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Contents

Foreword

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1 Scope

The present document specifies and establishes the characteristics of the physical layer procedures for control operations in 5G-NR.

2 References

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

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

[2] 3GPP TS 38.201: "NR; Physical Layer – General Description"

[3] 3GPP TS 38.202: "NR; Services provided by the physical layer"

[4] 3GPP TS 38.211: "NR; Physical channels and modulation"

[5] 3GPP TS 38.212: "NR; Multiplexing and channel coding"

[6] 3GPP TS 38.214: "NR; Physical layer procedures for data"

[7] 3GPP TS 38.215: "NR; Physical layer measurements"

[8-1] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone"

[8-2] 3GPP TS 38.101-2: "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone"

[8-3] 3GPP TS 38.101-3: "NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios"

[9] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"

[10] 3GPP TS 38.133: "NR; Requirements for support of radio resource management"

[11] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"

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

[13] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"

[14] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification"

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in [1, TR 21.905] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in [1, TR 21.905]. A parameter referenced in *italics* is provided by higher layers.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

3.3 Abbreviations

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

BPRE	Bits per resource element
BWP	Bandwidth part
CB	Code block
CBG	Code block group
CCE	Control channel element
CORESET	Control resource set
CP	Cyclic prefix
CRC	Cyclic redundancy check
CSI	Channel state information
CSS	Common search space
DAI	Downlink assignment index
DC	Dual connectivity
DCI	Downlink control information
DL	Downlink
DL-SCH	Downlink shared channel
EPRE	Energy per resource element
EN-DC	E-UTRA NR dual connectivity with MCG using E-UTRA and SCG using NR
FR1	Frequency range 1
FR2	Frequency range 2
GSCN	Global synchronization channel number
HARQ-ACK	Hybrid automatic repeat request acknowledgement
MCG	Master cell group
MCS	Modulation and coding scheme
NE-DC	E-UTRA NR dual connectivity with MCG using NR and SCG using E-UTRA
NR-DC	NR NR dual connectivity
PBCH	Physical broadcast channel
PCell	Primary cell
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PRACH	Physical random access channel
PRB	Physical resource block
PRG	Physical resource block group
PSCell	Primary secondary cell
PSS	Primary synchronization signal
PUCCH	Physical uplink control channel
PUCCH-SCell	PUCCH SCell
PUSCH	Physical uplink shared channel
QCL	Quasi co-location
RB	Resource block
RE	Resource element
RLM	Radio link monitoring
RRM	Radio resource management
RS	Reference signal
RSRP	Reference signal received power
SCG	Secondary cell group
SCS	Subcarrier spacing
SFN	System frame number
SLIV	Start and length indicator value
SPS	Semi-persistent scheduling
SR	Scheduling request
SRI	SRS resource indicator

SRS	Sounding reference signal
SSS	Secondary synchronization signal
TA	Timing advance
TAG	Timing advance group
TCI	Transmission Configuration Indicator
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel
USS	UE-specific search space

4 Synchronization procedures

4.1 Cell search

Cell search is the procedure for a UE to acquire time and frequency synchronization with a cell and to detect the physical layer Cell ID of the cell.

A UE receives the following synchronization signals (SS) in order to perform cell search: the primary synchronization signal (PSS) and secondary synchronization signal (SSS) as defined in [4, TS 38.211].

A UE assumes that reception occasions of a physical broadcast channel (PBCH), PSS, and SSS are in consecutive symbols, as defined in [4, TS 38.211], and form a SS/PBCH block. The UE assumes that SSS, PBCH DM-RS, and PBCH data have same EPRE. The UE may assume that the ratio of PSS EPRE to SSS EPRE in a SS/PBCH block is either 0 dB or 3 dB. If the UE has not been provided dedicated higher layer parameters, the UE may assume that the ratio of PDCCH DMRS EPRE to SSS EPRE is within -8 dB and 8 dB when the UE monitors PDCCHs for a DCI format 1_0 with CRC scrambled by SI-RNTI, P-RNTI, or RA-RNTI.

For a half frame with SS/PBCH blocks, the first symbol indexes for candidate SS/PBCH blocks are determined according to the SCS of SS/PBCH blocks as follows, where index 0 corresponds to the first symbol of the first slot in a half-frame.

- Case A - 15 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes of $\{2, 8\}+14\cdot n$. For carrier frequencies smaller than or equal to 3 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 3 GHz, $n=0, 1, 2, 3$.

- Case B - 30 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{4, 8, 16, 20\}+28\cdot n$. For carrier frequencies smaller than or equal to 3 GHz, $n=0$. For carrier frequencies within FR1 larger than 3 GHz, $n=0,1$.

- Case C - 30 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{2, 8\}+14\cdot n$.

  - For paired spectrum operation

    - For carrier frequencies smaller than or equal to 3 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 3 GHz, $n=0, 1, 2, 3$.

  - For unpaired spectrum operation

    - For carrier frequencies smaller than or equal to 2.3 GHz, $n=0,1$. For carrier frequencies within FR1 larger than 2.3 GHz, $n=0, 1, 2, 3$.

- Case D - 120 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{4, 8, 16, 20\}+28\cdot n$. For carrier frequencies within FR2, $n=0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18$.

- Case E - 240 kHz SCS: the first symbols of the candidate SS/PBCH blocks have indexes $\{8, 12, 16, 20, 32, 36, 40, 44\}+56\cdot n$. For carrier frequencies within FR2, $n=0, 1, 2, 3, 5, 6, 7, 8$.

From the above cases, if the SCS of SS/PBCH blocks is not provided by *ssbSubcarrierSpacing*, the applicable cases for a cell depend on a respective frequency band, as provided in [8-1, TS 38.101-1] and [8-2, TS 38.101-2]. A same case applies for all SS/PBCH blocks on the cell. If a 30 kHz SS/PBCH block SCS is indicated by *ssbSubcarrierSpacing*, Case B applies for frequency bands with only 15 kHz SS/PBCH block SCS as specified in [8-1, TS 38.101-1], and the case specified for 30 kHz SS/PBCH block SCS in [8-1, TS 38.101-1] applies for frequency bands with 30 kHz SS/PBCH block SCS or both 15 kHz and 30 kHz SS/PBCH block SCS as specified in [8-1, TS 38.101-1]. For a UE configured to operate with carrier aggregation over a set of cells in a frequency band of FR2 or with frequency-contiguous carrier aggregation over a set of cells in a frequency band of FR1, if the UE is provided SCS values by *ssbSubcarrierSpacing* for receptions of SS/PBCH blocks on any cells from the set of cells, the UE expects the SCS values to be same.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $L_{\max}-1$. A UE determines the 2 LSB bits, for $L_{\max}=4$, or the 3 LSB bits, for $L_{\max}>4$, of a SS/PBCH block index per half frame from a one-to-one mapping with an index of the DM-RS sequence transmitted in the PBCH. For $L_{\max}=64$, the UE determines the 3 MSB bits of the SS/PBCH block index per half frame from PBCH payload bits $\bar{a}_{\bar{A}+5},\bar{a}_{\bar{A}+6},\bar{a}_{\bar{A}+7}$ as described in [5, TS 38.212].

A UE can be provided per serving cell by *ssb-periodicityServingCell* a periodicity of the half frames for reception of the SS/PBCH blocks for the serving cell. If the UE is not configured a periodicity of the half frames for receptions of the SS/PBCH blocks, the UE assumes a periodicity of a half frame. A UE assumes that the periodicity is same for all SS/PBCH blocks in the serving cell.

For initial cell selection, a UE may assume that half frames with SS/PBCH blocks occur with a periodicity of 2 frames.

Upon detection of a SS/PBCH block, the UE determines from *MIB* that a CORESET for Type0-PDCCH CSS set, as described in Clause 13, is present if $k_{\text{SSB}} \le 23$ [4, TS 38.211] for FR1 or if $k_{\text{SSB}} \le 11$ for FR2. The UE determines from *MIB* that a CORESET for Type0-PDCCH CSS set is not present if $k_{\text{SSB}} > 23$ for FR1 or if $k_{\text{SSB}} > 11$ for FR2; the CORESET for Type0-PDCCH CSS set may be provided by *PDCCH-ConfigCommon*.

For a serving cell without transmission of SS/PBCH blocks, a UE acquires time and frequency synchronization with the serving cell based on receptions of SS/PBCH blocks on the PCell, or on the PSCell, of the cell group for the serving cell.

4.2 Transmission timing adjustments

A UE can be provided a value $N_{\text{TA,offset}}$ of a timing advance offset for a serving cell by *n-TimingAdvanceOffset* for the serving cell. If the UE is not provided *n-TimingAdvanceOffset* for a serving cell, the UE determines a default value $N_{\text{TA,offset}}$ of the timing advance offset for the serving cell as described in [10, TS 38.133].

If a UE is configured with two UL carriers for a serving cell, a same timing advance offset value $N_{\text{TA,offset}}$ applies to both carriers.

Upon reception of a timing advance command for a TAG, the UE adjusts uplink timing for PUSCH/SRS/PUCCH transmission on all the serving cells in the TAG based on a value $N_{\text{TA,offset}}$ that the UE expects to be same for all the serving cells in the TAG and based on the received timing advance command where the uplink timing for PUSCH/SRS/PUCCH transmissions is the same for all the serving cells in the TAG.

For a band with synchronous contiguous intra-band EN-DC in a band combination with non-applicable maximum transmit timing difference requirements as described in Note 1 of Table 7.5.3-1 of [10, TS 38.133], if the UE indicates *ul-TimingAlignmentEUTRA-NR* as 'required' and uplink transmission timing based on timing adjustment indication for a TAG from MCG and a TAG from SCG are determined to be different by the UE, the UE adjusts the transmission timing for PUSCH/SRS/PUCCH transmission on all serving cells part of the band with the synchronous contiguous intra-band EN-DC based on timing adjustment indication for a TAG from a serving cell in MCG in the band. The UE is not expected to transmit a PUSCH/SRS/PUCCH in one CG when the PUSCH/SRS/PUCCH is overlapping in time, even partially, with random access preamble transmitted in another CG.

For a SCS of $2^{\mu}\cdot 15$ kHz, the timing advance command for a TAG indicates the change of the uplink timing relative to the current uplink timing for the TAG in multiples of $16\cdot 64\cdot T_c/2^{\mu}$. The start timing of the random access preamble is described in [4, TS 38.211].

In case of random access response, a timing advance command [11, TS 38.321], T_{A}, for a TAG indicates N_{TA} values by index values of T_{A} = 0, 1, 2, ..., 3846, where an amount of the time alignment for the TAG with SCS of $2^{\mu}\cdot 15$ kHz is $N_{\text{TA}} = T_{\text{A}}\cdot 16\cdot 64/2^{\mu}$. N_{TA} is defined in [4, TS 38.211] and is relative to the SCS of the first uplink transmission from the UE after the reception of the random access response.

In other cases, a timing advance command [11, TS 38.321], T_A, for a TAG indicates adjustment of a current N_{TA} value, N_{TA_old}, to the new N_{TA} value, N_{TA_new}, by index values of T_A = 0, 1, 2,..., 63, where for a SCS of $2^\mu \cdot 15$ kHz, $N_{TA\_new} = N_{TA\_old} + (T_A - 31) \cdot 16 \cdot 64/2^\mu$.

If a UE has multiple active UL BWPs, as described in Clause 12, in a same TAG, including UL BWPs in two UL carriers of a serving cell, the timing advance command value is relative to the largest SCS of the multiple active UL BWPs. The applicable N_{TA_new} value for an UL BWP with lower SCS may be rounded to align with the timing advance granularity for the UL BWP with the lower SCS while satisfying the timing advance accuracy requirements in [10, TS38.133].

Adjustment of an N_{TA} value by a positive or a negative amount indicates advancing or delaying the uplink transmission timing for the TAG by a corresponding amount, respectively.

For a timing advance command received on uplink slot n and for a transmission other than a PUSCH scheduled by a RAR UL grant as described in Clause 8.3, the corresponding adjustment of the uplink transmission timing applies from the beginning of uplink slot $n+k+1$ where $k = \lceil N_{slot}^{subframe\mu} \cdot (N_{T,1} + N_{T,2} + N_{TA,max} + 0.5)/T_{sf} \rceil$, $N_{T,1}$ is a time duration in msec of N_1 symbols corresponding to a PDSCH processing time for UE processing capability 1 when additional PDSCH DM-RS is configured, $N_{T,2}$ is a time duration in msec of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214], $N_{TA,max}$ is the maximum timing advance value in msec that can be provided by a TA command field of 12 bits, $N_{slot}^{subframe,\mu}$ is the number of slots per subframe, and T_{sf} is the subframe duration of 1 msec. N_1 and N_2 are determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG and of all configured DL BWPs for the corresponding downlink carriers. For $\mu = 0$, the UE assumes $N_{1,0} = 14$ [6, TS 38.214]. Slot n and $N_{slot}^{subframe,\mu}$ are determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG. $N_{TA,max}$ is determined with respect to the minimum SCS among the SCSs of all configured UL BWPs for all uplink carriers in the TAG and for all configured initial UL BWPs provided by *initialUplinkBWP*. The uplink slot n is the last slot among uplink slot(s) overlapping with the slot(s) of PDSCH reception assuming $T_{TA} = 0$, where the PDSCH provides the timing advance command and T_{TA} is defined in [4, TS 38.211].

If a UE changes an active UL BWP between a time of a timing advance command reception and a time of applying a corresponding adjustment for the uplink transmission timing, the UE determines the timing advance command value based on the SCS of the new active UL BWP. If the UE changes an active UL BWP after applying an adjustment for the uplink transmission timing, the UE assumes a same absolute timing advance command value before and after the active UL BWP change.

If the received downlink timing changes and is not compensated or is only partly compensated by the uplink timing adjustment without timing advance command as described in [10, TS 38.133], the UE changes N_{TA} accordingly.

If two adjacent slots overlap due to a TA command, the latter slot is reduced in duration relative to the former slot.

4.3 Timing for secondary cell activation / deactivation

With reference to slots for PUCCH transmissions, when a UE receives in a PDSCH an activation command [11, TS 38.321] for a secondary cell ending in slot *n*, the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133] and no earlier than slot $n+k$, except for the following:

- the actions related to CSI reporting on a serving cell that is active in slot $n+k$
- the actions related to the *sCellDeactivationTimer* associated with the secondary cell [11, TS 38.321] that the UE applies in slot $n+k$
- the actions related to CSI reporting on a serving cell which is not active in slot $n+k$ that the UE applies in the earliest slot after $n+k$ in which the serving cell is active.

The value of k is $k_1 + 3 \cdot N_{\text{slot}}^{\text{subframe},\mu} + 1$ where k_1 is a number of slots for a PUCCH transmission with HARQ-ACK information for the PDSCH reception and is indicated by the PDSCH-to-HARQ_feedback timing indicator field in the DCI format scheduling the PDSCH reception as described in Clause 9.2.3 and $N_{\text{slot}}^{\text{subframe},\mu}$ is a number of slots per subframe for the SCS configuration μ of the PUCCH transmission.

With reference to slots for PUCCH transmissions, if a UE receives a deactivation command [11, TS 38.321] for a secondary cell ending in slot n, the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133], except for the actions related to CSI reporting on an activated serving cell which the UE applies in slot $n+k$.

If the *sCellDeactivationTimer* associated with the secondary cell expires in slot n, the UE applies the corresponding actions in [11, TS 38.321] no later than the minimum requirement defined in [10, TS 38.133], except for the actions related to CSI reporting on an activated serving cell which the UE applies in the first slot that is after slot $n+3 \cdot N_{\text{slot}}^{\text{subframe},\mu}$ where μ is the SCS configuration for PDSCH reception on the secondary cell.

5 Radio link monitoring

The downlink radio link quality of the primary cell is monitored by a UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP, as described in Clause 12, on the primary cell. If the active DL BWP is the initial DL BWP and for SS/PBCH block and CORESET multiplexing pattern 2 or 3, as described in Clause 13, the UE is expected to perform RLM using the associated SS/PBCH block when the associated SS/PBCH block index is provided by *RadioLinkMonitoringRS*.

If the UE is configured with a SCG, as described in [12, TS 38.331], and the parameter *rlf-TimersAndConstants* is provided by higher layers and is not set to release, the downlink radio link quality of the PSCell of the SCG is monitored by the UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP on the PSCell.

