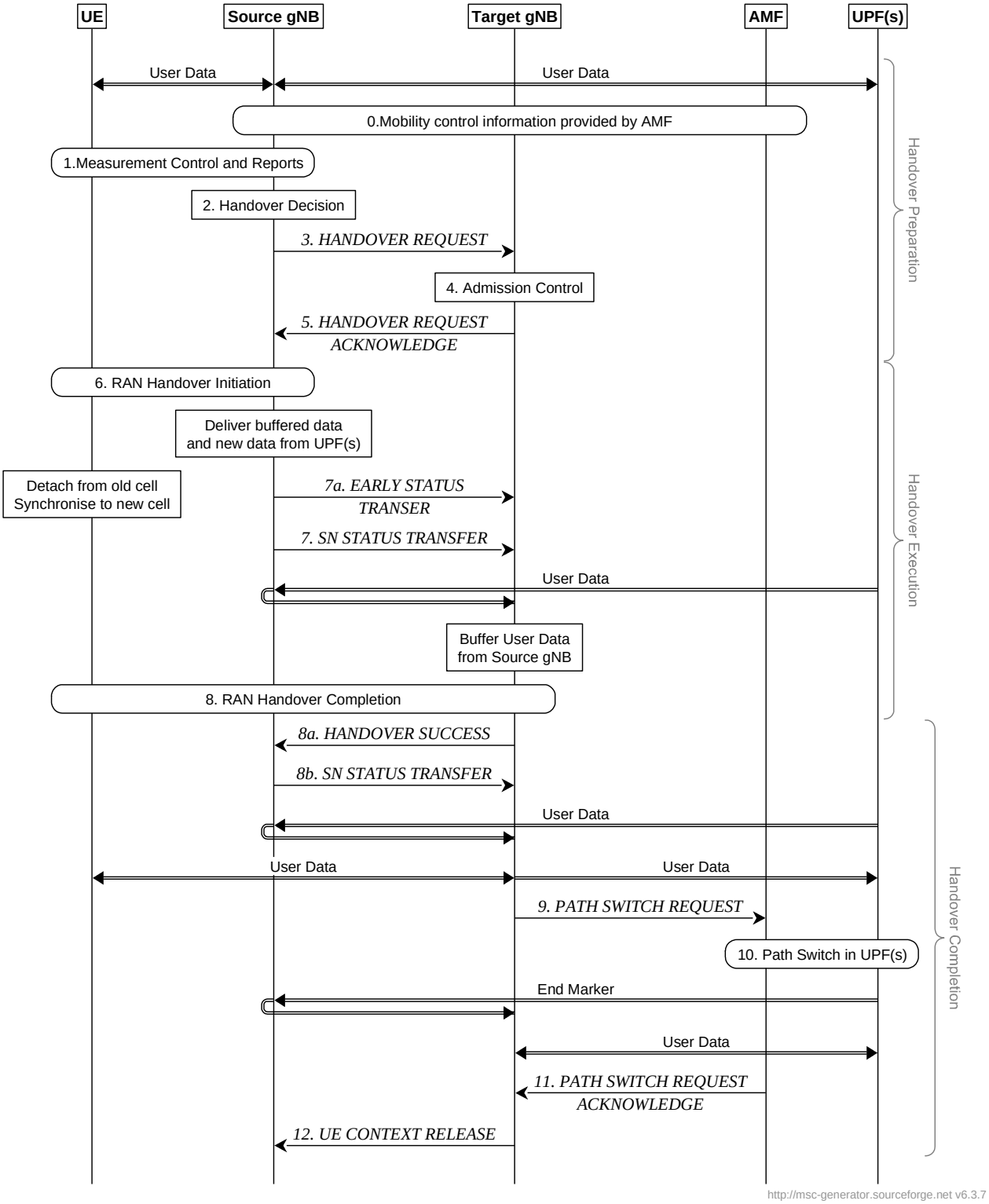


Figure 9.2.3.2.1-1: Intra-AMF/UPF Handover

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.

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 behaviors 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:

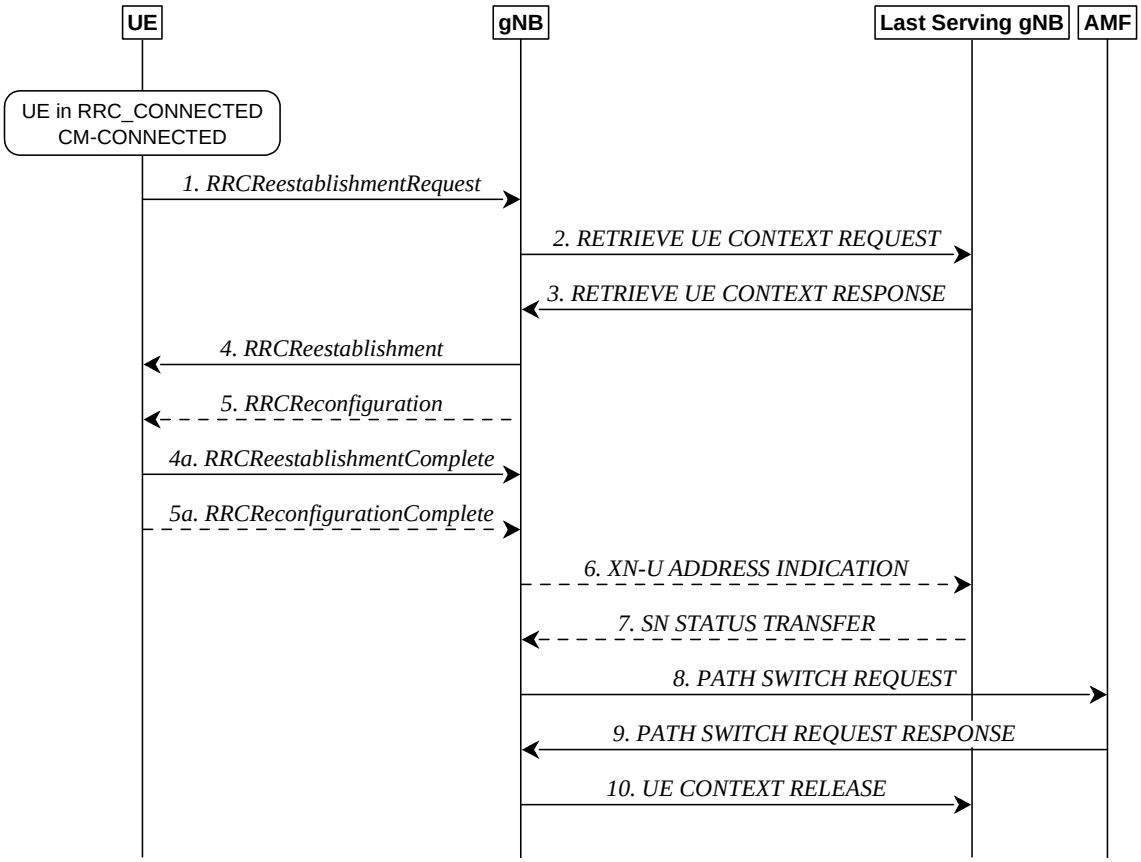


Figure 9.2.3.3-1: Re-establishment procedure

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), the UE executes the HO procedure as described in clause 9.2.3.2, 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 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:

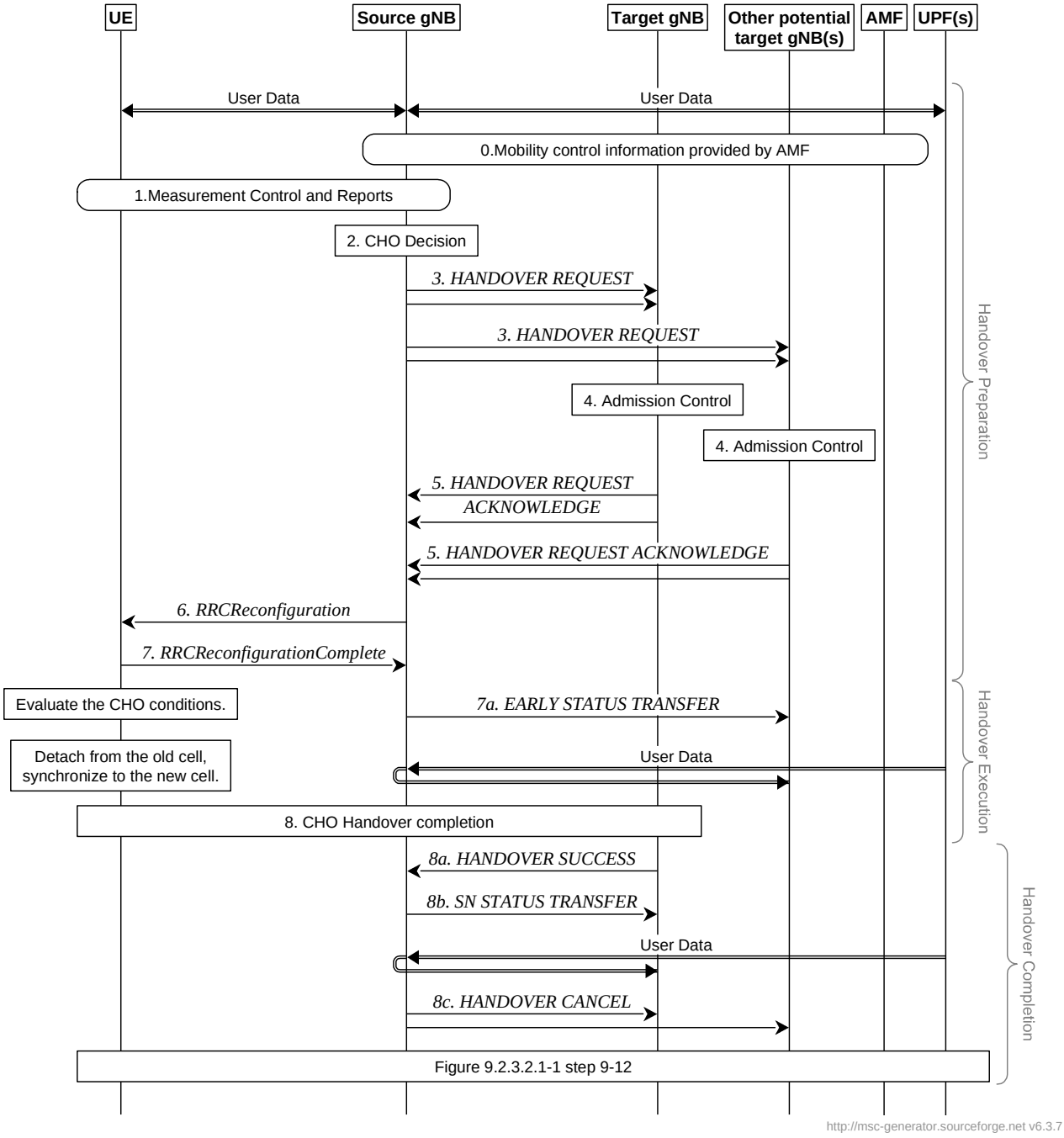


Figure 9.2.3.4.2-1: Intra-AMF/UPF Conditional Handover

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 other 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.

9.2.4 Measurements

In RRC_CONNECTED, 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.

The corresponding high-level measurement model is described below:

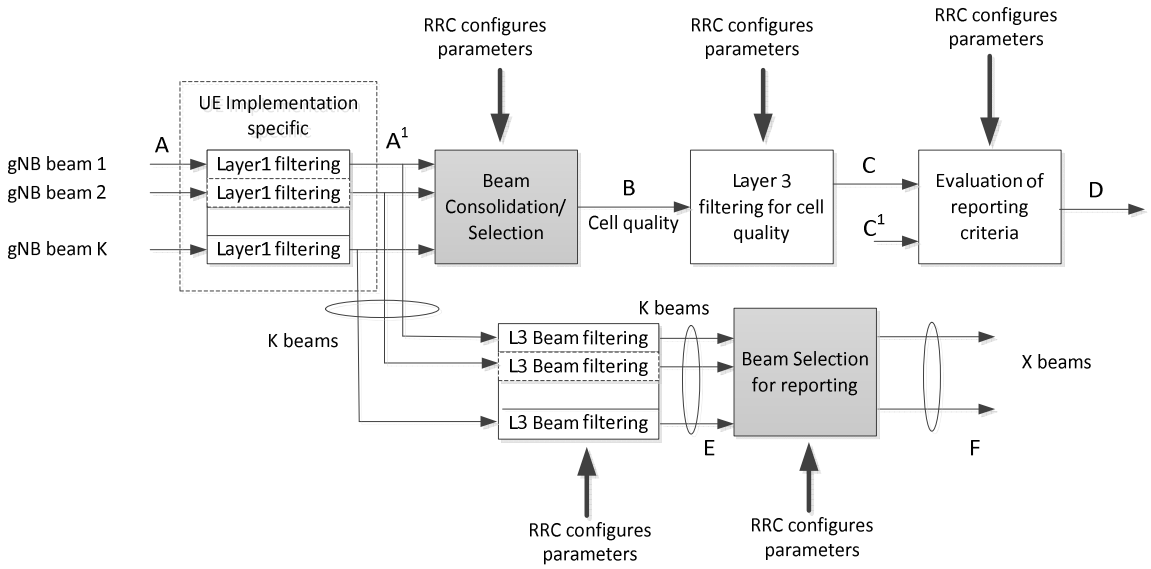


Figure 9.2.4-1: Measurement Model

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 by an implementation (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 necessary 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 (UE measurements).

- **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.

Measurement reports 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 a blacklist configured by the network are not used in event evaluation and reporting, and conversely when a whitelist is configured by the network, only the cells belonging to the whitelist 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).

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 center frequency of the SSB of 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 and the UE considers different SSBs as different cells.

- 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.

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;
  - 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.
- 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; in RRC_INACTIVE the UE also monitors paging channels for RAN-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.

When in RRC_CONNECTED, 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.

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.

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 when UL synchronisation status is "non-synchronised";
- UL data arrival during RRC_CONNECTED when there are no PUCCH resources for SR available;
- Handover;
- SR failure;
- Explicit request by RRC upon synchronous reconfiguration;
- RRC Connection Resume procedure from RRC_INACTIVE;
- To establish time alignment for a secondary TAG;
- Request for Other SI (see clause 7.3);
- Beam failure recovery;
- Consistent UL LBT failure on SpCell.

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:

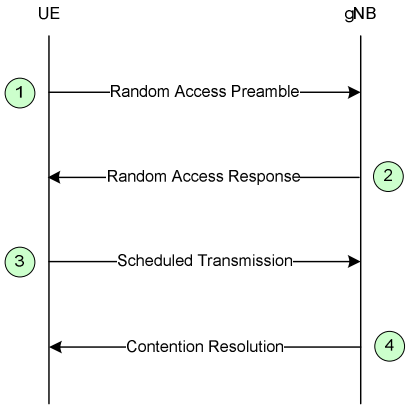
- when CFRA resources are not configured, an RSRP threshold is used by the UE to select between 2-step RA type and 4-step RA type;
- when CFRA resources for 4-step RA type are configured, UE performs random access with 4-step RA type;
- when CFRA resources for 2-step RA type are configured, UE performs 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.

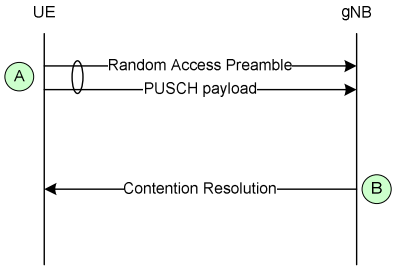
The MSG1 of the 4-step RA type consists of a preamble on PRACH. After MSG1 transmission, the UE monitors for a response from the network within a configured window. For CFRA, dedicated preamble for MSG1 transmission is assigned by the network and upon receiving random access response from the network, 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.

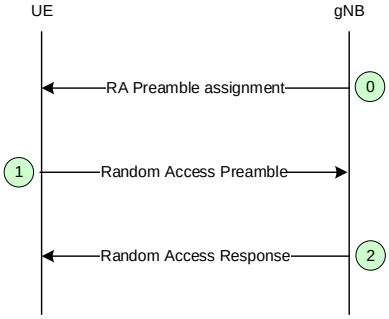
If the random access procedure with 2-step RA type is not completed after a number of MSGA transmissions, the UE can be configured to switch to CBRA with 4-step RA type.