A UE can be configured for each DL BWP of a SpCell [11, TS 38.321] with a set of resource indexes, through a corresponding set of *RadioLinkMonitoringRS*, for radio link monitoring by *failureDetectionResources*. The UE is provided either a CSI-RS resource configuration index, by *csi-RS-Index*, or a SS/PBCH block index, by *ssb-Index*. The UE can be configured with up to $N_{\text{LR-RLM}}$ *RadioLinkMonitoringRS* for link recovery procedures, as decribed in Clause 6, and for radio link monitoring. From the $N_{\text{LR-RLM}}$ *RadioLinkMonitoringRS*, up to N_{RLM} *RadioLinkMonitoringRS* can be used for radio link monitoring depending on a maximum number $L_{\max}$ of candidate SS/PBCH blocks per half frame as described in Clause 4.1, and up to two *RadioLinkMonitoringRS* can be used for link recovery procedures.

If the UE is not provided *RadioLinkMonitoringRS* and the UE is provided for PDCCH receptions TCI states that include one or more of a CSI-RS

- the UE uses for radio link monitoring the RS provided for the active TCI state for PDCCH reception if the active TCI state for PDCCH reception includes only one RS
- if the active TCI state for PDCCH reception includes two RS, the UE expects that one RS has QCL-TypeD [6, TS 38.214] and the UE uses the RS with QCL-TypeD for radio link monitoring; the UE does not expect both RS to have QCL-TypeD
- the UE is not required to use for radio link monitoring an aperiodic or semi-persistent RS
- For $L_{\max} = 4$, the UE selects the N_{RLM} RS provided for active TCI states for PDCCH receptions in CORESETs associated with the search space sets in an order from the shortest monitoring periodicity. If more than one CORESETs are associated with search space sets having same monitoring periodicity, the UE determines the order of the CORESET from the highest CORESET index as described in Clause 10.1.

A UE does not expect to use more than N_{RLM} *RadioLinkMonitoringRS* for radio link monitoring when the UE is not provided *RadioLinkMonitoringRS*.

Values of $N_{\text{LR-RLM}}$ and N_{RLM} for different values of $L_{\max}$ are given in Table 5-1.

Table 5-1: $N_{\mathrm{LR-RLM}}$ and N_{RLM} as a function of maximum number $L_{\max}$ of SS/PBCH blocks per half frame

$L_{\max}$	$N_{\mathrm{LR-RLM}}$	N_{RLM}
4	2	2
8	6	4
64	8	8

For a CSI-RS resource configuration, *powerControlOffsetSS* is not applicable and a UE expects to be provided only 'noCDM' from *cdm-Type*, only 'one' and 'three' from *density*, and only '1 port' from *nrofPorts* [6, TS 38.214].

If a UE is configured with multiple DL BWPs for a serving cell, the UE performs RLM using the RS(s) corresponding to resource indexes provided by *RadioLinkMonitoringRS* for the active DL BWP or, if *RadioLinkMonitoringRS* is not provided for the active DL BWP, using the RS(s) provided for the active TCI state for PDCCH receptions in CORESETs on the active DL BWP.

In non-DRX mode operation, the physical layer in the UE assesses once per indication period the radio link quality, evaluated over the previous time period defined in [10, TS 38.133] against thresholds (Q_{out} and Q_{in}) configured by *rlmInSyncOutOfSyncThreshold*. The UE determines the indication period as the maximum between the shortest periodicity for radio link monitoring resources and 10 msec.

In DRX mode operation, the physical layer in the UE assesses once per indication period the radio link quality, evaluated over the previous time period defined in [10, TS 38.133], against thresholds (Q_{out} and Q_{in}) provided by *rlmInSyncOutOfSyncThreshold*. The UE determines the indication period as the maximum between the shortest periodicity for radio link monitoring resources and the DRX period.

The physical layer in the UE indicates, in frames where the radio link quality is assessed, out-of-sync to higher layers when the radio link quality is worse than the threshold Q_{out} for all resources in the set of resources for radio link monitoring. When the radio link quality is better than the threshold Q_{in} for any resource in the set of resources for radio link monitoring, the physical layer in the UE indicates, in frames where the radio link quality is assessed, in-sync to higher layers.

6 Link recovery procedures

A UE can be provided, for each BWP of a serving cell, a set $\overline{q}_0$ of periodic CSI-RS resource configuration indexes by *failureDetectionResources* and a set $\overline{q}_1$ of periodic CSI-RS resource configuration indexes and/or SS/PBCH block indexes by *candidateBeamRSList* for radio link quality measurements on the BWP of the serving cell. If the UE is not provided *failureDetectionResources*, the UE determines the set $\overline{q}_0$ to include periodic CSI-RS resource configuration indexes with same values as the RS indexes in the RS sets indicated by *TCI-State* for respective CORESETs that the UE uses for monitoring PDCCH and, if there are two RS indexes in a TCI state, the set $\overline{q}_0$ includes RS indexes with QCL-TypeD configuration for the corresponding TCI states. The UE expects the set $\overline{q}_0$ to include up to two RS indexes. The UE expects single port RS in the set $\overline{q}_0$.

The thresholds $Q_{out,LR}$ and $Q_{in,LR}$ correspond to the default value of *rlmInSyncOutOfSyncThreshold*, as described in [10, TS 38.133] for Q_{out}, and to the value provided by *rsrp-ThresholdSSB*, respectively.

The physical layer in the UE assesses the radio link quality according to the set $\overline{q}_0$ of resource configurations against the threshold $Q_{out,LR}$. For the set $\overline{q}_0$, the UE assesses the radio link quality only according to periodic CSI-RS resource configurations or SS/PBCH blocks that are quasi co-located, as described in [6, TS 38.214], with the DM-RS of PDCCH receptions monitored by the UE. The UE applies the $Q_{in,LR}$ threshold to the L1-RSRP measurement obtained from a SS/PBCH block. The UE applies the $Q_{in,LR}$ threshold to the L1-RSRP measurement obtained for a CSI-RS resource after scaling a respective CSI-RS reception power with a value provided by *powerControlOffsetSS*.

In non-DRX mode operation, the physical layer in the UE provides an indication to higher layers when the radio link quality for all corresponding resource configurations in the set $\overline{q}_0$ that the UE uses to assess the radio link quality is worse than the threshold $Q_{out,LR}$. The physical layer informs the higher layers when the radio link quality is worse than the threshold $Q_{out,LR}$ with a periodicity determined by the maximum between the shortest periodicity among the periodic

CSI-RS configurations and/or SS/PBCH blocks in the set $\overline{q}_0$ that the UE uses to assess the radio link quality and 2 msec. In DRX mode operation, the physical layer provides an indication to higher layers when the radio link quality is worse than the threshold $Q_{out,LR}$ with a periodicity determined as described in [10, TS 38.133].

Upon request from higher layers, the UE provides to higher layers the periodic CSI-RS configuration indexes and/or SS/PBCH block indexes from the set $\overline{q}_1$ and the corresponding L1-RSRP measurements that are larger than or equal to the $Q_{in,LR}$ threshold.

A UE can be provided a CORESET through a link to a search space set provided by *recoverySearchSpaceId*, as described in Clause 10.1, for monitoring PDCCH in the CORESET. If the UE is provided *recoverySearchSpaceId*, the UE does not expect to be provided another search space set for monitoring PDCCH in the CORESET associated with the search space set provided by *recoverySearchSpaceId*.

The UE may receive by *PRACH-ResourceDedicatedBFR*, a configuration for PRACH transmission as described in Clause 8.1. For PRACH transmission in slot n and according to antenna port quasi co-location parameters associated with periodic CSI-RS resource configuration or with SS/PBCH block associated with index q_{new} provided by higher layers [11, TS 38.321], the UE monitors PDCCH in a search space set provided by *recoverySearchSpaceId* for detection of a DCI format with CRC scrambled by C-RNTI or MCS-C-RNTI starting from slot $n+4$ within a window configured by *BeamFailureRecoveryConfig*. For PDCCH monitoring in a search space set provided by *recoverySearchSpaceId* and for corresponding PDSCH reception, the UE assumes the same antenna port quasi-collocation parameters as the ones associated with index q_{new} until the UE receives by higher layers an activation for a TCI state or any of the parameters *tci-StatesPDCCH-ToAddList* and/or *tci-StatesPDCCH-ToReleaseList*. After the UE detects a DCI format with CRC scrambled by C-RNTI or MCS-C-RNTI in the search space set provided by *recoverySearchSpaceId*, the UE continues to monitor PDCCH candidates in the search space set provided by *recoverySearchSpaceId* until the UE receives a MAC CE activation command for a TCI state or *tci-StatesPDCCH-ToAddList* and/or *tci-StatesPDCCH-ToReleaseList*.

After 28 symbols from a last symbol of a first PDCCH reception in a search space set provided by *recoverySearchSpaceId* for which the UE detects a DCI format with CRC scrambled by C-RNTI or MCS-C-RNTI and until the UE receives an activation command for *PUCCH-SpatialRelationInfo* [11, TS 38.321] or is provided *PUCCH-SpatialRelationInfo* for PUCCH resource(s), the UE transmits a PUCCH on a same cell as the PRACH transmission using

- a same spatial filter as for the last PRACH transmission
- a power determined as described in Clause 7.2.1 with $q_u = 0$, $q_d = q_{\text{new}}$, and $l = 0$

After 28 symbols from a last symbol of a first PDCCH reception in a search space set provided by *recoverySearchSpaceId* where a UE detects a DCI format with CRC scrambled by C-RNTI or MCS-C-RNTI, the UE assumes same antenna port quasi-collocation parameters as the ones associated with index q_{new} for PDCCH monitoring in a CORESET with index 0.

7 Uplink Power control

Uplink power control determines a power for PUSCH, PUCCH, SRS, and PRACH transmissions.

A UE does not expect to simultaneously maintain more than four pathloss estimates per serving cell for all PUSCH/PUCCH/SRS transmissions as described in Clauses 7.1.1, 7.2.1, and 7.3.1.

A PUSCH/PUCCH/SRS/PRACH transmission occasion i is defined by a slot index $n_{s,f}^{\mu}$ within a frame with system frame number SFN, a first symbol S within the slot, and a number of consecutive symbols L.

7.1 Physical uplink shared channel

For a PUSCH transmission on active UL BWP b, as described in Clause 12, of carrier f of serving cell c, a UE first calculates a linear value $\hat{P}_{\text{PUSCH},b,f,c}(i,j,q_d,l)$ of the transmit power $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$, with parameters as defined

in Clause 7.1.1. For a PUSCH transmission scheduled by a DCI format 0_1 or configured by *ConfiguredGrantConfig* or *semiPersistentOnPUSCH*, if *txConfig* in *PUSCH-Config* is set to 'codebook' and each SRS resource in the *SRS-ResourceSet* with *usage* set to 'codebook' has more than one SRS port, the UE scales the linear value by the ratio of the number of antenna ports with a non-zero PUSCH transmission power to the maximum number of SRS ports supported by the UE in one SRS resource. The UE splits the power equally across the antenna ports on which the UE transmits the PUSCH with non-zero power.

7.1.1 UE behaviour

If a UE transmits a PUSCH on active UL BWP b of carrier f of serving cell c using parameter set configuration with index j and PUSCH power control adjustment state with index l, the UE determines the PUSCH transmission power $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$ in PUSCH transmission occasion i as

$$P_{\text{PUSCH},b,f,c}(i,j,q_d,l) = \min\left\{\begin{array}{l} P_{\text{CMAX},f,c}(i), \\ P_{\text{O\_PUSCH},b,f,c}(j) + 10\log_{10}(2^{\mu}\cdot M^{\text{PUSCH}}_{\text{RB},b,f,c}(i)) + \alpha_{b,f,c}(j)\cdot PL_{b,f,c}(q_d) + \Delta_{\text{TF},b,f,c}(i) + f_{b,f,c}(i,l) \end{array}\right\} \text{ [dBm]}$$

where,

- $P_{\text{CMAX},f,c}(i)$ is the UE configured maximum output power defined in [8-1, TS 38.101-1], [8-2, TS38.101-2] and [8-3, TS38.101-3] for carrier f of serving cell c in PUSCH transmission occasion i.

- $P_{\text{O\_PUSCH},b,f,c}(j)$ is a parameter composed of the sum of a component $P_{\text{O\_NOMINAL\_PUSCH},f,c}(j)$ and a component $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ where $j \in \{0, 1, ..., J-1\}$.

  - If a UE is not provided *P0-PUSCH-AlphaSet* or for a PUSCH transmission scheduled by a RAR UL grant as described in Clause 8.3, $j=0$, $P_{\text{O\_UE\_PUSCH},b,f,c}(0)=0$, and $P_{\text{O\_NOMINAL\_PUSCH},f,c}(0) = P_{\text{O\_PRE}} + \Delta_{PREAMBLE\_Msg3}$, where the parameter *preambleReceivedTargetPower* [11, TS 38.321] (for $P_{\text{O\_PRE}}$) and *msg3-DeltaPreamble* (for $\Delta_{PREAMBLE\_Msg3}$) are provided by higher layers, or $\Delta_{PREAMBLE\_Msg3}=0$ dB if *msg3-DeltaPreamble* is not provided, for carrier f of serving cell c

  - For a PUSCH (re)transmission configured by *ConfiguredGrantConfig*, $j=1$, $P_{\text{O\_NOMINAL\_PUSCH},f,c}(1)$ is provided by *p0-NominalWithoutGrant*, or $P_{\text{O\_NOMINAL\_PUSCH},f,c}(1) = P_{\text{O\_NOMINAL\_PUSCH},f,c}(0)$ if *p0-NominalWithoutGrant* is not provided, and $P_{\text{O\_UE\_PUSCH},b,f,c}(1)$ is provided by *p0* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* that provides an index *P0-PUSCH-AlphaSetId* to a set of *P0-PUSCH-AlphaSet* for active UL BWP b of carrier f of serving cell c

  - For $j \in \{2, ..., J-1\} = S_J$, a $P_{\text{O\_NOMINAL\_PUSCH},f,c}(j)$ value, applicable for all $j \in S_J$, is provided by *p0-NominalWithGrant*, or $P_{\text{O\_NOMINAL\_PUSCH},f,c}(j) = P_{\text{O\_NOMINAL\_PUSCH},f,c}(0)$ if *p0-NominalWithGrant* is not provided, for each carrier f of serving cell c and a set of $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ values are provided by a set of *p0* in *P0-PUSCH-AlphaSet* indicated by a respective set of *p0-PUSCH-AlphaSetId* for active UL BWP b of carrier f of serving cell c

    - If the UE is provided by *SRI-PUSCH-PowerControl* more than one values of *p0-PUSCH-AlphaSetId* and if DCI format 0_1 includes a SRI field, the UE obtains a mapping from *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 [5, TS 38.212] and a set of indexes provided by *p0-PUSCH-AlphaSetId* that map to a set of *P0-PUSCH-AlphaSet* values. If the PUSCH transmission is scheduled by a DCI format 0_1 that includes a SRI field, the UE determines the value of $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ from the *p0-PUSCH-AlphaSetId* value that is mapped to the SRI field value

- If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if *SRI-PUSCHPowerControl* is not provided to the UE, $j=2$, and the UE determines $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ from the value of the first *P0-PUSCH-AlphaSet* in *p0-AlphaSets*

- For $\alpha_{b,f,c}(j)$

  - For $j=0$, $\alpha_{b,f,c}(0)$ is a value of *msg3-Alpha*, when provided; otherwise, $\alpha_{b,f,c}(0)=1$

  - For $j=1$, $\alpha_{b,f,c}(1)$ is provided by *alpha* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* providing an index *P0-PUSCH-AlphaSetId* to a set of *P0-PUSCH-AlphaSet* for active UL BWP b of carrier f of serving cell c

  - For $j\in S_J$, a set of $\alpha_{b,f,c}(j)$ values are provided by a set of *alpha* in *P0-PUSCH-AlphaSet* indicated by a respective set of *p0-PUSCH-AlphaSetId* for active UL BWP b of carrier f of serving cell c