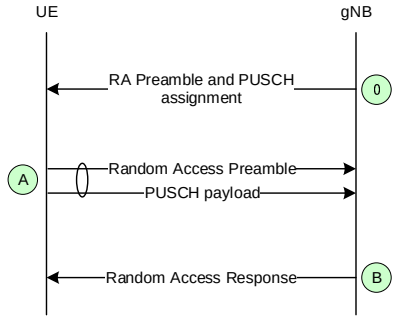
(a) CBRA with 4-step RA type



(b) CBRA with 2-step RA type



(c) CFRA with 4-step RA type



(d) CFRA with 2-step RA type

Figure 9.2.6-1: Random Access Procedures

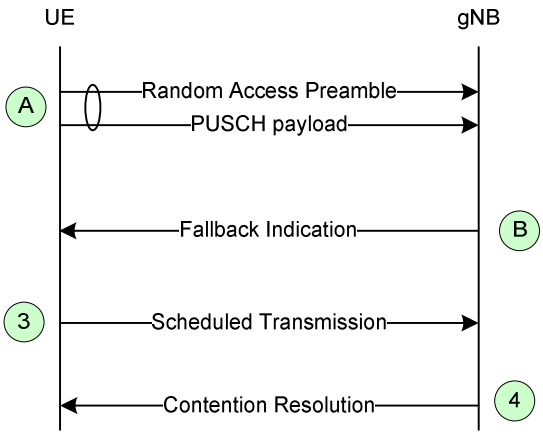


Figure 9.2.6-2: Fallback for CBRA with 2-step RA type

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.

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.

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 SSB associated to the initial DL BWP and can only be configured for the initial DL BWP and for DL BWPs containing the SSB associated to the initial DL BWP. For other DL BWPs, RLM can only be performed based on CSI-RS. 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 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.
- 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.

In case the RRC re-establishment procedure fails, the IAB-node may transmit a BH RLF indication to its child nodes. The BH RLF indication is transmitted as BAP Control PDU.

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.

SSB-based Beam Failure Detection is based on the SSB associated to the initial DL BWP and can only be configured for the initial DL BWPs and for DL BWPs containing the SSB associated to the initial DL BWP. For other DL BWPs, Beam Failure Detection can only be performed based on CSI-RS.

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.

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).

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.

For a UE configured with E-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.

9.3.2 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.

For a UE configured with E-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.

9.3.2.4 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. 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. 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 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 and the Equivalent PLMNs, 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 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 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. Eight LCGs and two 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).

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.

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 neither the MFBR(s) nor the UE-AMBR are 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 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.

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:

- Cross-carrier scheduling does not apply to SpCell i.e. SpCell is always scheduled via its PDCCH;
- 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

In general, the IAB-DU and the IAB-MT of an IAB-node are subject to a half-duplex constraint, as 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. An IAB-node can report its duplexing constraints between the IAB-MT and the IAB-DU via F1AP.

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.

11 UE Power Saving

The PDCCH monitoring activity of the UE in RRC connected mode is governed by DRX, BA, and DCP.

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);
- **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, and the time when the UE is performing continuous reception while waiting for a retransmission opportunity.

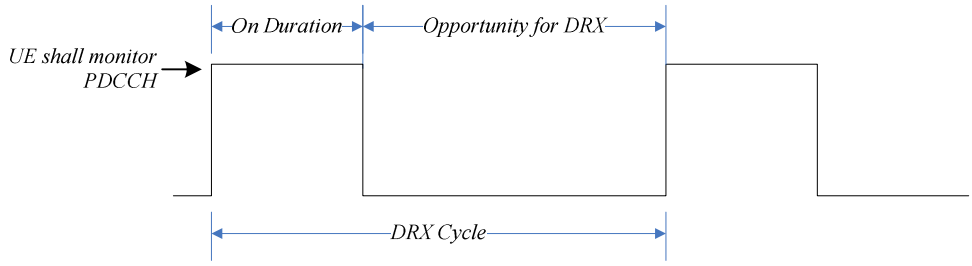


Figure 11-1: DRX Cycle

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, 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 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.

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].

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.

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 and IAB-MT in SA mode, 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.

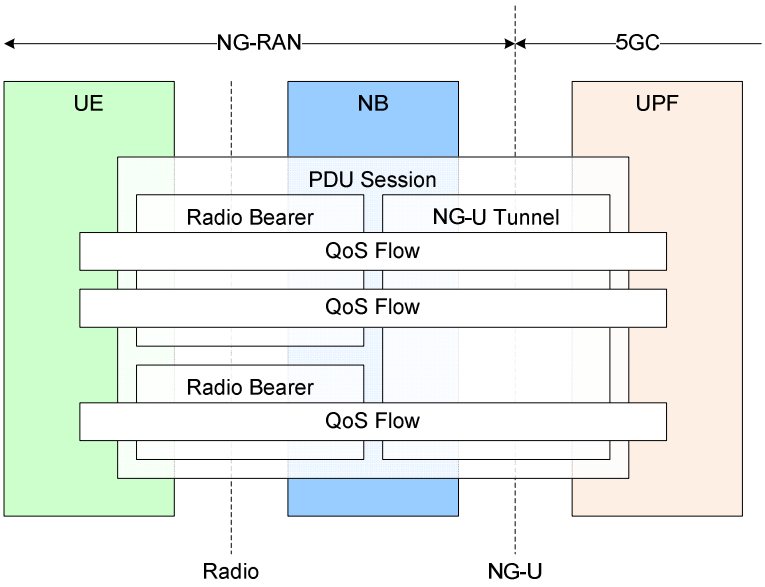


Figure 12-1: QoS architecture

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 GFBR can no longer (or again) be fulfilled for a QoS Flow. If, for a given GBR QoS Flow, notification control is enabled and the RAN determines that the GFBR 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 GFBR 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 GFBR 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) and to each UE (UE-AMBR). 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 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:

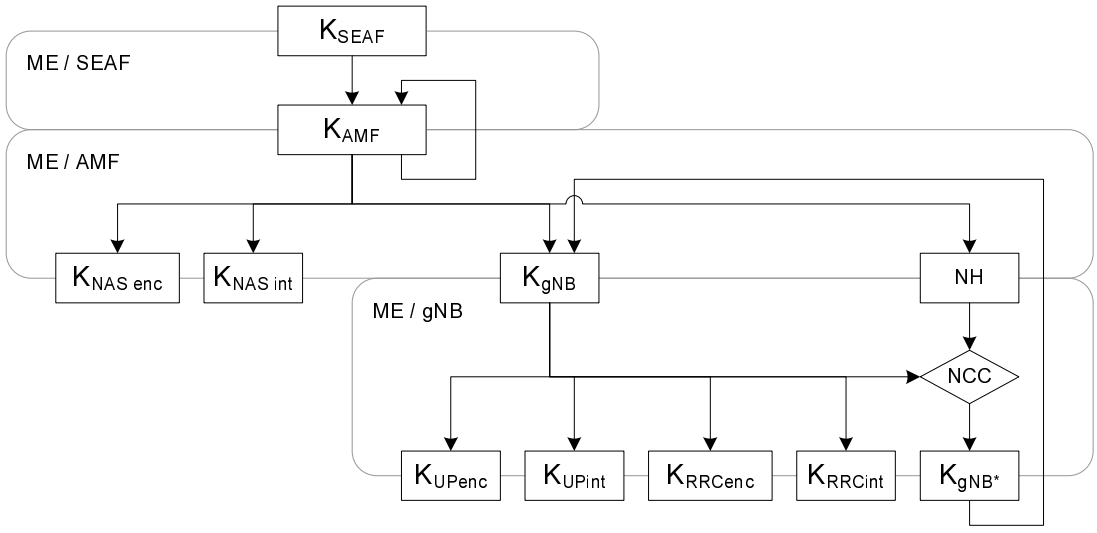


Figure 13.1-1: 5G Key Derivation

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 UE 5G security capabilities to the gNB. 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 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:

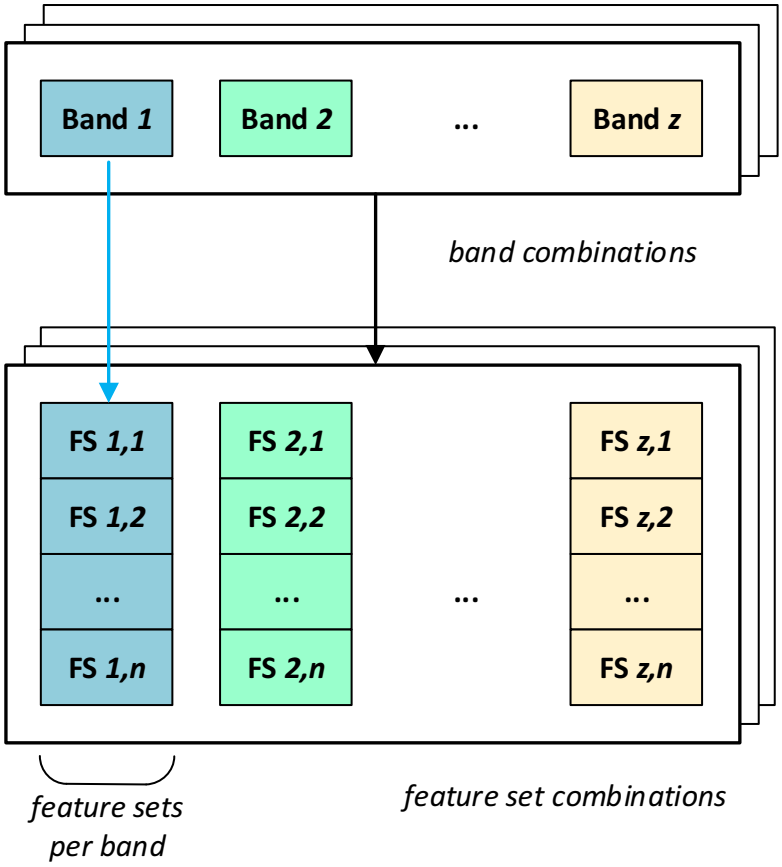


Figure 14-1: Feature Set Combinations

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].

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].

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:

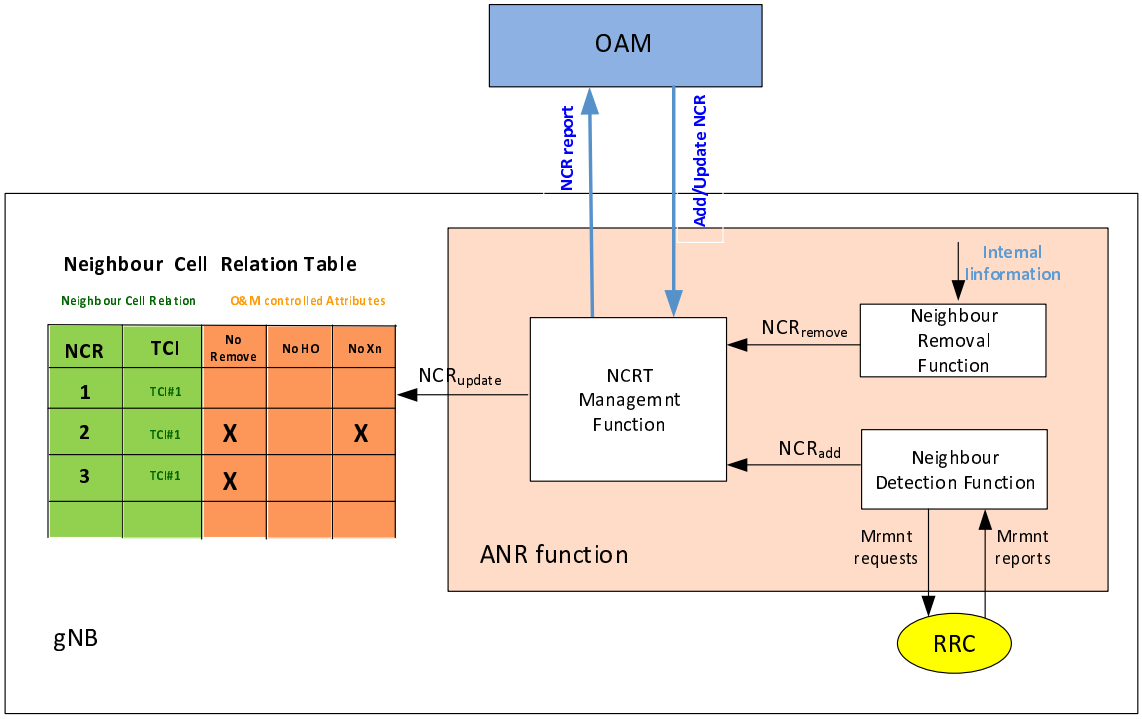


Figure 15.3.3.1-1: Interaction between gNB and OAM due to ANR

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].

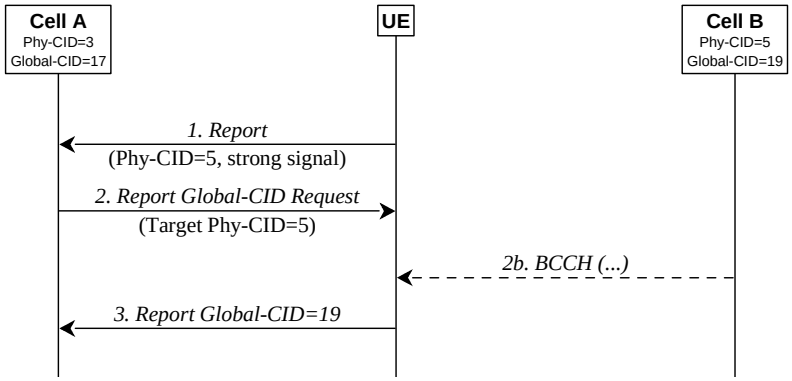


Figure 15.3.3.2-1: Automatic Neighbour Relation Function

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). 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), 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.

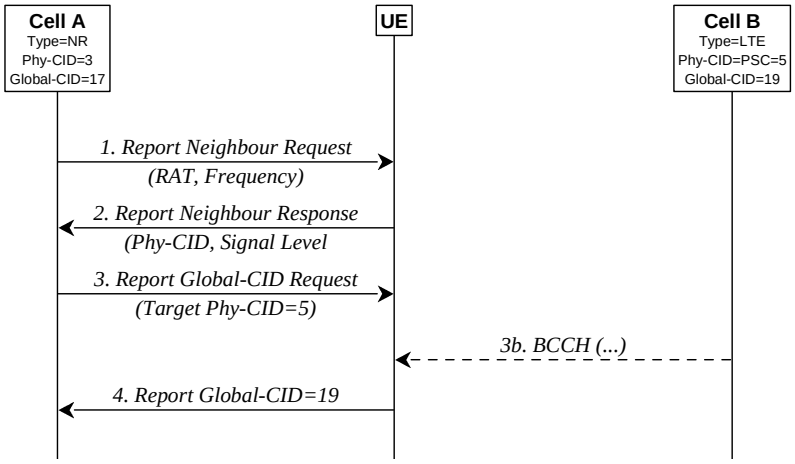


Figure 15.3.3.5-1: Automatic Neighbour Relation Function in case of E-UTRAN detected cell

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: In this version of the specification, it is assumed that the NG-RAN node is able to determine the gNB ID length of the candidate gNB (e.g. based on OAM configuration).

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.

15.4.2 Solution description

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.

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.

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 and intra-system inter-RAT load balancing scenarios are supported.

In general, support for mobility load balancing consists of one or more of following functions:

- Load reporting;
- Load balancing action based on handovers;
- Adapting handover and/or reselection configuration.

15.5.1.2 Load reporting

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);
- 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.

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.

15.5.2 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.

MRO provides means to distinguish the above problems from NR coverage related problems and other problems, not related to mobility.

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. 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.

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).
- Intra-system Too Early Handover: there is a recent handover 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 is the cell that served the UE at the last handover initialisation.
- Intra-system Handover to Wrong Cell: there is a recent handover 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 is neither the cell that served the UE at the last handover initialisation nor the cell that served the UE where the RLF happened or the cell that the handover was initialized toward.