    - If the UE is provided *SRI-PUSCH-PowerControl* and more than one values of *p0-PUSCH-AlphaSetId*, and if DCI format 0_1 includes a SRI field, the UE obtains a mapping from *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 [5, TS 38.212] and a set of indexes provided by *p0-PUSCH-AlphaSetId* that map to a set of *P0-PUSCH-AlphaSet* values. If the PUSCH transmission is scheduled by a DCI format 0_1 that includes a SRI field, the UE determines the values of $\alpha_{b,f,c}(j)$ from the *p0-PUSCH-AlphaSetId* value that is mapped to the SRI field value

    - If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if *SRI-PUSCH-PowerControl* is not provided to the UE, $j=2$, and the UE determines $\alpha_{b,f,c}(j)$ from the value of the first *P0-PUSCH-AlphaSet* in *p0-AlphaSets*

- $M_{\text{RB},b,f,c}^{\text{PUSCH}}(i)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c and μ is a SCS configuration defined in [4, TS 38.211]

- $PL_{b,f,c}(q_d)$ is a downlink pathloss estimate in dB calculated by the UE using reference signal (RS) index q_d for the active DL BWP, as described in Clause 12, of carrier f of serving cell c

  - If the UE is not provided *PUSCH-PathlossReferenceRS* or before the UE is provided dedicated higher layer parameters, the UE calculates $PL_{b,f,c}(q_d)$ using a RS resource from the SS/PBCH block that the UE uses to obtain *MIB*

  - If the UE is configured with a number of RS resource indexes, up to the value of *maxNrofPUSCH-PathlossReferenceRSs*, and a respective set of RS configurations for the number of RS resource indexes by *PUSCH-PathlossReferenceRS*, the set of RS resource indexes can include one or both of a set of SS/PBCH block indexes, each provided by *ssb-Index* when a value of a corresponding *pusch-PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by *csi-RS-Index* when a value of a corresponding *pusch-PathlossReferenceRS-Id* maps to a CSI-RS resource index. The UE identifies a RS resource index q_d in the set of RS resource indexes to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by *pusch-PathlossReferenceRS-Id* in *PUSCH-PathlossReferenceRS*

  - If the PUSCH transmission is scheduled by a RAR UL grant as described in Clause 8.3, the UE uses the same RS resource index q_d as for a corresponding PRACH transmission

  - If the UE is provided *SRI-PUSCH-PowerControl* and more than one values of *PUSCH-PathlossReferenceRS-Id*, the UE obtains a mapping from *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 and a set of *PUSCH-PathlossReferenceRS-Id* values. If the PUSCH transmission is scheduled by a DCI format 0_1 that includes a SRI field, the UE determines the RS resource index q_d from the value of *PUSCH-PathlossReferenceRS-Id*

that is mapped to the SRI field value where the RS resource is either on serving cell c or, if provided, on a serving cell indicated by a value of *pathlossReferenceLinking*

- If the PUSCH transmission is scheduled by a DCI format 0_0, and if the UE is provided a spatial setting by *PUCCH-SpatialRelationInfo* for a PUCCH resource with a lowest index for active UL BWP b of each carrier f and serving cell c, as described in Clause 9.2.2, the UE uses the same RS resource index q_d as for a PUCCH transmission in the PUCCH resource with the lowest index

- If the PUSCH transmission is scheduled by a DCI format 0_0 and if the UE is not provided a spatial setting for a PUCCH transmission, or by a DCI format 0_1 that does not include a SRI field, or if *SRI-PUSCH-PowerControl* is not provided to the UE, the UE determines a RS resource index q_d with a respective *PUSCH-PathlossReferenceRS-Id* value being equal to zero where the RS resource is either on serving cell c or, if provided, on a serving cell indicated by a value of *pathlossReferenceLinking*

- For a PUSCH transmission configured by *ConfiguredGrantConfig*, if *rrc-ConfiguredUplinkGrant* is included in *ConfiguredGrantConfig* , a RS resource index q_d is provided by a value of *pathlossReferenceIndex* included in *rrc-ConfiguredUplinkGrant* where the RS resource is either on serving cell c or, if provided, on a serving cell indicated by a value of *pathlossReferenceLinking*

- For a PUSCH transmission configured by *ConfiguredGrantConfig* that does not include *rrc-ConfiguredUplinkGrant*, the UE determines a RS resource index q_d from a value of *PUSCH-PathlossReferenceRS-Id* that is mapped to a SRI field value in a DCI format activating the PUSCH transmission. If the DCI format activating the PUSCH transmission does not include a SRI field, the UE determines a RS resource index q_d with a respective *PUSCH-PathlossReferenceRS-Id* value being equal to zero where the RS resource is either on serving cell c or, if provided, on a serving cell indicated by a value of *pathlossReferenceLinking*

$PL_{b,f,c}(q_d)$ = *referenceSignalPower* – higher layer filtered RSRP, where *referenceSignalPower* is provided by higher layers and RSRP is defined in [7, TS 38.215] for the reference serving cell and the higher layer filter configuration provided by *QuantityConfig* is defined in [12, TS 38.331] for the reference serving cell

If the UE is not configured periodic CSI-RS reception, *referenceSignalPower* is provided by *ss-PBCH-BlockPower*. If the UE is configured periodic CSI-RS reception, *referenceSignalPower* is provided either by *ss-PBCH-BlockPower* or by *powerControlOffsetSS* providing an offset of the CSI-RS transmission power relative to the SS/PBCH block transmission power [6, TS 38.214]. If *powerControlOffsetSS* is not provided to the UE, the UE assumes an offset of 0 dB.

- $\Delta_{\mathrm{TF},b,f,c}(i) = 10\log_{10}\left(\left(2^{\mathrm{BPRE}\cdot K_S}-1\right)\cdot\beta_{\mathrm{offset}}^{\mathrm{PUSCH}}\right)$ for $K_S = 1.25$ and $\Delta_{\mathrm{TF},b,f,c}(i) = 0$ for $K_S = 0$ where K_S is provided by *deltaMCS* for each UL BWP b of each carrier f and serving cell c. If the PUSCH transmission is over more than one layer [6, TS 38.214], $\Delta_{\mathrm{TF},b,f,c}(i) = 0$. BPRE and $\beta_{\mathrm{offset}}^{\mathrm{PUSCH}}$, for active UL BWP b of each carrier f and each serving cell c, are computed as below

  - $\mathrm{BPRE} = \sum_{r=0}^{C-1} K_r / N_{\mathrm{RE}}$ for PUSCH with UL-SCH data and $\mathrm{BPRE} = Q_{\mathrm{m}} \cdot R \Big/ \beta_{\mathrm{offset}}^{\mathrm{PUSCH}}$ for CSI transmission in a PUSCH without UL-SCH data, where

    - C is a number of transmitted code blocks, K_r is a size for code block r, and N_{RE} is a number of resource elements determined as $N_{\mathrm{RE}} = M_{\mathrm{RB},b,f,c}^{\mathrm{PUSCH}}(i) \cdot \sum_{j=0}^{N_{\mathrm{symb},b,f,c}^{\mathrm{PUSCH}}(i)-1} N_{\mathrm{sc,data}}^{\mathrm{RB}}(i,j)$, where $N_{\mathrm{symb},b,f,c}^{\mathrm{PUSCH}}(i)$ is a number of symbols for PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c, $N_{\mathrm{sc,data}}^{\mathrm{RB}}(i,j)$ is a number of subcarriers excluding DM-RS subcarriers and phase-tracking RS samples [4, TS 38.211] in PUSCH symbol j, $0 \le j < N_{\mathrm{symb},b,f,c}^{\mathrm{PUSCH}}(i)$, and C , K_r are defined in [5, TS 38.212]

  - $\beta_{\mathrm{offset}}^{\mathrm{PUSCH}} = 1$ when the PUSCH includes UL-SCH data and $\beta_{\mathrm{offset}}^{\mathrm{PUSCH}} = \beta_{\mathrm{offset}}^{\mathrm{CSI,1}}$, as described in Clause 9.3, when the PUSCH includes CSI and does not include UL-SCH data

- Q_m is the modulation order and R is the target code rate, as described in [6, TS 38.214], provided by the DCI format scheduling the PUSCH transmission that includes CSI and does not include UL-SCH data

- For the PUSCH power control adjustment state $f_{b,f,c}(i,l)$ for active UL BWP b of carrier f of serving cell c in PUSCH transmission occasion i

  - $\delta_{\text{PUSCH},b,f,c}(i,l)$ is a TPC command value included in a DCI format 0_0 or DCI format 0_1 that schedules the PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c or jointly coded with other TPC commands in a DCI format 2_2 with CRC scrambled by TPC-PUSCH-RNTI, as described in Clause 11.3

    - $l \in \{0,1\}$ if the UE is configured with *twoPUSCH-PC-AdjustmentStates* and $l=0$ if the UE is not configured with *twoPUSCH-PC-AdjustmentStates* or if the PUSCH transmission is scheduled by a RAR UL grant as described in Clause 8.3

      - For a PUSCH (re)transmission configured by *ConfiguredGrantConfig*, the value of $l \in \{0,1\}$ is provided to the UE by *powerControlLoopToUse*

      - If the UE is provided *SRI-PUSCH-PowerControl*, the UE obtains a mapping between a set of values for the SRI field in DCI format 0_1 and the l value(s) provided by *sri-PUSCH-ClosedLoopIndex*. If the PUSCH transmission is scheduled by a DCI format 0_1 and if DCI format 0_1 includes a SRI field, the UE determines the l value that is mapped to the SRI field value

      - If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if a *SRI-PUSCH-PowerControl* is not provided to the UE, $l=0$

      - If the UE obtains one TPC command from a DCI format 2_2 with CRC scrambled by a TPC-PUSCH-RNTI, the l value is provided by the closed loop indicator field in DCI format 2_2

  - $f_{b,f,c}(i,l) = f_{b,f,c}(i-i_0,l) + \sum_{m=0}^{\mathcal{C}(D_i)-1} \delta_{\text{PUSCH},b,f,c}(m,l)$ is the PUSCH power control adjustment state l for active UL BWP b of carrier f of serving cell c and PUSCH transmission occasion i if the UE is not provided *tpc-Accumulation*, where

    - The $\delta_{\text{PUSCH}b,f,c}$ values are given in Table 7.1.1-1

    - $\sum_{m=0}^{\mathcal{C}(D_i)-1} \delta_{\text{PUSCH},\,b,f,c}(m,l)$ is a sum of TPC command values in a set D_i of TPC command values with cardinality $\mathcal{C}(D_i)$ that the UE receives between $K_{\text{PUSCH}}(i-i_0)-1$ symbols before PUSCH transmission occasion $i-i_0$ and $K_{\text{PUSCH}}(i)$ symbols before PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c for PUSCH power control adjustment state l, where $i_0>0$ is the smallest integer for which $K_{\text{PUSCH}}(i-i_0)$ symbols before PUSCH transmission occasion $i-i_0$ is earlier than $K_{\text{PUSCH}}(i)$ symbols before PUSCH transmission occasion i

    - If a PUSCH transmission is scheduled by a DCI format 0_0 or DCI format 0_1, $K_{\text{PUSCH}}(i)$ is a number of symbols for active UL BWP b of carrier f of serving cell c after a last symbol of a corresponding PDCCH reception and before a first symbol of the PUSCH transmission

    - If a PUSCH transmission is configured by *ConfiguredGrantConfig*, $K_{\text{PUSCH}}(i)$ is a number of $K_{\text{PUSCH,min}}$ symbols equal to the product of a number of symbols per slot, $N_{\text{symb}}^{\text{slot}}$, and the minimum of the values provided by *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

- If the UE has reached maximum power for active UL BWP b of carrier f of serving cell c at PUSCH transmission occasion $i - i_0$ and $\sum_{m=0}^{\mathcal{C}(D_i)-1} \delta_{\text{PUSCH},b,f,c}(m,l) \geq 0$, then $f_{b,f,c}(i,l) = f_{b,f,c}(i-i_0,l)$

- If UE has reached minimum power for active UL BWP b of carrier f of serving cell c at PUSCH transmission occasion $i - i_0$ and $\sum_{m=0}^{\mathcal{C}(D_i)-1} \delta_{\text{PUSCH},b,f,c}(m,l) \leq 0$, then $f_{b,f,c}(i,l) = f_{b,f,c}(i-i_0,l)$

- A UE resets accumulation of a PUSCH power control adjustment state l for active UL BWP b of carrier f of serving cell c to $f_{b,f,c}(k,l) = 0, k = 0,1,...,i$

  - If a configuration for a corresponding $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ value is provided by higher layers

  - If a configuration for a corresponding $\alpha_{b,f,c}(j)$ value is provided by higher layers

  where l is determined from the value of j as

  - If $j > 1$ and the UE is provided higher *SRI-PUSCH-PowerControl*, l is the *sri-PUSCH-ClosedLoopIndex* value(s) configured in any *SRI-PUSCH-PowerControl* with the *sri-P0-PUSCH-AlphaSetId* value corresponding to j

  - If $j > 1$ and the UE is not provided *SRI-PUSCH-PowerControl* or $j = 0$, $l = 0$

  - If $j = 1$, l is provided by the value of *powerControlLoopToUse*

- $f_{b,f,c}(i,l) = \delta_{\text{PUSCH}b,f,c}(i,l)$ is the PUSCH power control adjustment state for active UL BWP b of carrier f of serving cell c and PUSCH transmission occasion i if the UE is provided *tpc-Accumulation*, where

  - $\delta_{\text{PUSCH},b,f,c}$ absolute values are given in Table 7.1.1-1

- If the UE receives a random access response message in response to a PRACH transmission on active UL BWP b of carrier f of serving cell c as described in Clause 8

  - $f_{b,f,c}(0,l) = \Delta P_{rampup,b,f,c} + \delta_{msg2,b,f,c}$, where $l = 0$ and

    - $\delta_{msg2,b,f,c}$ is a TPC command value indicated in the random access response grant of the random access response message corresponding to the PRACH transmission on active UL BWP b of carrier f in the serving cell c, and

    - $$\Delta P_{rampup,b,f,c} = \min\left[\left\{\max\left(0, P_{\text{CMAX},f,c} - \begin{pmatrix} 10\log_{10}(2^{\mu} \cdot M^{\text{PUSCH}}_{\text{RB},b,f,c}(0)) \\ + P_{\text{O\_PUSCH},b,f,c}(0) + \alpha_{b,f,c}(0) \cdot PL_c \\ + \Delta_{\text{TF},b,f,c}(0) + \delta_{msg2,b,f,c} \end{pmatrix}\right)\right\}, \quad \Delta P_{rampuprequested,b,f,c}\right]$$

      and $\Delta P_{rampuprequested,b,f,c}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last random access preamble for carrier f in the serving cell c, $M^{\text{PUSCH}}_{\text{RB},b,f,c}(0)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for the first PUSCH transmission on active UL BWP b of carrier f of serving cell c, and $\Delta_{TF,b,f,c}(0)$ is the power adjustment of first PUSCH transmission on active UL BWP b of carrier f of serving cell c.

Table 7.1.1-1: Mapping of TPC Command Field in DCI format 0_0, DCI format 0_1, or DCI format 2_2, with CRC scrambled by TPC-PUSCH-RNTI, or DCI format 2_3, to absolute and accumulated $\delta_{\text{PUSCH},b,f,c}$ values or $\delta_{\text{SRS},b,f,c}$ values

TPC Command Field	Accumulated $\delta_{\text{PUSCH},b,f,c}$ or $\delta_{\text{SRS},b,f,c}$ [dB]	Absolute $\delta_{\text{PUSCH},b,f,c}$ or $\delta_{\text{SRS},b,f,c}$ [dB]
0	-1	-4
1	0	-1
2	1	1
3	3	4

7.2 Physical uplink control channel

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG.

- When the procedures are applied for MCG, the term 'serving cell' in this clause refers to serving cell belonging to the MCG.
- When the procedures are applied for SCG, the term 'serving cell' in this clause refers to serving cell belonging to the SCG. The term 'primary cell' in this clause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this clause for both primary PUCCH group and secondary PUCCH group.

- When the procedures are applied for the primary PUCCH group, the term 'serving cell' in this clause refers to serving cell belonging to the primary PUCCH group.
- When the procedures are applied for the secondary PUCCH group, the term 'serving cell' in this clause refers to serving cell belonging to the secondary PUCCH group. The term 'primary cell' in this clause refers to the PUCCH-SCell of the secondary PUCCH group.