The "UE reported timer" above indicates the time elapsed since the last handover initialisation 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.

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.

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. 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; the UE attempts to re-connect to the source cell or to another cell belonging to an E-UTRAN 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 proceed as deined 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 and Too Early Inter-system Handover 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.

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

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.

15.5.3 Support for RACH Optimization

RACH optimization is supported by UE reported information made available at the NG RAN node and by PRACH parameters exchange between NG RAN nodes.

The contents of the RACH information 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 *rsrp-ThresholdSSB* threshold per RACH attempt.

15.5.4 UE History Information from the UE

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.

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.

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.

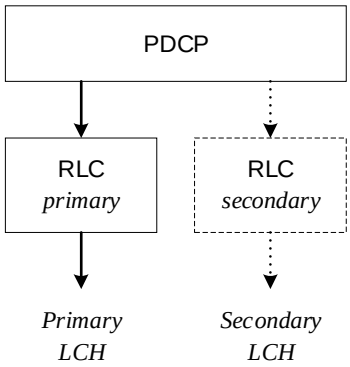


Figure 16.1.3-1: Packet Duplication

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.

16.2 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.

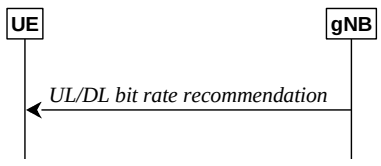


Figure 16.2.1.1-1: UL or DL bit rate recommendation

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.

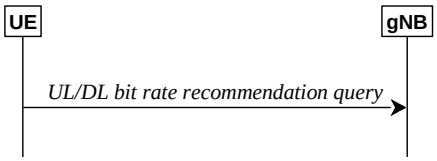


Figure 16.2.1.1-2: UL or DL bit rate recommendation query

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.

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. 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

- Some slices may be available only in part of the network. The NG-RAN supported S-NSSAI(s) is 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. It is assumed that the slice availability does not change within the UE's registration area.

- 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.

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.

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. 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

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 or dedicated radio resource up to RRM implementation and SLA.

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.

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.

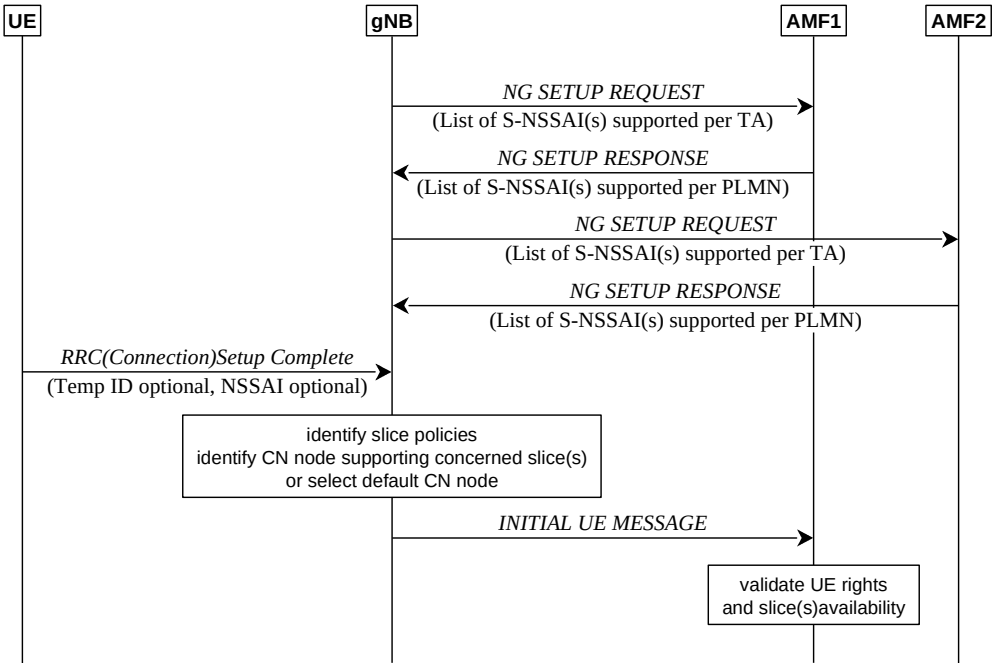


Figure 16.3.4.2-1: AMF selection

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. 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.

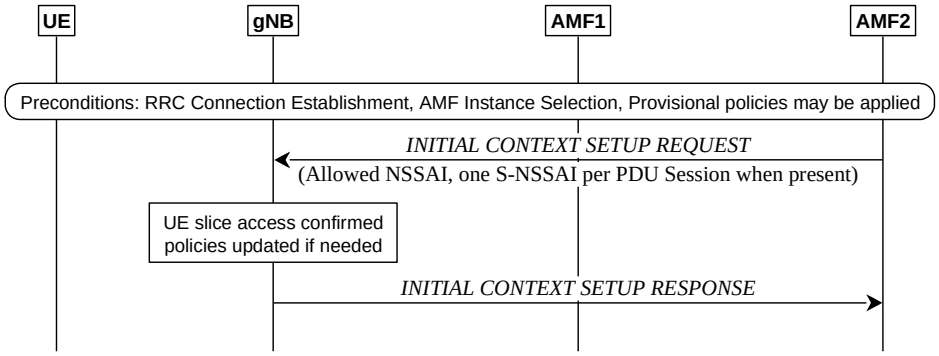


Figure 16.3.4.3-1: Network Slice-aware Initial Context Setup

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.

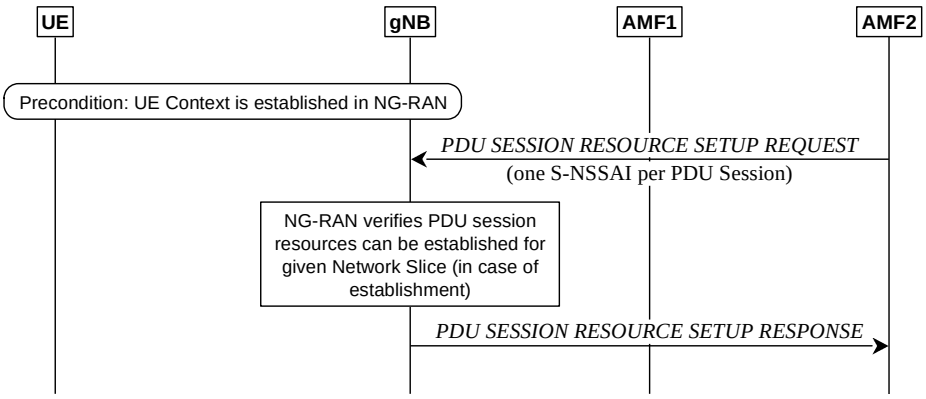


Figure 16.3.4.4-1: Network Slice-aware PDU Session Resource Setup

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.

Both NG and Xn 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. 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.

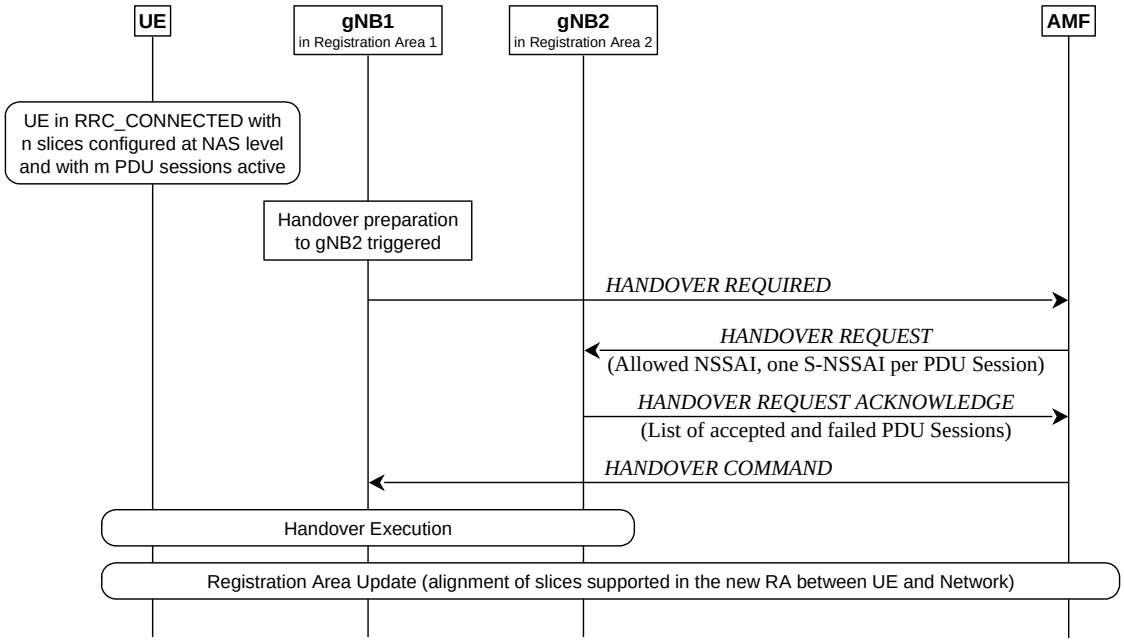


Figure 16.3.4.5-1: NG based mobility across different Registration Areas

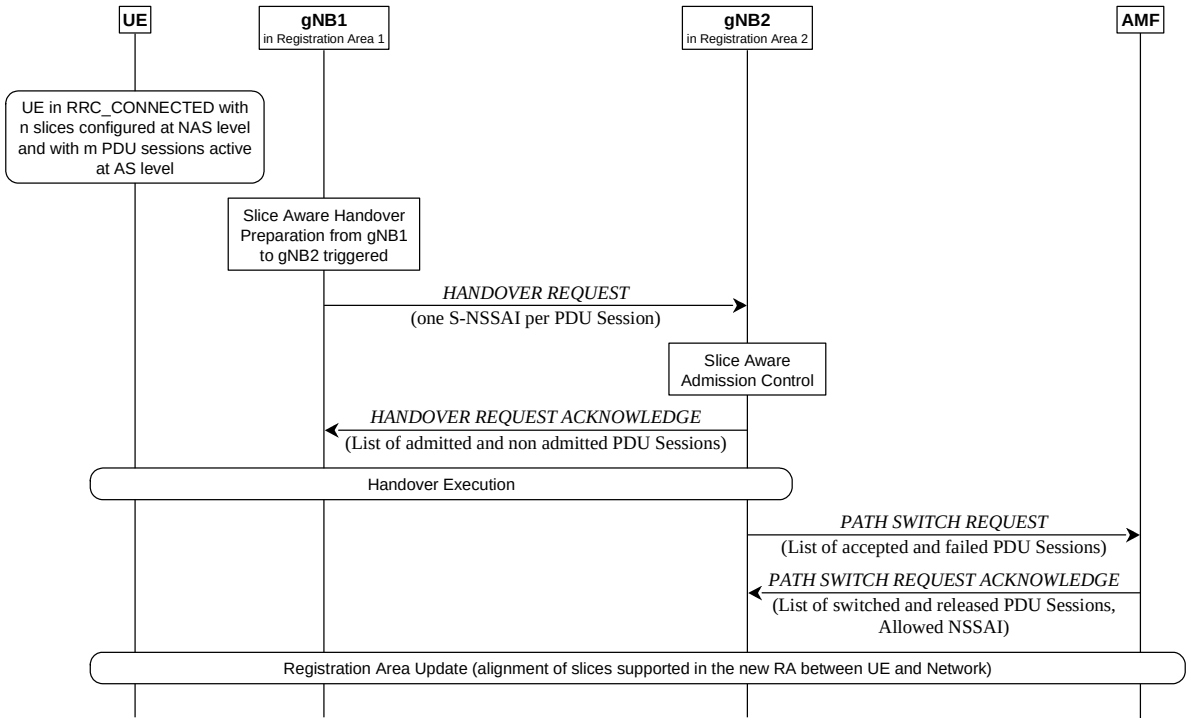


Figure 16.3.4.5-2: Xn based mobility across different Registration Areas

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 RRC_INACTIVE. UE monitors ETWS/CMAS indication in any paging occasion for RRC Connected. 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 [45]. 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].

16.6 Stand-Alone NPN

16.6.1 General

A 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 are not supported in SNPN.

NR-NR Dual Connectivity within a single SNPN 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 and a cell can only be considered as suitable if the PLMN and NID broadcast by the cell matches the selected/registered SNPN.

An SNPN-only cell can only be suitable for its subscribers and is barred otherwise.

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 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 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].

16.7 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

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.

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 and burst periodicity. 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.

16.9 Sidelink

16.9.1 General

In this clause, an overview of NR sidelink communication and how NG-RAN supports NR sidelink communication and V2X sidelink communication is given. V2X sidelink communication is specified in TS 36.300 [2].

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.

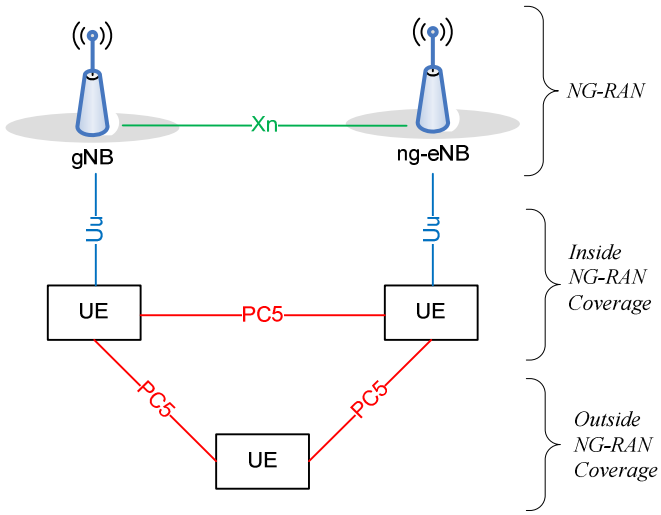


Figure 16.9.1-1: NG-RAN Architecture supporting the PC5 interface

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.

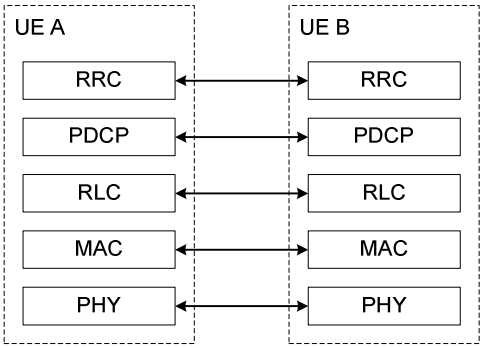


Figure 16.9.2.1-1: Control plane protocol stack for SCCH for RRC.

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.

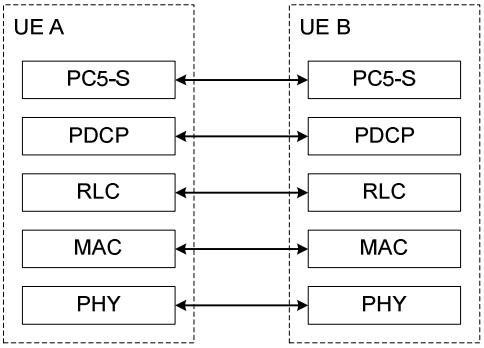


Figure 16.9.2.1-2: Control plane protocol stack for SCCH for PC5-S.

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.

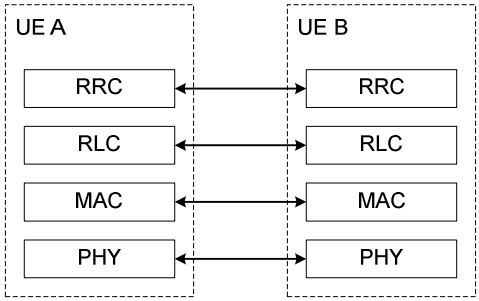


Figure 16.9.2.1-3: Control plane protocol stack for SBCCH.

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.

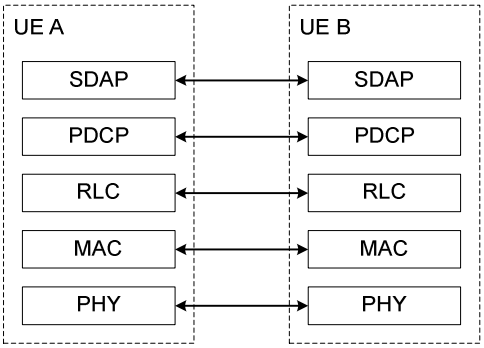


Figure 16.9.2.1-4: User plane protocol stack for STCH.