7.2.1 UE behaviour

If a UE transmits a PUCCH on active UL BWP b of carrier f in the primary cell c using PUCCH power control adjustment state with index l, the UE determines the PUCCH transmission power $P_{\text{PUCCH}b,f,c}(i,q_u,q_d,l)$ in PUCCH transmission occasion i as

$$P_{\text{PUCCH},b,f,c}(i,q_u,q_d,l) = \min\left\{\begin{matrix} P_{\text{CMAX},f,c}(i), \\ P_{\text{O\_PUCCH},b,f,c}(q_u) + 10\log_{10}(2^{\mu}\cdot M^{\text{PUCCH}}_{\text{RB},b,f,c}(i)) + PL_{b,f,c}(q_d) + \Delta_{\text{F\_PUCCH}}(F) + \Delta_{\text{TF},b,f,c}(i) + g_{b,f,c}(i,l) \end{matrix}\right\} \quad \text{[dBm]}$$

where

- $P_{\text{CMAX},f,c}(i)$ is the UE configured maximum output power defined in [8-1, TS 38.101-1], [8-2, TS38.101-2] and [8-3, TS38.101-3] for carrier f of serving cell c in PUCCH transmission occasion i
- $P_{\text{O\_PUCCH},b,f,c}(q_u)$ is a parameter composed of the sum of a component $P_{\text{O\_NOMINAL\_PUCCH}}$, provided by *p0-nominal*, or $P_{\text{O\_NOMINAL\_PUCCH}} = 0$ dBm if *p0-nominal* is not provided, for carrier f of primary cell c and, if provided, a component $P_{\text{O\_UE\_PUCCH}}(q_u)$ provided by *p0-PUCCH-Value* in *P0-PUCCH* for active UL BWP b of carrier f of primary cell c, where $0 \le q_u < Q_u$. Q_u is a size for a set of $P_{\text{O\_UE\_PUCCH}}$ values provided by *maxNrofPUCCH-P0-PerSet*. The set of $P_{\text{O\_UE\_PUCCH}}$ values is provided by *p0-Set*. If *p0-Set* is not provided to the UE, $P_{\text{O\_UE\_PUCCH}}(q_u) = 0$, $0 \le q_u < Q_u$
  - If the UE is provided *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of *p0-PUCCH-Value* values. If the UE is provided more than one values for *pucch-SpatialRelationInfoId* and the UE receives an activation

command [11, TS 38.321] indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the *p0-PUCCH-Value* value through the link to a corresponding *p0-PUCCH-Id* index. The UE applies the activation command in the first slot that is after slot $k+3\cdot N_{\text{slot}}^{\text{subframe},\mu}$ where k is the slot where the UE would transmit a PUCCH with HARQ-ACK information for the PDSCH providing the activation command and μ is the SCS configuration for the PUCCH

- If the UE is not provided *PUCCH-SpatialRelationInfo*, the UE obtains the *p0-PUCCH-Value* value from the *P0-PUCCH* with *p0-PUCCH-Id* value equal to the minimum *p0-PUCCH-Id* value in *p0-Set*

- $M_{\text{RB},b,f,c}^{\text{PUCCH}}(i)$ is a bandwidth of the PUCCH resource assignment expressed in number of resource blocks for PUCCH transmission occasion i on active UL BWP b of carrier f of serving cell c and μ is a SCS configuration defined in [4, TS 38.211]

- $PL_{b,f,c}(q_d)$ is a downlink pathloss estimate in dB calculated by the UE using RS resource index q_d as described in Clause 7.1.1 for the active DL BWP b of carrier f of the primary cell c as described in Clause 12

  - If the UE is not provided *pathlossReferenceRSs* or before the UE is provided dedicated higher layer parameters, the UE calculates $PL_{b,f,c}(q_d)$ using a RS resource obtained from the SS/PBCH block that the UE uses to obtain *MIB*

  - If the UE is provided a number of RS resource indexes, the UE calculates $PL_{b,f,c}(q_d)$ using RS resource with index q_d, where $0 \le q_d < Q_d$. Q_d is a size for a set of RS resources provided by *maxNrofPUCCH-PathlossReferenceRSs*. The set of RS resources is provided by *pathlossReferenceRSs*. The set of RS resources can include one or both of a set of SS/PBCH block indexes, each provided by *ssb-Index* in *PUCCH-PathlossReferenceRS* when a value of a corresponding *pucch-PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by *csi-RS-Index* when a value of a corresponding *pucch-PathlossReferenceRS-Id* maps to a CSI-RS resource index. The UE identifies a RS resource in the set of RS resources to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by *pucch-PathlossReferenceRS-Id* in *PUCCH-PathlossReferenceRS*

  - If the UE is provided *pathlossReferenceRSs* and *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by indexes provided by corresponding values of *pucch-PathlossReferenceRS-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of *referenceSignal* values provided by *PUCCH-PathlossReferenceRS*. If the UE is provided more than one values for *pucch-SpatialRelationInfoId* and the UE receives an activation command [11, TS 38.321] indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the *referenceSignal* value in *PUCCH-PathlossReferenceRS* through the link to a corresponding *pucch-PathlossReferenceRS-Id* index. The UE applies the activation command in the first slot that is after slot $k+3\cdot N_{\text{slot}}^{\text{subframe},\mu}$ where k is the slot where the UE would transmit a PUCCH with HARQ-ACK information for the PDSCH providing the activation command and μ is the SCS configuration for the PUCCH

  - If *PUCCH-SpatialRelationInfo* includes *servingCellId* indicating a serving cell, the UE receives the RS for resource index q_d on the active DL BWP of the serving cell

  - If the UE is provided *pathlossReferenceRSs* and is not provided *PUCCH-SpatialRelationInfo*, the UE obtains the *referenceSignal* value in *PUCCH-PathlossReferenceRS* from the *pucch-PathlossReferenceRS-Id* with index 0 in *PUCCH-PathlossReferenceRS* where the RS resource is either on a same serving cell or, if provided, on a serving cell indicated by a value of *pathlossReferenceLinking*

- The parameter $\Delta_{\text{F\_PUCCH}}(F)$ is a value of *deltaF-PUCCH-f0* for PUCCH format 0, *deltaF-PUCCH-f1* for PUCCH format 1, *deltaF-PUCCH-f2* for PUCCH format 2, *deltaF-PUCCH-f3* for PUCCH format 3, and *deltaF-PUCCH-f4* for PUCCH format 4, if provided; otherwise $\Delta_{\text{F\_PUCCH}}(F) = 0$.

- $\Delta_{\text{TF},b,f,c}(i)$ is a PUCCH transmission power adjustment component on active UL BWP b of carrier f of primary cell c

- For a PUCCH transmission using PUCCH format 0 or PUCCH format 1,
  $\Delta_{\mathrm{TF},b,f,c}(i) = 10\log_{10}\left(\frac{N_{\mathrm{ref}}^{\mathrm{PUCCH}}}{N_{\mathrm{symb}}^{\mathrm{PUCCH}}(i)}\right) + \Delta_{\mathrm{UCI}}(i)$ where
  - $N_{\mathrm{symb}}^{\mathrm{PUCCH}}(i)$ is a number of PUCCH format 0 symbols or PUCCH format 1 symbols for the PUCCH transmission as described in Clause 9.2.
  - $N_{\mathrm{ref}}^{\mathrm{PUCCH}} = 2$ for PUCCH format 0
  - $N_{\mathrm{ref}}^{\mathrm{PUCCH}} = N_{\mathrm{symb}}^{\mathrm{slot}}$ for PUCCH format 1
  - $\Delta_{\mathrm{UCI}}(i) = 0$ for PUCCH format 0
  - $\Delta_{\mathrm{UCI}}(i) = 10\log_{10}\left(O_{\mathrm{UCI}}(i)\right)$ for PUCCH format 1, where $O_{\mathrm{UCI}}(i)$ is a number of UCI bits in PUCCH transmission occasion i
- For a PUCCH transmission using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and for a number of UCI bits smaller than or equal to 11,
  $\Delta_{\mathrm{TF},b,f,c}(i) = 10\log_{10}\left(K_1 \cdot \left(n_{\mathrm{HARQ\text{-}ACK}}(i) + O_{\mathrm{SR}}(i) + O_{\mathrm{CSI}}(i)\right) / N_{\mathrm{RE}}(i)\right)$, where
  - $K_1 = 6$
  - $n_{\mathrm{HARQ\text{-}ACK}}(i)$ is a number of HARQ-ACK information bits that the UE determines as described in Clause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Clause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided with *pdsch-HARQ-ACK-Codebook*, $n_{\mathrm{HARQ\text{-}ACK}}(i) = 1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $n_{\mathrm{HARQ\text{-}ACK}}(i) = 0$
    - $O_{\mathrm{SR}}(i)$ is a number of SR information bits that the UE determines as described in Clause 9.2.5.1
    - $O_{\mathrm{CSI}}(i)$ is a number of CSI information bits that the UE determines as described in Clause 9.2.5.2
  - $N_{\mathrm{RE}}(i)$ is a number of resource elements determined as $N_{\mathrm{RE}}(i) = M_{\mathrm{RB}b,f,c}^{\mathrm{PUCCH}}(i) \cdot N_{\mathrm{sc,ctrl}}^{\mathrm{RB}}(i) \cdot N_{\mathrm{symb\text{-}UCI}b,f,c}^{\mathrm{PUCCH}}(i)$, where $N_{\mathrm{sc,ctrl}}^{\mathrm{RB}}(i)$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N_{\mathrm{symb\text{-}UCI}b,f,c}^{\mathrm{PUCCH}}(i)$ is a number of symbols excluding symbols used for DM-RS transmission, as defined in Clause 9.2.5.2, for PUCCH transmission occasion i on active UL BWP b of carrier f of serving cell c
- For a PUCCH transmission using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and for a number of UCI bits larger than 11, $\Delta_{\mathrm{TF},b,f,c}(i) = 10\log_{10}\left(2^{K_2 \cdot \mathrm{BPRE}(i)} - 1\right)$, where
  - $K_2 = 2.4$
  - $\mathrm{BPRE}(i) = \left(O_{\mathrm{ACK}}(i) + O_{\mathrm{SR}}(i) + O_{\mathrm{CSI}}(i) + O_{\mathrm{CRC}}(i)\right) / N_{\mathrm{RE}}(i)$
  - $O_{\mathrm{ACK}}(i)$ is a number of HARQ-ACK information bits that the UE determines as described in Clause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Clause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided *pdsch-HARQ-ACK-Codebook*, $O_{\mathrm{ACK}} = 1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $O_{\mathrm{ACK}} = 0$
  - $O_{\mathrm{SR}}(i)$ is a number of SR information bits that the UE determines as described in Clause 9.2.5.1
  - $O_{\mathrm{CSI}}(i)$ is a number of CSI information bits that the UE determines as described in Clause 9.2.5.2
  - $O_{\mathrm{CRC}}(i)$ is a number of CRC bits that the UE determines as described in Clause 9.2

- $N_{\text{RE}}(i)$ is a number of resource elements that the UE determines as $N_{\text{RE}}(i) = M^{\text{PUCCH}}_{\text{RB},b,f,c}(i) \cdot N^{\text{RB}}_{\text{sc,ctrl}}(i) \cdot N^{\text{PUCCH}}_{\text{symb-UCI},b,f,c}(i)$, where $N^{\text{RB}}_{\text{sc, ctrl}}(i)$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N^{\text{PUCCH}}_{\text{symb-UCI},b,f,c}(i)$ is a number of symbols excluding symbols used for DM-RS transmission, as defined in Clause 9.2.5.2, for PUCCH transmission occasion i on active UL BWP b of carrier f of serving cell c.

- For the PUCCH power control adjustment state $g_{b,f,c}(i,l)$ for active UL BWP b of carrier f of primary cell c and PUCCH transmission occasion i

  - $\delta_{\text{PUCCH},b,f,c}(i,l)$ is a TPC command value and is included in a DCI format 1_0 or DCI format 1_1 for active UL BWP b of carrier f of the primary cell c that the UE detects for PUCCH transmission occasion i or is jointly coded with other TPC commands in a DCI format 2_2 with CRC scrambled by TPC-PUCCH-RNTI [5, TS 36.212], as described in Clause 11.3

    - $l \in \{0,1\}$ if the UE is provided *twoPUCCH-PC-AdjustmentStates* and *PUCCH-SpatialRelationInfo* and $l = 0$ if the UE is not provided *twoPUCCH-PC-AdjustmentStates* or *PUCCH-SpatialRelationInfo*

    - If the UE obtains a TPC command value from a DCI format 1_0 or a DCI format 1_1 and if the UE is provided *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of values for *closedLoopIndex* that provide the l value(s). If the UE receives an activation command indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the value *closedLoopIndex* that provides the value of l through the link to a corresponding *p0-PUCCH-Id* index

    - If the UE obtains one TPC command from a DCI format 2_2 with CRC scrambled by a TPC-PUCCH-RNTI, the l value is provided by the closed loop indicator field in DCI format 2_2

  - $g_{b,f,c}(i,l) = g_{b,f,c}(i-i_0,l) + \sum_{m=0}^{\mathcal{C}(C_i)-1} \delta_{\text{PUCCH},b,f,c}(m,l)$ is the current PUCCH power control adjustment state l for active UL BWP b of carrier f of serving cell c and PUCCH transmission occasion i, where

    - The $\delta_{\text{PUCCH},b,f,c}$ values are given in Table 7.1.2-1

    - $\sum_{m=0}^{\mathcal{C}(C_i)-1} \delta_{\text{PUCCH},b,f,c}(m,l)$ is a sum of TPC command values in a set C_i of TPC command values with cardinality $\mathcal{C}(C_i)$ that the UE receives between $K_{\text{PUCCH}}(i-i_0)-1$ symbols before PUCCH transmission occasion $i-i_0$ and $K_{\text{PUCCH}}(i)$ symbols before PUCCH transmission occasion i on active UL BWP b of carrier f of serving cell c for PUCCH power control adjustment state, where $i_0 > 0$ is the smallest integer for which $K_{\text{PUCCH}}(i-i_0)$ symbols before PUCCH transmission occasion $i-i_0$ is earlier than $K_{\text{PUCCH}}(i)$ symbols before PUCCH transmission occasion i

    - If the PUCCH transmission is in response to a detection by the UE of a DCI format 1_0 or DCI format 1_1, $K_{\text{PUCCH}}(i)$ is a number of symbols for active UL BWP b of carrier f of serving cell c after a last symbol of a corresponding PDCCH reception and before a first symbol of the PUCCH transmission

    - If the PUCCH transmission is not in response to a detection by the UE of a DCI format 1_0 or DCI format 1_1, $K_{\text{PUCCH}}(i)$ is a number of $K_{\text{PUCCH, min}}$ symbols equal to the product of a number of symbols per slot, $N^{\text{slot}}_{\text{symb}}$, and the minimum of the values provided by *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

    - If the UE has reached maximum power for active UL BWP b of carrier f of primary cell c at PUCCH transmission occasion $i-i_0$ and $\sum_{m=0}^{\mathcal{C}(C_i)-1} \delta_{\text{PUCCH, }b,f,c}(m,l) \geq 0$, then $g_{b,f,c}(i,l) = g_{b,f,c}(i-i_0,l)$

- If UE has reached minimum power for active UL BWP b of carrier f of primary cell c at PUCCH transmission occasion $i - i_0$ and $\sum_{m=0}^{\mathcal{O}(C_i)-1} \delta_{\text{PUCCH},b,f,c}(m,l) \le 0$, then $g_{b,f,c}(i,l) = g_{b,f,c}(i-i_0,l)$

- If a configuration of a $P_{\text{O\_PUCCH},b,f,c}(q_u)$ value for a corresponding PUCCH power control adjustment state l for active UL BWP b of carrier f of serving cell c is provided by higher layers,

  - $g_{b,f,c}(k,l) = 0, k = 0,1,...,i$

    If the UE is provided *PUCCH-SpatialRelationInfo*, the UE determines the value of l from the value of q_u based on a *pucch-SpatialRelationInfoId* value associated with the *p0-PUCCH-Id* value corresponding to q_u and with the *closedLoopIndex* value corresponding to l; otherwise, $l = 0$