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 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) 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;

- Duplication is not supported over the PC5 interface.

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].

16.9.4 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 (for NR sidelink communication only) 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.

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 Cross Link Interference (CLI).

To mitigate 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 CLI measurements. There are two types of 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.

Layer 3 filtering applies to CLI measurement results and both event triggered and periodic reporting are supported.

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].

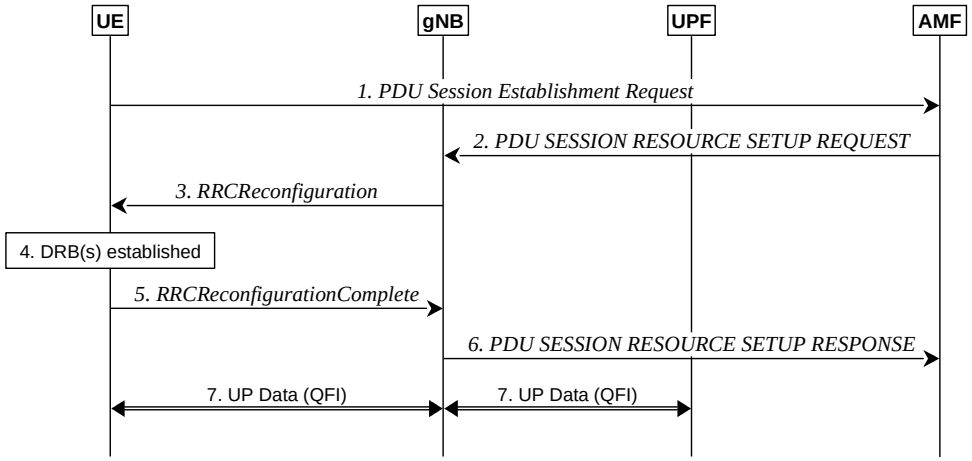


Figure A.1-1: PDU session establishment

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.

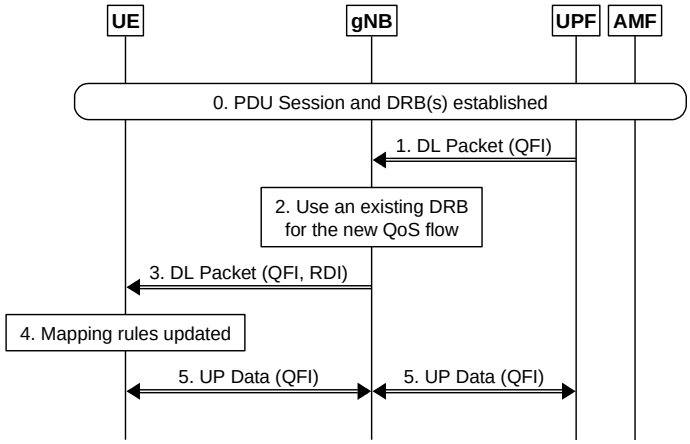


Figure A.2-1: DL data with new QFI sent over existing DRB

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.

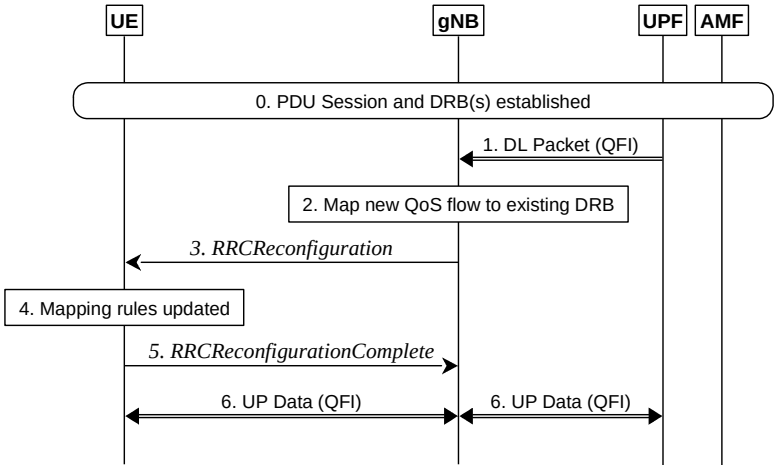


Figure A.3-1: DL data with new QFI sent over existing DRB

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].

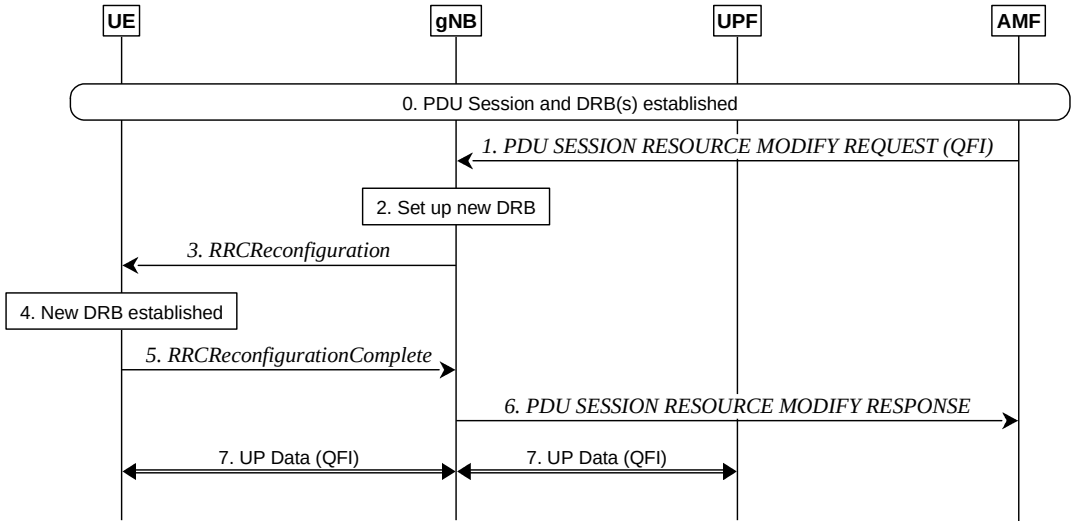


Figure A.4-1: DL data with new QoS Flow ID sent over new DRB with explicit signalling

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].

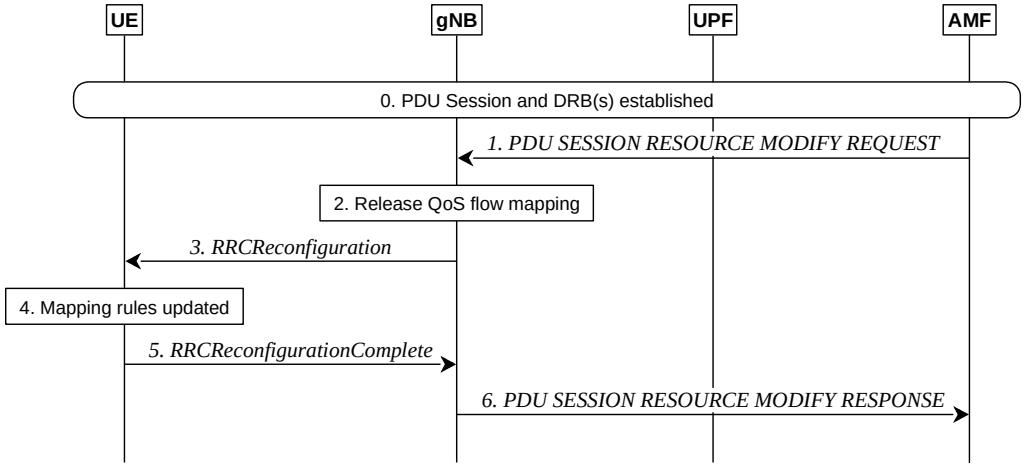


Figure A.5-1: Release of QoS Flow with Explicit Signalling

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.