- Else,

  - $g_{b,f,c}(0,l) = \Delta P_{rampup,b,f,c} + \delta_{b,f,c}$, where $l = 0$, and $\delta_{b,f,c}$ is the TPC command value indicated in a random access response grant corresponding to a PRACH transmission or is the TPC command value in a DCI format with CRC scrambled by C-RNTI or MCS-C-RNTI that the UE detects in a first PDCCH reception in a search space set provided by *recoverySearchSpaceId* if the PUCCH transmission is a first PUCCH transmission after 28 symbols from a last symbol of the first PDCCH reception, and, if the UE transmits PUCCH on active UL BWP b of carrier f of serving cell c,

$$\Delta P_{rampup,b,f,c} = \min\left[\begin{array}{l}\max\left(0,\ P_{CMAX,f,c} - (P_{O\_PUCCH,b,f,c} + PL_{b,f,c}(q_d) + \Delta_{F\_PUCCH}(F) + \Delta_{TF,b,f,c} + \delta_{b,f,c})\right)\\ \Delta P_{rampuprequested,b,f,c}\end{array}\right];$$

otherwise,

$$\Delta P_{rampup,b,f,c} = \min\left[\begin{array}{l}\max\left(0,\ P_{\text{CMAX},f,c} - \left(P_{\text{O\_PUCCH},b,f,c} + PL_{b,f,c}(q_d)\right)\right),\\ \Delta P_{rampuprequested,b,f,c}\end{array}\right]$$ where $\Delta P_{rampuprequested,b,f,c}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble for active UL BWP b of carrier f of primary cell c, and $\Delta_{\text{F\_PUCCH}}(F)$ corresponds to PUCCH format 0 or PUCCH format 1

Table 7.2.1-1: Mapping of TPC Command Field in DCI format 1_0 or DCI format 1_1 or DCI format 2_2 with CRC scrambled by TPC-PUCCH-RNTI to accumulated $\delta_{\text{PUCCH},b,f,c}$ values

TPC Command Field	Accumulated $\delta_{\text{PUCCH},b,f,c}$ [dB]
0	-1
1	0
2	1
3	3

7.3 Sounding reference signals

For SRS, a UE splits a linear value $\hat{P}_{\text{SRS},b,f,c}(i,q_s,l)$ of the transmit power $P_{\text{SRS},b,f,c}(i,q_s,l)$ on active UL BWP b of carrier f of serving cell c equally across the configured antenna ports for SRS.

7.3.1 UE behaviour

If a UE transmits SRS on active UL BWP b of carrier f of serving cell c using SRS power control adjustment state with index l, the UE determines the SRS transmission power $P_{\text{SRS},b,f,c}(i,q_s,l)$ in SRS transmission occasion i as

$$P_{\text{SRS},b,f,c}(i,q_s,l) = \min\left\{\begin{matrix} P_{\text{CMAX},f,c}(i), \\ P_{\text{O\_SRS},b,f,c}(q_s) + 10\log_{10}(2^{\mu}\cdot M_{\text{SRS},b,f,c}(i)) + \alpha_{\text{SRS},b,f,c}(q_s)\cdot PL_{b,f,c}(q_d) + h_{b,f,c}(i,l) \end{matrix}\right\} \text{ [dBm]}$$

where,

- $P_{\text{CMAX},f,c}(i)$ is the UE configured maximum output power defined in [8, TS 38.101-1], [8-2, TS38.101-2] and [TS 38.101-3] for carrier f of serving cell c in SRS transmission occasion i
- $P_{\text{O\_SRS},b,f,c}(q_s)$ is provided by *p0* for active UL BWP b of carrier f of serving cell c and SRS resource set q_s provided by *SRS-ResourceSet* and *SRS-ResourceSetId*
- $M_{\text{SRS},b,f,c}(i)$ is a SRS bandwidth expressed in number of resource blocks for SRS transmission occasion i on active UL BWP b of carrier f of serving cell c and μ is a SCS configuration defined in [4, TS 38.211]
- $\alpha_{\text{SRS},b,f,c}(q_s)$ is provided by *alpha* for active UL BWP b of carrier f of serving cell c and SRS resource set q_s
- $PL_{b,f,c}(q_d)$ is a downlink pathloss estimate in dB calculated by the UE using RS resource index q_d as described in Clause 7.1.1 for the active DL BWP of serving cell c and SRS resource set q_s [6, TS 38.214].

  The RS resource index q_d is provided by *pathlossReferenceRS* associated with the SRS resource set q_s and is either a *ssb-Index* providing a SS/PBCH block index or a *csi-RS-Index* providing a CSI-RS resource index

  - If the UE is not provided *pathlossReferenceRS* or before the UE is provided dedicated higher layer parameters, the UE calculates $PL_{b,f,c}(q_d)$ using a RS resource obtained from the SS/PBCH block that the UE uses to obtain *MIB*
  - If the UE is provided *pathlossReferenceLinking*, the RS resource is on a serving cell indicated by a value of *pathlossReferenceLinking*
- For the SRS power control adjustment state for active UL BWP b of carrier f of serving cell c and SRS transmission occasion i
  - $h_{b,f,c}(i,l) = f_{b,f,c}(i,l)$, where $f_{b,f,c}(i,l)$ is the current PUSCH power control adjustment state as described in Clause 7.1.1, if *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions; or
  - $h_{b,f,c}(i) = h_{b,f,c}(i-i_0) + \sum_{m=0}^{\mathcal{C}(S_i)-1}\delta_{\text{SRS},b,f,c}(m)$ if the UE is not configured for PUSCH transmissions on active UL BWP b of carrier f of serving cell c, or if *srs-PowerControlAdjustmentStates* indicates separate power control adjustment states between SRS transmissions and PUSCH transmissions, and if *tpc-Accumulation* is not provided, where
    - The $\delta_{\text{SRS},b,f,c}$ values are given in Table 7.1.1-1
    - $\delta_{\text{SRS},b,f,c}(m)$ is jointly coded with other TPC commands in a PDCCH with DCI format 2_3, as described in Clause 11.4

- $\sum_{m=0}^{\mathcal{C}(S_i)-1}\delta_{\text{SRS},b,f,c}(m)$ is a sum of TPC command values in a set S_i of TPC command values with cardinality $\mathcal{C}(S_i)$ that the UE receives between $K_{\text{SRS}}(i-i_0)-1$ symbols before SRS transmission occasion $i-i_0$ and $K_{\text{SRS}}(i)$ symbols before SRS transmission occasion i on active UL BWP b of carrier f of serving cell c for SRS power control adjustment state, where $i_0>0$ is the smallest integer for which $K_{\text{SRS}}(i-i_0)$ symbols before SRS transmission occasion $i-i_0$ is earlier than $K_{\text{SRS}}(i)$ symbols before SRS transmission occasion i

- if the SRS transmission is aperiodic, $K_{\text{SRS}}(i)$ is a number of symbols for active UL BWP b of carrier f of serving cell c after a last symbol of a corresponding PDCCH triggering the SRS transmission and before a first symbol of the SRS transmission

- if the SRS transmission is semi-persistent or periodic, $K_{\text{SRS}}(i)$ is a number of $K_{\text{SRS, min}}$ symbols equal to the product of a number of symbols per slot, $N_{\text{symb}}^{\text{slot}}$, and the minimum of the values provided by *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

- If the UE has reached maximum power for active UL BWP b of carrier f of serving cell c at SRS transmission occasion $i-i_0$ and $\sum_{m=0}^{\mathcal{C}(S_i)-1}\delta_{\text{SRS},b,f,c}(m)\geq 0$, then $h_{b,f,c}(i)=h_{b,f,c}(i-i_0)$

- If UE has reached minimum power for active UL BWP b of carrier f of serving cell c at SRS transmission occasion $i-i_0$ and $\sum_{m=0}^{\mathcal{C}(S_i)-1}\delta_{\text{SRS},b,f,c}(m)\leq 0$, then $h_{b,f,c}(i)=h_{b,f,c}(i-i_0)$

- If a configuration for a $P_{\text{O\_SRS},b,f,c}(q_s)$ value or for a $\alpha_{\text{SRS},b,f,c}(q_s)$ value for a corresponding SRS power control adjustment state l for active UL BWP b of carrier f of serving cell c is provided by higher layers

  - $h_{b,f,c}(k)=0, k=0,1,...,i$

- Else

  - $h_{b,f,c}(0)=\Delta P_{rampup,b,f,c}+\delta_{msg2,b,f,c}$

  where

  $\delta_{msg2,b,f,c}$ is the TPC command value indicated in the random access response grant corresponding to the random access preamble that the UE transmitted on active UL BWP b of carrier f of the serving cell c, and

$$\Delta P_{rampup,b,f,c}=\min\begin{bmatrix}\max\begin{pmatrix}0,\\ P_{\text{CMAX},f,c}-\left(P_{\text{O\_SRS},b,f,c}(q_s)+10\log_{10}(2^{\mu}\cdot M_{\text{SRS},b,f,c}(i))+\alpha_{\text{SRS},b,f,c}(q_s)\cdot PL_{b,f,c}(q_d)\right)\end{pmatrix},\\ \Delta P_{rampuprequested,b,f,c}\end{bmatrix};$$

  where $\Delta P_{rampuprequested,b,f,c}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble for active UL BWP b of carrier f of serving cell c.

- $h_{b,f,c}(i)=\delta_{\text{SRS},b,f,c}(i)$ if the UE is not configured for PUSCH transmissions on active UL BWP b of carrier f of serving cell c, or if *srs-PowerControlAdjustmentStates* indicates separate power control adjustment states between SRS transmissions and PUSCH transmissions, and *tpc-Accumulation* is provided, and the UE

detects a DCI format 2_3 $K_{\text{SRS, min}}$ symbols before a first symbol of SRS transmission occasion i, where absolute values of $\delta_{\text{SRS, } b,f,c}$ are provided in Table 7.1.1-1

- if *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions, the update of the power control adjustment state for SRS transmission occasion i occurs at the beginning of each SRS resource in the SRS resource set q_s; otherwise, the update of the power control adjustment state SRS transmission occasion i occurs at the beginning of the first transmitted SRS resource in the SRS resource set q_s.

7.4 Physical random access channel

A UE determines a transmission power for a physical random access channel (PRACH), $P_{\text{PRACH, } b,f,c}(i)$, on active UL BWP b of carrier f of serving cell c based on DL RS for serving cell c in transmission occasion i as

$$P_{\text{PRACH},b,f,c}(i) = \min\left\{P_{\text{CMAX},f,c}(i), P_{\text{PRACH,target},f,c} + PL_{b,f,c}\right\} \text{ [dBm],}$$

where $P_{\text{CMAX, } f,c}(i)$ is the UE configured maximum output power defined in [8-1, TS 38.101-1], [8-2, TS38.101-2] and [38.101-3] for carrier f of serving cell c within transmission occasion i, $P_{\text{PRACH, target, } f,c}$ is the PRACH target reception power *PREAMBLE_RECEIVED_TARGET_POWER* provided by higher layers [11, TS 38.321] for the active UL BWP b of carrier f of serving cell c, and $PL_{b,f,c}$ is a pathloss for the active UL BWP b of carrier f based on the DL RS associated with the PRACH transmission on the active DL BWP of serving cell c and calculated by the UE in dB as *referenceSignalPower* – higher layer filtered RSRP in dBm, where RSRP is defined in [7, TS 38.215] and the higher layer filter configuration is defined in [12, TS 38.331]. If the active DL BWP is the initial DL BWP and for SS/PBCH block and CORESET multiplexing pattern 2 or 3, as described in Clause 13, the UE determines $PL_{b,f,c}$ based on the SS/PBCH block associated with the PRACH transmission.

If a PRACH transmission from a UE is not in response to a detection of a PDCCH order by the UE, or is in response to a detection of a PDCCH order by the UE that triggers a contention based random access procedure, or is associated with a link recovery procedure where a corresponding index q_{new} is associated with a SS/PBCH block, as described in Clause 6, *referenceSignalPower* is provided by *ss-PBCH-BlockPower*.

If a PRACH transmission from a UE is in response to a detection of a PDCCH order by the UE that triggers a contention-free random access procedure and depending on the DL RS that the DM-RS of the PDCCH order is quasi-collocated with as described in Clause 10.1, *referenceSignalPower* is provided by *ss-PBCH-BlockPower* or, if the UE is configured resources for a periodic CSI-RS reception or the PRACH transmission is associated with a link recovery procedure where a corresponding index q_{new} is associated with a periodic CSI-RS configuration as described in Clause 6, *referenceSignalPower* is obtained by *ss-PBCH-BlockPower* and *powerControlOffsetSS* where *powerControlOffsetSS* provides an offset of CSI-RS transmission power relative to SS/PBCH block transmission power [6, TS 38.214]. If *powerControlOffsetSS* is not provided to the UE, the UE assumes an offset of 0 dB. If the active TCI state for the PDCCH that provides the PDCCH order includes two RS, the UE expects that one RS has QCL-TypeD properties and the UE uses the one RS when applying a value provided by *powerControlOffsetSS*.

If within a random access response window, as described in Clause 8.2, the UE does not receive a random access response that contains a preamble identifier corresponding to the preamble sequence transmitted by the UE, the UE determines a transmission power for a subsequent PRACH transmission, if any, as described in [11, TS 38.321].

If prior to a PRACH retransmission, a UE changes the spatial domain transmission filter, Layer 1 notifies higher layers to suspend the power ramping counter as described in [11, TS 38.321].

If due to power allocation to PUSCH/PUCCH/PRACH/SRS transmissions as described in Clause 7.5, or due to power allocation in EN-DC or NE-DC operation as described in Clause 7.6.1 or Clause 7.6.1A, respectively, the UE does not transmit a PRACH in a transmission occasion, Layer 1 notifies higher layers to suspend the corresponding power ramping counter. If due to power allocation to PUSCH/PUCCH/PRACH/SRS transmissions as described in Clause 7.5, or due to power allocation in EN-DC or NE-DC operation as described in Clause 7.6.1 or Clause 7.6.1A, respectively, the UE transmits a PRACH with reduced power in a transmission occasion, Layer 1 may notify higher layers to suspend the corresponding power ramping counter.

7.5 Prioritizations for transmission power reductions

For single cell operation with two uplink carriers or for operation with carrier aggregation, if a total UE transmit power for PUSCH or PUCCH or PRACH or SRS transmissions on serving cells in a frequency range in a respective transmission occasion i would exceed $\hat{P}_{\text{CMAX}}(i)$, where $\hat{P}_{\text{CMAX}}(i)$ is the linear value of $P_{\text{CMAX}}(i)$ in transmission occasion i as defined in [8-1, TS 38.101-1] for FR1 and [8-2, TS38.101-2] for FR2, the UE allocates power to PUSCH/PUCCH/PRACH/SRS transmissions according to the following priority order (in descending order) so that the total UE transmit power for transmissions on serving cells in the frequency range is smaller than or equal to $\hat{P}_{\text{CMAX}}(i)$ for that frequency range in every symbol of transmission occasion i. When determining a total transmit power for serving cells in a frequency range in a symbol of transmission occasion i, the UE does not include power for transmissions starting after the symbol of transmission occasion i. The total UE transmit power in a symbol of a slot is defined as the sum of the linear values of UE transmit powers for PUSCH, PUCCH, PRACH, and SRS in the symbol of the slot.

- PRACH transmission on the PCell
- PUCCH transmission with HARQ-ACK information and/or SR or PUSCH transmission with HARQ-ACK information
- PUCCH transmission with CSI or PUSCH transmission with CSI
- PUSCH transmission without HARQ-ACK information or CSI
- SRS transmission, with aperiodic SRS having higher priority than semi-persistent and/or periodic SRS, or PRACH transmission on a serving cell other than the PCell

In case of same priority order and for operation with carrier aggregation, the UE prioritizes power allocation for transmissions on the primary cell of the MCG or the SCG over transmissions on a secondary cell. In case of same priority order and for operation with two UL carriers, the UE prioritizes power allocation for transmissions on the carrier where the UE is configured to transmit PUCCH. If PUCCH is not configured for any of the two UL carriers, the UE prioritizes power allocation for transmissions on the non-supplementary UL carrier.

7.6 Dual connectivity

7.6.1 EN-DC

If a UE is configured with a MCG using E-UTRA radio access and with a SCG using NR radio access, the UE is configured a maximum power P_{LTE} for transmissions on the MCG by *p-MaxEUTRA* and a maximum power P_{NR} for transmissions in FR1 on the SCG by *p-NR-FR1*.

The UE determines a transmission power for the MCG as described in [13, TS 36.213] using P_{LTE} as the maximum transmission power. The UE determines transmission power for the SCG in FR1 as described Clauses 7.1 through 7.5 using P_{NR} as the maximum transmission power. The UE determines transmission power for the SCG in FR2 as described Clauses 7.1 through 7.5.

A UE does not expect to be configured for operation with shortened TTI and/or processing time [13, TS 36.213] on a cell that is included in an EN-DC configuration.

If a UE is configured with $\hat{P}_{\text{LTE}} + \hat{P}_{\text{NR}} > \hat{P}_{\text{Total}}^{\text{EN-DC}}$, where $\hat{P}_{\text{LTE}}$ is the linear value of P_{LTE}, $\hat{P}_{\text{NR}}$ is the linear value of P_{NR}, and $\hat{P}_{\text{Total}}^{\text{EN-DC}}$ is the linear value of a configured maximum transmission power for EN-DC operation as defined in [8-3, TS 38.101-3] for FR1, the UE determines a transmission power for the SCG as follows.

- If the UE is configured with reference TDD configuration for E-UTRA (by *tdm-PatternConfig-r15* in [13, TS 36.213])
  - If the UE does not indicate a capability for dynamic power sharing between E-UTRA and NR for EN-DC, the UE does not expect to transmit in a slot on the SCG in FR1 when a corresponding subframe on the MCG is an UL subframe in the reference TDD configuration.

- If the UE indicates a capability for dynamic power sharing between E-UTRA and NR for EN-DC and
  - if UE transmission(s) in subframe i_1 of the MCG overlap in time with UE transmission(s) in slot i_2 of the SCG in FR1, and
  - if $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) > \hat{P}_{\text{Total}}^{\text{EN-DC}}$ in any portion of slot i_2 of the SCG,

    the UE reduces transmission power in any portion of slot i_2 of the SCG so that $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) \le \hat{P}_{\text{Total}}^{\text{EN-DC}}$ in any portion of slot i_2, where $\hat{P}_{\text{MCG}}(i_1)$ and $\hat{P}_{\text{SCG}}(i_2)$ are the linear values of the total UE transmission powers in subframe i_1 of the MCG and in slot i_2 of the SCG in FR1, respectively. The UE is not required to transmit in any portion of slot i_2 of the SCG if $\hat{P}_{\text{SCG}}(i_2)$ would need to be reduced by more than the value provided by X_{SCALE} in order for $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) \le \hat{P}_{\text{Total}}^{\text{EN-DC}}$ in any portion of slot i_2 of the SCG. The UE is required to transmit in slot i_2 of the SCG if $\hat{P}_{\text{SCG}}(i_2)$ would not need to be reduced by more than the value provided by X_{SCALE} in order for $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) \le \hat{P}_{\text{Total}}^{\text{EN-DC}}$ in all portions of slot i_2.
- If the UE does not indicate a capability for dynamic power sharing between E-UTRA and NR for EN-DC, the UE expects to be configured with reference TDD configuration for E-UTRA (by *tdm-PatternConfig-r15* in [13, TS 36.213]).

7.6.1A NE-DC

If a UE is configured with a MCG using NR radio access and with a SCG using E-UTRA radio access, the UE is configured a maximum power P_{NR} for transmissions in FR1 on the MCG by *p-NR-FR1* and a maximum power P_{LTE} for transmissions on the SCG by *p-MaxEUTRA*.

The UE determines transmission power for the MCG in FR1 as described Clauses 7.1 through 7.5 using P_{NR} as the maximum transmission power for $P_{\text{CMAX}} \le P_{\text{NR}}$. The UE determines transmission power for the MCG in FR2 as described Clauses 7.1 through 7.5.

If the UE is not provided *tdd-UL-DL-ConfigurationCommon* for the MCG, the UE determines a transmission power for the SCG as described in [13, TS 36.213] using P_{LTE} as the maximum transmission power.

If at least one symbol of slot i_1 of the MCG that is indicated as uplink or flexible by *tdd-UL-DL-ConfigurationCommon* or *tdd-UL-DL-ConfigurationDedicated* overlaps with subframe i_2 of the SCG

- for subframe i_2, the UE determines a transmission power for the SCG as described in [13, TS 36.213] using P_{LTE} as the maximum transmission power

otherwise

- the UE determines a transmission power for the SCG as described in [13, TS 36.213] without considering P_{LTE} as the maximum transmission power

If a UE is configured with $\hat{P}_{\text{LTE}} + \hat{P}_{\text{NR}} > \hat{P}_{\text{Total}}^{\text{NE-DC}}$, where $\hat{P}_{\text{LTE}}$ is the linear value of P_{LTE}, $\hat{P}_{\text{NR}}$ is the linear value of P_{NR}, and $\hat{P}_{\text{Total}}^{\text{NE-DC}}$ is the linear value of a configured maximum transmission power for NE-DC operation as defined in [8-3, TS 38.101-3] for FR1, the UE determines a transmission power for the MCG as follows

- If the UE is configured with reference TDD configuration for E-UTRA (by *tdm-PatternConfig-r15* in [13, TS 36.213])
  - If the UE does not indicate a capability for dynamic power sharing between E-UTRA and NR for NE-DC, the UE does not expect to transmit in a slot on the MCG in FR1 when a corresponding subframe on the SCG is an UL subframe in the reference TDD configuration.
- If the UE indicates a capability for dynamic power sharing between E-UTRA and NR for NE-DC and
  - if the UE transmission(s) in slot i_1 of the MCG in FR1 overlap in time with UE transmission(s) in subframe i_2 of the SCG, and

- if $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) > \hat{P}_{\text{Total}}^{\text{NE-DC}}$ in any portion of slot i_1 of the MCG,

  the UE reduces transmission power in any portion of slot i_1 of the MCG so that $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) \le \hat{P}_{\text{Total}}^{\text{NE-DC}}$ in all portions of slot i_1, where $\hat{P}_{\text{MCG}}(i_1)$ and $\hat{P}_{\text{SCG}}(i_2)$ are the linear values of the total UE transmission powers in slot i_1 of the MCG in FR1 and in subframe i_2 of the SCG, respectively.

- If the UE does not indicate a capability for dynamic power sharing between E-UTRA and NR for NE-DC, the UE expects to be configured with reference TDD configuration for E-UTRA (by *tdm-PatternConfig-r15* in [13, TS 36.213]).

7.6.2 NR-DC

If a UE is configured with a MCG using NR radio access in FR1 or in FR2 and with a SCG using NR radio access in FR2 or in FR1, respectively, the UE performs transmission power control independently per cell group as described in Clauses 7.1 through 7.5.

7.7 Power headroom report

The types of UE power headroom reports are the following. A Type 1 UE power headroom PH that is valid for PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c. A Type 3 UE power headroom PH that is valid for SRS transmission occasion i on active UL BWP b of carrier f of serving cell c.

A UE determines whether a power headroom report for an activated serving cell [11, TS 38.321] is based on an actual transmission or a reference format based on the higher layer signalling of configured grant and periodic/semi-persistent sounding reference signal transmissions and downlink control information the UE received until and including the PDCCH monitoring occasion where the UE detects the first DCI format 0_0 or DCI format 0_1 scheduling an initial transmission of a transport block since a power headroom report was triggered if the power headroom report is reported on a PUSCH triggered by the first DCI. Otherwise, a UE determines whether a power headroom report is based on an actual transmission or a reference format based on the higher layer signalling of configured grant and periodic/semi-persistent sounding reference signal transmissions and downlink control information the UE received until the first uplink symbol of a configured PUSCH transmission minus $T'_{proc,2}=T_{proc,2}$ where $T_{proc,2}$ is determined according to [6, TS 38.214] assuming $d_{2,1} = 1$, $d_{2,2}=0$, and with μ_{DL} corresponding to the subcarrier spacing of the active downlink BWP of the scheduling cell for a configured grant if the power headroom report is reported on the PUSCH using the configured grant.

If a UE

- is configured with two UL carriers for a serving cell, and
- determines a Type 1 power headroom report and a Type 3 power headroom report for the serving cell

the UE

- provides the Type 1 power headroom report if both the Type 1 and Type 3 power headroom reports are based on respective actual transmissions or on respective reference transmissions
- provides the power headroom report that is based on a respective actual transmission if either the Type 1 report or the Type 3 report is based on a respective reference transmission

If a UE is configured with a SCG and if *phr-ModeOtherCG* for a CG indicates 'virtual' then, for power headroom reports transmitted on the CG, the UE computes *PH* assuming that the UE does not transmit PUSCH/PUCCH on any serving cell of the other CG.

If the UE is configured with a SCG,

- For computing power headroom for cells belonging to MCG, the term 'serving cell' in this clause refers to serving cell belonging to the MCG.
- For computing power headroom for cells belonging to SCG, the term 'serving cell' in this clause refers to serving cell belonging to the SCG. The term 'primary cell' in this clause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell,

- For computing power headroom for cells belonging to primary PUCCH group, the term 'serving cell' in this clause refers to serving cell belonging to the primary PUCCH group.
- For computing power headroom for cells belonging to secondary PUCCH group, the term 'serving cell' in this clause refers to serving cell belonging to the secondary PUCCH group. The term 'primary cell' in this clause refers to the PUCCH-SCell of the secondary PUCCH group.

For a UE configured with EN-DC/NE-DC and capable of dynamic power sharing, if E-UTRA Dual Connectivity PHR [14, TS 36.321] is triggered and,

- if the duration of NR slot on active UL BWP is different from that of E-UTRA subframe carrying the Dual Connectivity PHR, the UE provides power headroom of the first NR slot that fully overlaps with the E-UTRA subframe;
- if the duration of NR slot on active UL BWP is the same as that of E-UTRA subframe carrying the Dual Connectivity PHR for asynchronous EN-DC/NE-DC [10, TS 38.133], the UE provides power headroom of the first NR slot that overlaps with the E-UTRA subframe.

7.7.1 Type 1 PH report

If a UE determines that a Type 1 power headroom report for an activated serving cell is based on an actual PUSCH transmission then, for PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c, the UE computes the Type 1 power headroom report as

$$PH_{\text{type1},b,f,c}(i,j,q_d,l) = P_{\text{CMAX},f,c}(i) - \left\{ P_{\text{O\_PUSCH}b,f,c}(j) + 10\log_{10}(2^{\mu} \cdot M^{\text{PUSCH}}_{\text{RB},b,f,c}(i)) + \alpha_{b,f,c}(j) \cdot PL_{b,f,c}(q_d) + \Delta_{\text{TF},b,f,c}(i) + f_{b,f,c}(i,l) \right\} \text{ [dB]}$$

where $P_{\text{CMAX},f,c}(i)$, $P_{\text{O\_PUSCH}b,f,c}(j)$, $M^{\text{PUSCH}}_{\text{RB},b,f,c}(i)$, $\alpha_{b,f,c}(j)$, $PL_{b,f,c}(q_d)$, $\Delta_{\text{TF},b,f,c}(i)$ and $f_{b,f,c}(i,l)$ are defined in Clause 7.1.1.

If a UE is configured with multiple cells for PUSCH transmissions, where a SCS configuration μ_1 on active UL BWP b_1 of carrier f_1 of serving cell c_1 is smaller than a SCS configuration μ_2 on active UL BWP b_2 of carrier f_2 of serving cell c_2, and if the UE provides a Type 1 power headroom report in a PUSCH transmission in a slot on active UL BWP b_1 that overlaps with multiple slots on active UL BWP b_2, the UE provides a Type 1 power headroom report for the first PUSCH, if any, on the first slot of the multiple slots on active UL BWP b_2 that fully overlaps with the slot on active UL BWP b_1. If a UE is configured with multiple cells for PUSCH transmissions, where a same SCS configuration on active UL BWP b_1 of carrier f_1 of serving cell c_1 and active UL BWP b_2 of carrier f_2 of serving cell c_2, and if the UE provides a Type 1 power headroom report in a PUSCH transmission in a slot on active UL BWP b_1, the UE provides a Type 1 power headroom report for the first PUSCH, if any, on the slot on active UL BWP b_2 that overlaps with the slot on active UL BWP b_1.

For a UE configured with EN-DC/NE-DC and capable of dynamic power sharing, if E-UTRA Dual Connectivity PHR [14, TS 36.321] is triggered, the UE provides power headroom of the first PUSCH, if any, on the determined NR slot as described in clause 7.7.

If a UE is configured with multiple cells for PUSCH transmissions, the UE does not consider for computation of a Type 1 power headroom report in a first PUSCH transmission that includes an initial transmission of transport block on active UL BWP b_1 of carrier f_1 of serving cell c_1, a second PUSCH transmission on active UL BWP b_2 of carrier f_2 of serving cell c_2 that overlaps with the first PUSCH transmission if

- the second PUSCH transmission is scheduled by a DCI format 0_0 or a DCI format 0_1 in a PDCCH received in a second PDCCH monitoring occasion, and
- the second PDCCH monitoring occasion is after a first PDCCH monitoring occasion where the UE detects the earliest DCI format 0_0 or DCI format 0_1 scheduling an initial transmission of a transport block after a power headroom report was triggered

or

- the second PUSCH transmission is after the first uplink symbol of the first PUSCH transmission minus $T'_{proc,2}=T_{proc,2}$ where $T_{proc,2}$ is determined according to [6, TS 38.214] assuming $d_{2,1}=1$, $d_{2,2}=0$, and with μ_{DL} corresponding to the subcarrier spacing of the active downlink BWP of the scheduling cell for a configured grant if the first PUSCH transmission is on a configured grant after a power headroom report was triggered.

If the UE determines that a Type 1 power headroom report for an activated serving cell is based on a reference PUSCH transmission then, for PUSCH transmission occasion i on active UL BWP b of carrier f of serving cell c, the UE computes the Type 1 power headroom report as

$$PH_{\text{type1},b,f,c}(i,j,q_d,l)=\tilde{P}_{\text{CMAX},f,c}(i)-\left\{P_{\text{O\_PUSCH},b,f,c}(j)+\alpha_{b,f,c}(j)\cdot PL_{b,f,c}(q_d)+f_{b,f,c}(i,l)\right\} \quad \text{[dB]}$$

where $\tilde{P}_{\text{CMAX},f,c}(i)$ is computed assuming MPR=0 dB, A-MPR=0 dB, P-MPR=0 dB. ΔT_C = 0 dB. MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1], [8-2, TS38.101-2] and [8-3, TS 38.101-3]. The remaining parameters are defined in Clause 7.1.1 where $P_{\text{O\_PUSCH},b,f,c}(j)$ and $\alpha_{b,f,c}(j)$ are obtained using $P_{\text{O\_NOMINAL\_PUSCH},f,c}(0)$ and *p0-PUSCH-AlphaSetId* = 0, $PL_{b,f,c}(q_d)$ is obtained using *pusch-PathlossReferenceRS-Id* = 0, and $l=0$.

If a UE is configured with two UL carriers for a serving cell and the UE determines a Type 1 power headroom report for the serving cell based on a reference PUSCH transmission, the UE computes a Type 1 power headroom report for the serving cell assuming a reference PUSCH transmission on the UL carrier provided by *pusch-Config*. If the UE is provided *pusch-Config* for both UL carriers, the UE computes a Type 1 power headroom report for the serving cell assuming a reference PUSCH transmission on the UL carrier provided by *pucch-Config*. If *pucch-Config* is not provided to the UE for any of the two UL carriers, the UE computes a Type 1 power headroom report for the serving cell assuming a reference PUSCH transmission on the non-supplementary UL carrier.

7.7.2 Type 2 PH report

This clause is reserved.