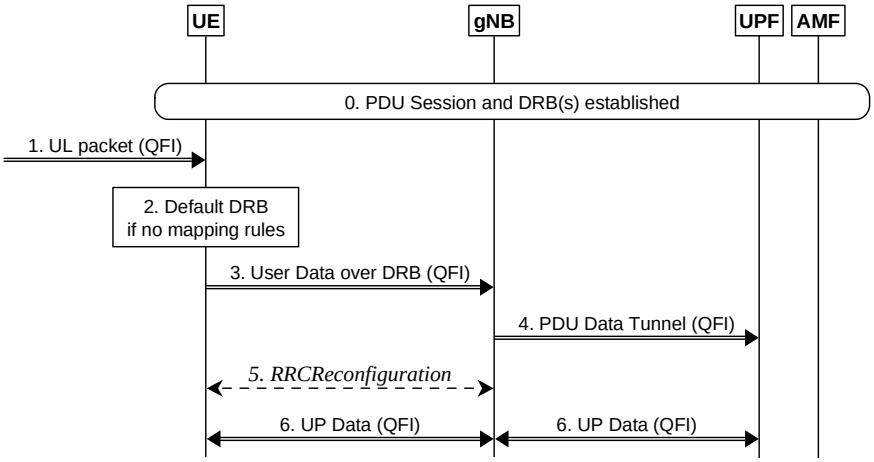


Figure A.6-1: UL packet with a new QoS flow for which a mapping does not exist in UE

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:

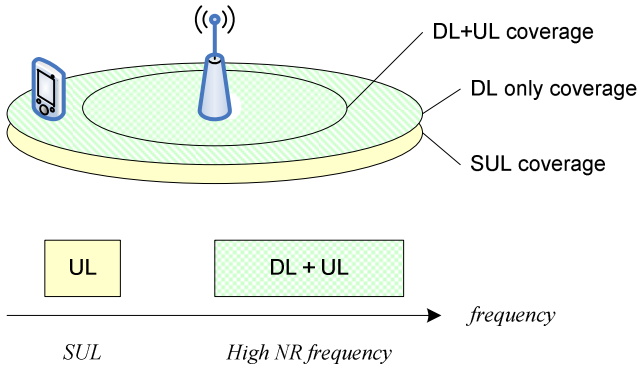


Figure B.1-1: Example of Supplementary Uplink

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.

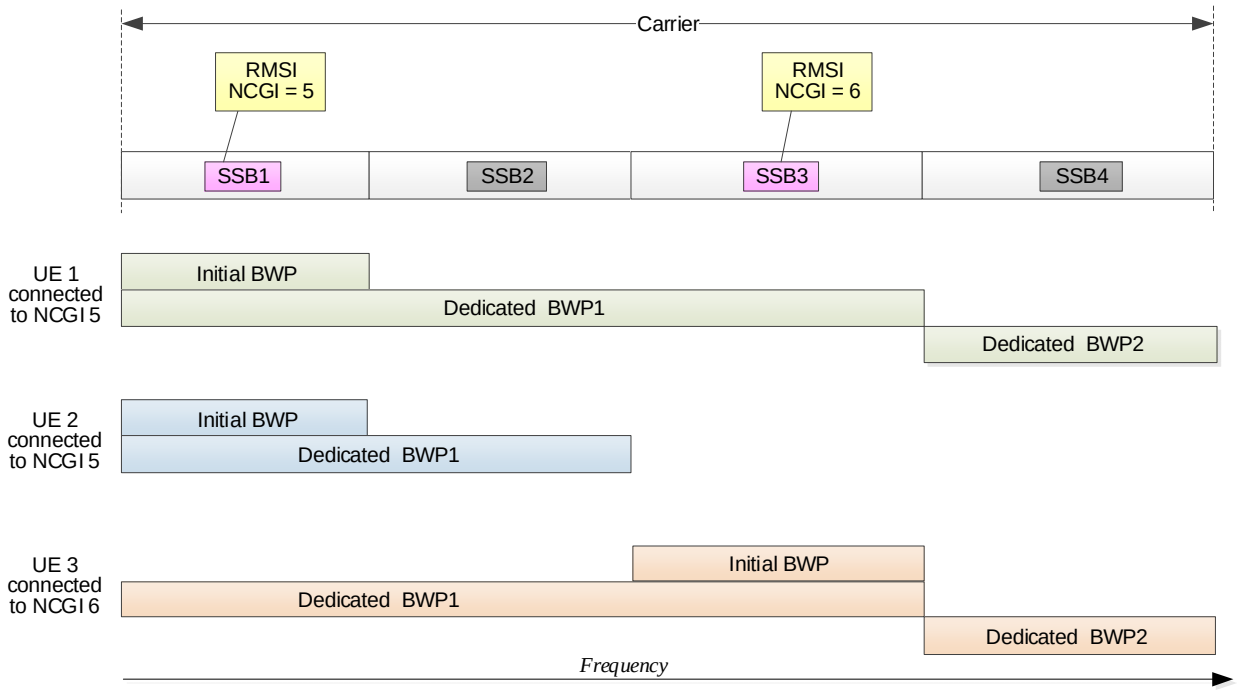


Figure B.2-1: Example of multiple SSBs in a carrier

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.

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 SPID values are defined in Annex I of TS 36.300 [2].

From the SPID reference values, only the SPID=253 also applies for 5GC.

Annex E:
NG-RAN Architecture for Radio Access Network Sharing with multiple cell ID broadcast (informative)

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 (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 - L2 Data Flow aligned with Stage 3 agreements - References updated RAN3 TP incorporated (R3-172610)	0.6.0
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	1.1.1

						- 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.	
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	16.0.0

						and 5GS	
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
2022-06	RP-96	RP-221713	0470	1	F	Support of UL Tx switching for inter-band UL CA and SUL	16.9.0
	RP-96	RP-221714	0471	-	F	Correction of LBT access mode	16.9.0
	RP-96	RP-221714	0479	-	F	Inter-system direct data forwarding between source SgNB and target gNB	16.9.0
2022-09	RP-97	RP-222516	0551	-	F	NR Correction related to RNA	16.10.0
	RP-97	RP-222519	0556	-	F	CAG access control without mobility restrictions	16.10.0
2022-12	RP-98	RP-223404	0600	1	F	Clarification for ePWS	16.11.0
2023-03	RP-99	RP-230685	0638	1	A	Clarification on the PDCCH Ordered RACH for SCell in 38.300	16.12.0
	RP-99	RP-230686	0643	-	F	Corrections on PSBCH Symbols number for NR sidelink.	16.12.0
2023-06	RP-100	RP-231409	0663	2	A	Correction to information delivered in Handover Request message	16.13.0
2023-09	RP-101	RP-232566	0700	1	F	Miscellaneous stage 2 corrections for sidelink	16.14.0
	RP-101	RP-232566	0704	-	F	Stage2 correction on UE Identities	16.14.0
2023-12	RP-102	RP-233885	0725	1	F	Miscellaneous Corrections	16.15.0
	RP-102	RP-233885	0737	1	F	Correction on NR SL Stage 2	16.15.0
2024-06	RP-104	RP-241550	0839	1	F	Clarification on the combination of HST and RRM measurement relaxation	16.16.0
	RP-104	RP-241548	0844	2	A	Correction to UE capability description for fallback BC behavior	16.16.0
2024-09	RP-105	RP-242233	0890	1	A	Correction on Transport Channels	16.17.0
	RP-105	RP-242233	0899	-	A	Alignment of mps-PriorityAccess cause in RRC Resume	16.17.0
2024-12	RP-106	RP-243223	0906	3	F	Gap requirement for CSI-RS based measurements and inter-RAT measurements	16.18.0
	RP-106	RP-243221	0927	-	A	Maximum number of configured CCs	16.18.0
2025-03	RP-107	RP-250656	0951	-	A	Correction on L3 beam filtering	16.19.0
	RP-107	RP-250656	0974	-	A	Clarification on supported features on the PSCell	16.19.0
2025-06	RP-108	RP-251690	0983	1	F	Corrections on DCP	16.20.0
	RP-108	RP-251689	0996	1	A	Correction on servingCellMO configuration for SSB-less SCell	16.20.0
2025-12	RP-110	RP-253714	1050	1	A	Clarification of the single SCS per frequency restriction	16.21.0

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