7.7.3 Type 3 PH report

If a UE determines that a Type 3 power headroom report for an activated serving cell is based on an actual SRS transmission then, for SRS transmission occasion i on active UL BWP b of carrier f of serving cell c and if the UE is not configured for PUSCH transmissions on carrier f of serving cell c, the UE computes a Type 3 power headroom report as

$$PH_{\text{type3},b,f,c}(i,q_s)=P_{\text{CMAX},f,c}(i)-\left\{P_{\text{O\_SRS},b,f,c}(q_s)+10\log_{10}(2^{\mu}\cdot M_{\text{SRS},b,f,c}(i))+\alpha_{\text{SRS},b,f,c}(q_s)\cdot PL_{b,f,c}(q_d)+h_{b,f,c}(i)\right\}$$
[dB]

where $P_{\text{CMAX},f,c}(i)$, $P_{\text{O\_SRS},b,f,c}(q_s)$, $M_{\text{SRS},b,f,c}(i)$, $\alpha_{\text{SRS},b,f,c}(q_s)$, $PL_{b,f,c}(q_d)$ and $h_{b,f,c}(i)$ are defined in Clause 7.3.1.

If the UE determines that a Type 3 power headroom report for an activated serving cell is based on a reference SRS transmission then, for SRS transmission occasion i on UL BWP b of carrier f of serving cell c, and if the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c, the UE computes a Type 3 power headroom report as

$$PH_{\text{type3},b,f,c}(i,q_s)=\tilde{P}_{\text{CMAX},f,c}(i)-\left\{P_{\text{O\_SRS},b,f,c}(q_s)+\alpha_{\text{SRS},b,f,c}(q_s)\cdot PL_{b,f,c}(q_d)+h_{b,f,c}(i)\right\} \quad \text{[dB]}$$

where q_s is a SRS resource set corresponding to *SRS-ResourceSetId = 0* for UL BWP b and $P_{\text{O\_SRS},b,f,c}(q_s)$, $\alpha_{\text{SRS},f,c}(q_s)$, $PL_{b,f,c}(q_d)$ and $h_{b,f,c}(i)$ are defined in Clause 7.3.1 with corresponding values obtained from *SRS-ResourceSetId = 0* for UL BWP b. $\tilde{P}_{\text{CMAX},f,c}(i)$ is computed assuming MPR=0 dB, A-MPR=0 dB, P-MPR=0 dB

and ΔT_C =0 dB. MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1], [8-2, TS38.101-2] and [8-3, TS 38.101-3].

If a UE is configured with two UL carriers for a serving cell and the UE determines a Type 3 power headroom report for the serving cell based on a reference SRS transmission, the UE computes a Type 3 power headroom report for the serving cell assuming a reference SRS transmission on the UL carrier provided by *pucch-Config*. If *pucch-Config* is not provided to the UE for any of the two UL carriers, the UE computes a Type 3 power headroom report for the serving cell assuming a reference SRS transmission on the non-supplementary UL carrier.

8 Random access procedure

Prior to initiation of the physical random access procedure, Layer 1 receives from higher layers a set of SS/PBCH block indexes and provides to higher layers a corresponding set of RSRP measurements.

Prior to initiation of the physical random access procedure, Layer 1 receives the following information from the higher layers:

- Configuration of physical random access channel (PRACH) transmission parameters (PRACH preamble format, time resources, and frequency resources for PRACH transmission).
- Parameters for determining the root sequences and their cyclic shifts in the PRACH preamble sequence set (index to logical root sequence table, cyclic shift (N_{CS}), and set type (unrestricted, restricted set A, or restricted set B)).

From the physical layer perspective, the L1 random access procedure includes the transmission of random access preamble (Msg1) in a PRACH, random access response (RAR) message with a PDCCH/PDSCH (Msg2), and when applicable, the transmission of a PUSCH scheduled by a RAR UL grant, and PDSCH for contention resolution.

If a random access procedure is initiated by a PDCCH order to the UE, a PRACH transmission is with a same SCS as a PRACH transmission initiated by higher layers.

If a UE is configured with two UL carriers for a serving cell and the UE detects a PDCCH order, the UE uses the UL/SUL indicator field value from the detected PDCCH order to determine the UL carrier for the corresponding PRACH transmission.

8.1 Random access preamble

Physical random access procedure is triggered upon request of a PRACH transmission by higher layers or by a PDCCH order. A configuration by higher layers for a PRACH transmission includes the following:

- A configuration for PRACH transmission [4, TS 38.211].
- A preamble index, a preamble SCS, $P_{\text{PRACH,target}}$, a corresponding RA-RNTI, and a PRACH resource.

A PRACH is transmitted using the selected PRACH format with transmission power $P_{\text{PRACH},b,f,c}(i)$, as described in Clause 7.4, on the indicated PRACH resource.

A UE is provided a number N of SS/PBCH blocks associated with one PRACH occasion and a number R of contention based preambles per SS/PBCH block per valid PRACH occasion by *ssb-perRACH-OccasionAndCB-PreamblesPerSSB*. If $N<1$, one SS/PBCH block is mapped to $1/N$ consecutive valid PRACH occasions and R contention based preambles with consecutive indexes associated with the SS/PBCH block per valid PRACH occasion start from preamble index 0. If $N\geq 1$, R contention based preambles with consecutive indexes associated with SS/PBCH block n , $0 \leq n \leq N-1$, per valid PRACH occasion start from preamble index $n \cdot N_{\text{preamble}}^{\text{total}} / N$ where $N_{\text{preamble}}^{\text{total}}$ is provided by *totalNumberOfRA-Preambles* and is an integer multiple of N .

For link recovery, a UE is provided N SS/PBCH blocks associated with one PRACH occasion by *ssb-perRACH-Occasion* in *BeamFailureRecoveryConfig*. For a dedicated RACH configuration provided by *RACH-ConfigDedicated*, if *cfra* is provided, a UE is provided N SS/PBCH blocks associated with one PRACH occasion by *ssb-perRACH-*

Occasion in *occasions*. If $N<1$, one SS/PBCH block is mapped to $1/N$ consecutive valid PRACH occasions. If $N\geq 1$, all consecutive N SS/PBCH blocks are associated with one PRACH occasion.

SS/PBCH block indexes provided by *ssb-PositionsInBurst* in *SIB1* or in *ServingCellConfigCommon* are mapped to valid PRACH occasions in the following order where the parameters are described in [4, TS 38.211].

- First, in increasing order of preamble indexes within a single PRACH occasion
- Second, in increasing order of frequency resource indexes for frequency multiplexed PRACH occasions
- Third, in increasing order of time resource indexes for time multiplexed PRACH occasions within a PRACH slot
- Fourth, in increasing order of indexes for PRACH slots

An association period, starting from frame 0, for mapping SS/PBCH blocks to PRACH occasions is the smallest value in the set determined by the PRACH configuration period according Table 8.1-1 such that $N_{\text{Tx}}^{\text{SSB}}$ SS/PBCH blocks are mapped at least once to the PRACH occasions within the association period, where a UE obtains $N_{\text{Tx}}^{\text{SSB}}$ from the value of *ssb-PositionsInBurst* in *SIB1* or in *ServingCellConfigCommon*. If after an integer number of SS/PBCH blocks to PRACH occasions mapping cycles within the association period there is a set of PRACH occasions or PRACH preambles that are not mapped to $N_{\text{Tx}}^{\text{SSB}}$ SS/PBCH blocks, no SS/PBCH blocks are mapped to the set of PRACH occasions or PRACH preambles. An association pattern period includes one or more association periods and is determined so that a pattern between PRACH occasions and SS/PBCH blocks repeats at most every 160 msec. PRACH occasions not associated with SS/PBCH blocks after an integer number of association periods, if any, are not used for PRACH transmissions.

For a PRACH transmission triggered by a PDCCH order, the PRACH mask index field [5, TS 38.212], if the value of the random access preamble index field is not zero, indicates the PRACH occasion for the PRACH transmission where the PRACH occasions are associated with the SS/PBCH block index indicated by the SS/PBCH block index field of the PDCCH order.

For a PRACH transmission triggered by higher layers, if *ssb-ResourceList* is provided, the PRACH mask index is indicated by *ra-ssb-OccasionMaskIndex* which indicates the PRACH occasions for the PRACH transmission where the PRACH occasions are associated with the selected SS/PBCH block index.

The PRACH occasions are mapped consecutively per corresponding SS/PBCH block index. The indexing of the PRACH occasion indicated by the mask index value is reset per mapping cycle of consecutive PRACH occasions per SS/PBCH block index. The UE selects for a PRACH transmission the PRACH occasion indicated by PRACH mask index value for the indicated SS/PBCH block index in the first available mapping cycle.

For the indicated preamble index, the ordering of the PRACH occasions is

- First, in increasing order of frequency resource indexes for frequency multiplexed PRACH occasions
- Second, in increasing order of time resource indexes for time multiplexed PRACH occasions within a PRACH slot
- Third, in increasing order of indexes for PRACH slots

For a PRACH transmission triggered upon request by higher layers, a value of *ra-OccasionList* [12, TS 38.331], if *csirs-ResourceList* is provided, indicates a list of PRACH occasions for the PRACH transmission where the PRACH occasions are associated with the selected CSI-RS index indicated by *csi-RS*. The indexing of the PRACH occasions indicated by *ra-OccasionList* is reset per association pattern period.

Table 8.1-1: Mapping between PRACH configuration period and SS/PBCH block to PRACH occasion association period

PRACH configuration period (msec)	Association period (number of PRACH configuration periods)
10	{1, 2, 4, 8, 16}
20	{1, 2, 4, 8}
40	{1, 2, 4}
80	{1, 2}
160	{1}

For paired spectrum all PRACH occasions are valid. For unpaired spectrum, if a UE is not provided *tdd-UL-DL-ConfigurationCommon*, a PRACH occasion in a PRACH slot is valid if it does not precede a SS/PBCH block in the PRACH slot and starts at least N_{gap} symbols after a last SS/PBCH block symbol, where N_{gap} is provided in Table 8.1-2.

If a UE is provided *tdd-UL-DL-ConfigurationCommon*, a PRACH occasion in a PRACH slot is valid if

- it is within UL symbols, or
- it does not precede a SS/PBCH block in the PRACH slot and starts at least N_{gap} symbols after a last downlink symbol and at least N_{gap} symbols after a last SS/PBCH block symbol, where N_{gap} is provided in Table 8.1-2.

For preamble format B4 [4, TS 38.211], $N_{\text{gap}} = 0$.

Table 8.1-2: N_{gap} values for different preamble SCS μ

Preamble SCS	N_{gap}
1.25 kHz or 5 kHz	0
15 kHz or 30 kHz or 60 kHz or 120 kHz	2

If a random access procedure is initiated by a PDCCH order, the UE, if requested by higher layers, transmits a PRACH in the selected PRACH occasion, as described in [11, TS 38.321], for which a time between the last symbol of the PDCCH order reception and the first symbol of the PRACH transmission is larger than or equal to $N_{\text{T,2}} + \Delta_{\text{BWPSwitching}} + \Delta_{\text{Delay}}$ msec, where $N_{\text{T,2}}$ is a time duration of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214] assuming μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH order and the SCS configuration of the corresponding PRACH transmission, $\Delta_{\text{BWPSwitching}} = 0$ if the active UL BWP does not change and $\Delta_{\text{BWPSwitching}}$ is defined in [10, TS 38.133] otherwise, and $\Delta_{\text{Delay}} = 0.5$ msec for FR1 and $\Delta_{\text{Delay}} = 0.25$ msec for FR2. For a PRACH transmission using 1.25 kHz or 5 kHz SCS, the UE determines N_2 assuming SCS configuration $\mu = 0$.

For single cell operation or for operation with carrier aggregation in a same frequency band, a UE does not transmit PRACH and PUSCH/PUCCH/SRS in a same slot or when a gap between the first or last symbol of a PRACH transmission in a first slot is separated by less than N symbols from the last or first symbol, respectively, of a PUSCH/PUCCH/SRS transmission in a second slot where $N=2$ for $\mu=0$ or $\mu=1$, $N=4$ for $\mu=2$ or $\mu=3$, and μ is the SCS configuration for the active UL BWP.

8.2 Random access response

In response to a PRACH transmission, a UE attempts to detect a DCI format 1_0 with CRC scrambled by a corresponding RA-RNTI during a window controlled by higher layers [11, TS 38.321]. The window starts at the first symbol of the earliest CORESET the UE is configured to receive PDCCH for Type1-PDCCH CSS set, as defined in Clause 10.1, that is at least one symbol, after the last symbol of the PRACH occasion corresponding to the PRACH transmission, where the symbol duration corresponds to the SCS for Type1-PDCCH CSS set as defined in Clause 10.1. The length of the window in number of slots, based on the SCS for Type1-PDCCH CSS set, is provided by *ra-ResponseWindow*.

If the UE detects the DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI and a transport block in a corresponding PDSCH within the window, the UE passes the transport block to higher layers. The higher layers parse the transport block for a random access preamble identity (RAPID) associated with the PRACH transmission. If the higher layers identify the RAPID in RAR message(s) of the transport block, the higher layers indicate an uplink grant to the physical layer. This is referred to as random access response (RAR) UL grant in the physical layer.

If the UE does not detect the DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI within the window, or if the UE does not correctly receive the transport block in the corresponding PDSCH within the window, or if the higher layers do not identify the RAPID associated with the PRACH transmission from the UE, the higher layers can indicate to the physical layer to transmit a PRACH. If requested by higher layers, the UE is expected to transmit a PRACH no later than $N_{T,1}+0.75$ msec after the last symbol of the window, or the last symbol of the PDSCH reception, where $N_{T,1}$ is a time duration of N_1 symbols corresponding to a PDSCH processing time for UE processing capability 1 assuming μ corresponds to the smallest SCS configuration among the SCS configurations for the PDCCH carrying the DCI format 1_0, the corresponding PDSCH when additional PDSCH DM-RS is configured, and the corresponding PRACH. For $\mu = 0$, the UE assumes $N_{1,0} = 14$ [6, TS 38.214]. For a PRACH transmission using 1.25 kHz or 5 kHz SCS, the UE determines N_1 assuming SCS configuration $\mu = 0$.

If the UE detects a DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI and receives a transport block in a corresponding PDSCH, the UE may assume same DM-RS antenna port quasi co-location properties, as described in [6, TS 38.214], as for a SS/PBCH block or a CSI-RS resource the UE used for PRACH association, as described in Clause 8.1, regardless of whether or not the UE is provided *TCI-State* for the CORESET where the UE receives the PDCCH with the DCI format 1_0. If the UE attempts to detect the DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI in response to a PRACH transmission initiated by a PDCCH order that triggers a contention-free random access procedure for the SpCell [11, TS 38.321], the UE may assume that the PDCCH that includes the DCI format 1_0 and the PDCCH order have same DM-RS antenna port quasi co-location properties. If the UE attempts to detect the DCI format 1_0 with CRC scrambled by the corresponding RA-RNTI in response to a PRACH transmission initiated by a PDCCH order that triggers a contention-free random access procedure for a secondary cell, the UE may assume the DM-RS antenna port quasi co-location properties of the CORESET associated with the Type1-PDCCH CSS set for receiving the PDCCH that includes the DCI format 1_0.

A RAR UL grant schedules a PUSCH transmission from the UE. The contents of the RAR UL grant, starting with the MSB and ending with the LSB, are given in Table 8.2-1.

If the value of the frequency hopping flag is 0, the UE transmits the PUSCH without frequency hopping; otherwise, the UE transmits the PUSCH with frequency hopping.

The UE determines the MCS of the PUSCH transmission from the first sixteen indexes of the applicable MCS index table for PUSCH as described in [6, TS 38.214].

The TPC command value $\delta_{msg2,b,f,c}$ is used for setting the power of the PUSCH transmission, as described in Clause 7.1.1, and is interpreted according to Table 8.2-2.

The CSI request field is reserved.

Table 8.2-1: Random Access Response Grant Content field size

RAR grant field	Number of bits
Frequency hopping flag	1
PUSCH frequency resource allocation	14
PUSCH time resource allocation	4
MCS	4
TPC command for PUSCH	3
CSI request	1

Table 8.2-2: TPC Command $\delta_{msg2,b,f,c}$ for PUSCH

TPC Command	Value (in dB)
0	-6
1	-4
2	-2
3	0
4	2
5	4
6	6
7	8

Unless the UE is configured a SCS, the UE receives subsequent PDSCH using same SCS as for the PDSCH reception providing the RAR message.

If the UE does not detect the DCI format with CRC scrambled by the corresponding RA-RNTI or the UE does not correctly receive a corresponding transport block within the window, the UE procedure is as described in [11, TS 38.321].

8.3 PUSCH scheduled by RAR UL grant

An active UL BWP, as described in Clause 12 and in [4, TS 38.211], for a PUSCH transmission scheduled by a RAR UL grant is indicated by higher layers. For determining the frequency domain resource allocation for the PUSCH transmission within the active UL BWP

- if the active UL BWP and the initial UL BWP have same SCS and same CP length and the active UL BWP includes all RBs of the initial UL BWP, or the active UL BWP is the initial UL BWP, the initial UL BWP is used
- else, the RB numbering starts from the first RB of the active UL BWP and the maximum number of RBs for frequency domain resource allocation equals the number of RBs in the initial UL BWP

The frequency domain resource allocation is by uplink resource allocation type 1 [6, TS 38.214]. For an initial UL BWP size of $N_{\mathrm{BWP}}^{\mathrm{size}}$ RBs, a UE processes the frequency domain resource assignment field as follows

- if $N_{\mathrm{BWP}}^{\mathrm{size}} \le 180$
  - truncate the frequency domain resource assignment field to its $\left\lceil \log_2\left(N_{\mathrm{BWP}}^{\mathrm{size}} \cdot \left(N_{\mathrm{BWP}}^{\mathrm{size}}+1\right)/2\right)\right\rceil$ least significant bits and interpret the truncated frequency resource assignment field as for the frequency resource assignment field in DCI format 0_0 as described in [5, TS 38.212]
- else
  - insert $\left\lceil \log_2\left(N_{\mathrm{BWP}}^{\mathrm{size}} \cdot \left(N_{\mathrm{BWP}}^{\mathrm{size}}+1\right)/2\right)\right\rceil - 14$ most significant bits with value set to '0' after the $N_{\mathrm{UL,hop}}$ bits to the frequency domain resource assignment field, where $N_{\mathrm{UL,hop}} = 0$ if the frequency hopping flag is set to '0' and $N_{\mathrm{UL,hop}}$ is provided in Table 8.3-1 if the hopping flag bit is set to '1', and interpret the expanded frequency resource assignment field as for the frequency resource assignment field in DCI format 0_0 as described in [5, TS 38.212]
- end if

A UE determines whether or not to apply transform precoding as described in [6, TS 38.214].

For a PUSCH transmission with frequency hopping scheduled by RAR UL grant or for a Msg3 PUSCH retransmission, the frequency offset for the second hop [6, TS 38.214] is given in Table 8.3-1.

Table 8.3-1: Frequency offset for second hop of PUSCH transmission with frequency hopping scheduled by RAR UL grant or of Msg3 PUSCH retransmission

Number of PRBs in initial UL BWP	Value of $N_{\text{UL,hop}}$ Hopping Bits	Frequency offset for 2nd hop
$N_{\text{BWP}}^{\text{size}} < 50$	0	$\lfloor N_{\text{BWP}}^{\text{size}} / 2 \rfloor$
	1	$\lfloor N_{\text{BWP}}^{\text{size}} / 4 \rfloor$
$N_{\text{BWP}}^{\text{size}} \geq 50$	00	$\lfloor N_{\text{BWP}}^{\text{size}} / 2 \rfloor$
	01	$\lfloor N_{\text{BWP}}^{\text{size}} / 4 \rfloor$
	10	$-\lfloor N_{\text{BWP}}^{\text{size}} / 4 \rfloor$
	11	Reserved

A SCS for the PUSCH transmission is provided by *subcarrierSpacing* in *BWP-UplinkCommon*. A UE transmits PRACH and the PUSCH on a same uplink carrier of a same serving cell.

A UE transmits a transport block in a PUSCH scheduled by a RAR UL grant in a corresponding RAR message using redundancy version number 0. If a TC-RNTI is provided by higher layers, the scrambling initialization of the PUSCH corresponding to the RAR UL grant in clause 8.2 is by TC-RNTI. Otherwise, the scrambling initialization of the PUSCH corresponding to the RAR UL grant in clause 8.2 is by C-RNTI. Msg3 PUSCH retransmissions, if any, of the transport block, are scheduled by a DCI format 0_0 with CRC scrambled by a TC-RNTI provided in the corresponding RAR message [11, TS 38.321]. The UE always transmits the PUSCH scheduled by a RAR UL grant without repetitions.

With reference to slots for a PUSCH transmission scheduled by a RAR UL grant, if a UE receives a PDSCH with a RAR message ending in slot n for a corresponding PRACH transmission from the UE, the UE transmits the PUSCH in slot $n+k_2+\Delta$, where k_2 and Δ are provided in [6, TS 38.214].

The UE may assume a minimum time between the last symbol of a PDSCH reception conveying a RAR message with a RAR UL grant and the first symbol of a corresponding PUSCH transmission scheduled by the RAR UL grant is equal to $N_{\text{T},1}+N_{\text{T},2}+0.5$ msec, where $N_{\text{T},1}$ is a time duration of N_1 symbols corresponding to a PDSCH processing time for UE processing capability 1 when additional PDSCH DM-RS is configured, $N_{\text{T},2}$ is a time duration of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214] and, for determining the minimum time, the UE considers that N_1 and N_2 correspond to the smaller of the SCS configurations for the PDSCH and the PUSCH. For $\mu = 0$, the UE assumes $N_{1,0} = 14$ [6, TS 38.214].

8.4 PDSCH with UE contention resolution identity

In response to a PUSCH transmission scheduled by a RAR UL grant when a UE has not been provided a C-RNTI, the UE attempts to detect a DCI format 1_0 with CRC scrambled by a corresponding TC-RNTI scheduling a PDSCH that includes a UE contention resolution identity [11, TS 38.321]. In response to the PDSCH reception with the UE contention resolution identity, the UE transmits HARQ-ACK information in a PUCCH. The PUCCH transmission is within a same active UL BWP as the PUSCH transmission. A minimum time between the last symbol of the PDSCH reception and the first symbol of the corresponding PUCCH transmission with the HARQ-ACK information is equal to $N_{\text{T},1}+0.5$ msec. $N_{\text{T},1}$ is a time duration of N_1 symbols corresponding to a PDSCH processing time for UE processing capability 1 when additional PDSCH DM-RS is configured. For $\mu = 0$, the UE assumes $N_{1,0} = 14$ [6, TS 38.214].

When detecting a DCI format in response to a PUSCH transmission scheduled by a RAR UL grant, as described in [11, TS 38.321], or corresponding PUSCH retransmission scheduled by a DCI format 0_0 with CRC scrambled by a TC-RNTI provided in the corresponding RAR message [11, TS 38.321], the UE may assume the PDCCH carrying the DCI format has the same DM-RS antenna port quasi co-location properties, as described in [6, TS 38.214], as for a SS/PBCH block the UE used for PRACH association, as described in Clause 8.1, regardless of whether or not the UE is provided TCI-State for the CORESET where the UE receives the PDCCH with the DCI format.

9 UE procedure for reporting control information

If a UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG.

- When the procedures are applied for MCG, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term 'primary cell' in this clause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this clause for both primary PUCCH group and secondary PUCCH group

- When the procedures are applied for the primary PUCCH group, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the primary PUCCH group respectively.
- When the procedures are applied for secondary PUCCH group, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including the PUCCH-SCell), serving cell, serving cells belonging to the secondary PUCCH group respectively. The term 'primary cell' in this clause refers to the PUCCH-SCell of the secondary PUCCH group.

If a UE is configured for NR-DC operation, the UE does not expect to be configured with a PUCCH-SCell.

If a UE would transmit on a serving cell a PUSCH without UL-SCH that overlaps with a PUCCH transmission on a serving cell that includes positive SR information, the UE does not transmit the PUSCH.

If a UE would transmit CSI reports on overlapping physical channels, the UE applies the priority rules described in [6, TS 38.214] for the multiplexing of CSI reports.

If a UE has overlapping resources for PUCCH transmissions in a slot and at least one of the PUCCH transmissions is with repetitions over multiple slots, the UE first follows the procedures described in Clause 9.2.6 for resolving the overlapping among the resources for the PUCCH transmissions.

If a UE

- would multiplex UCI in a PUCCH transmission that overlaps with a PUSCH transmission, and
- the PUSCH and PUCCH transmissions fulfill the conditions in Clause 9.2.5 for UCI multiplexing,

the UE

- multiplexes only HARQ-ACK information, if any, from the UCI in the PUSCH transmission and does not transmit the PUCCH if the UE multiplexes aperiodic or semi-persistent CSI reports in the PUSCH;
- multiplexes only HARQ-ACK information and CSI reports, if any, from the UCI in the PUSCH transmission and does not transmit the PUCCH if the UE does not multiplex aperiodic or semi-persistent CSI reports in the PUSCH.

A UE does not expect to multiplex in a PUSCH transmission in one slot with SCS configuration μ_1 UCI of same type that the UE would transmit in PUCCHs in different slots with SCS configuration μ_2 if $\mu_1 < \mu_2$.

A UE does not expect a PUCCH resource that results from multiplexing overlapped PUCCH resources, if applicable, to overlap with more than one PUSCHs if each of the more than one PUSCHs includes aperiodic CSI reports.

A UE does not expect to detect a DCI format scheduling a PDSCH reception or a SPS PDSCH release and indicating a resource for a PUCCH transmission with corresponding HARQ-ACK information in a slot if the UE previously detects a DCI format scheduling a PUSCH transmission in the slot and if the UE multiplexes HARQ-ACK information in the PUSCH transmission.

If a UE multiplexes aperiodic CSI in a PUSCH and the UE would multiplex UCI that includes HARQ-ACK information in a PUCCH that overlaps with the PUSCH and the timing conditions for overlapping PUCCHs and

PUSCHs in Clause 9.2.5 are fulfilled, the UE multiplexes only the HARQ-ACK information in the PUSCH and does not transmit the PUCCH.

If a UE transmits multiple PUSCHs in a slot on respective serving cells that include first PUSCHs that are scheduled by DCI format(s) 0_0 or DCI format(s) 0_1 and second PUSCHs configured by respective *ConfiguredGrantConfig* or *semiPersistentOnPUSCH*, and the UE would multiplex UCI in one of the multiple PUSCHs, and the multiple PUSCHs fulfil the conditions in Clause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in a PUSCH from the first PUSCHs.

If a UE transmits multiple PUSCHs in a slot on respective serving cells and the UE would multiplex UCI in one of the multiple PUSCHs and the UE does not multiplex aperiodic CSI in any of the multiple PUSCHs, the UE multiplexes the UCI in a PUSCH of the serving cell with the smallest *ServCellIndex* subject to the conditions in Clause 9.2.5 for UCI multiplexing being fulfilled. If the UE transmits more than one PUSCHs in the slot on the serving cell with the smallest *ServCellIndex* that fulfil the conditions in Clause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in the earliest PUSCH that the UE transmits in the slot.

If a UE transmits a PUSCH over multiple slots and the UE would transmit a PUCCH with HARQ-ACK and/or CSI information over a single slot and in a slot that overlaps with the PUSCH transmission in one or more slots of the multiple slots, and the PUSCH transmission in the one or more slots fulfills the conditions in Clause 9.2.5 for multiplexing the HARQ-ACK and/or CSI information, the UE multiplexes the HARQ-ACK and/or CSI information in the PUSCH transmission in the one or more slots. The UE does not multiplex HARQ-ACK and/or CSI information in the PUSCH transmission in a slot from the multiple slots if the UE would not transmit a single-slot PUCCH with HARQ-ACK and/or CSI information in the slot in case the PUSCH transmission was absent.

If the PUSCH transmission over the multiple slots is scheduled by a DCI format 0_1, the same value of a DAI field is applicable for multiplexing HARQ-ACK information in the PUSCH transmission in any slot from the multiple slots where the UE multiplexes HARQ-ACK information.

A HARQ-ACK information bit value of 0 represents a negative acknowledgement (NACK) while a HARQ-ACK information bit value of 1 represents a positive acknowledgement (ACK).

9.1 HARQ-ACK codebook determination

If a UE receives a PDSCH without receiving a corresponding PDCCH, or if the UE receives a PDCCH indicating a SPS PDSCH release, the UE generates one corresponding HARQ-ACK information bit.

If a UE is not provided *PDSCH-CodeBlockGroupTransmission*, the UE generates one HARQ-ACK information bit per transport block.

For a HARQ-ACK information bit, a UE generates an ACK if the UE detects a DCI format 1_0 that provides a SPS PDSCH release or correctly decodes a transport block, and generates a NACK if the UE does not correctly decode the transport block.

A UE does not expect to be indicated to transmit HARQ-ACK information for more than one SPS PDSCH receptions in a same PUCCH.

In the following, the CRC for DCI format 1_0 or DCI format 1_1 is scrambled with a C-RNTI, an MCS-C-RNTI, or a CS-RNTI.

9.1.1 CBG-based HARQ-ACK codebook determination

If a UE is provided *PDSCH-CodeBlockGroupTransmission* for a serving cell, the UE receives a PDSCH scheduled by DCI format 1_1, that includes code block groups (CBGs) of a transport block. The UE is also provided *maxCodeBlockGroupsPerTransportBlock* indicating a maximum number $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ of CBGs for generating respective HARQ-ACK information bits for a transport block reception for the serving cell.

For a number of C code blocks (CBs) in a transport block, the UE determines a number of CBGs M according to Clause 5.1.7.1 of [6, TS 38.214] and determines a number of HARQ-ACK bits for the transport block as $N_{\text{HARQ-ACK}}^{\text{CBG/TB}} = M$.

The UE generates an ACK for the HARQ-ACK information bit of a CBG if the UE correctly received all code blocks of the CBG and generates a NACK for the HARQ-ACK information bit of a CBG if the UE incorrectly received at least one code block of the CBG. If the UE receives two transport blocks, the UE concatenates the HARQ-ACK information bits for CBGs of the second transport block after the HARQ-ACK information bits for CBGs of the first transport block.

The HARQ-ACK codebook includes the $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ HARQ-ACK information bits and, if $N_{\text{HARQ-ACK}}^{\text{CBG/TB}} < N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ for a transport block, the UE generates a NACK value for the last $N_{\text{HARQ-ACK}}^{\text{CBG/TB, max}} - N_{\text{HARQ-ACK}}^{\text{CBG/TB}}$ HARQ-ACK information bits for the transport block in the HARQ-ACK codebook.

If the UE generates a HARQ-ACK codebook in response to a retransmission of a transport block, corresponding to a same HARQ process as a previous transmission of the transport block, the UE generates an ACK for each CBG that the UE correctly decoded in a previous transmission of the transport block.

If a UE correctly detects each of the $N_{\text{HARQ-ACK}}^{\text{CBG/TB}}$ CBGs and does not correctly detect the transport block for the $N_{\text{HARQ -ACK}}^{\text{CBG/TB}}$ CBGs, the UE generates a NACK value for each of the $N_{\text{HARQ-ACK}}^{\text{CBG/TB}}$ CBGs.

9.1.2 Type-1 HARQ-ACK codebook determination

This clause applies if the UE is configured with *pdsch-HARQ-ACK-Codebook = semi-static*.

A UE reports HARQ-ACK information for a corresponding PDSCH reception or SPS PDSCH release only in a HARQ-ACK codebook that the UE transmits in a slot indicated by a value of a PDSCH-to-HARQ_feedback timing indicator field in a corresponding DCI format 1_0 or DCI format 1_1. The UE reports NACK value(s) for HARQ-ACK information bit(s) in a HARQ-ACK codebook that the UE transmits in a slot not indicated by a value of a PDSCH-to-HARQ_feedback timing indicator field in a corresponding DCI format 1_0 or DCI format 1_1.

If the UE is provided *pdsch-AggregationFactor*, $N_{\text{PDSCH}}^{\text{repeat}}$ is a value of *pdsch-AggregationFactor*; otherwise, $N_{\text{PDSCH}}^{\text{repeat}} = 1$. The UE reports HARQ-ACK information for a PDSCH reception from slot $n - N_{\text{PDSCH}}^{\text{repeat}} + 1$ to slot n only in a HARQ-ACK codebook that the UE includes in a PUCCH or PUSCH transmission in slot $n+k$, where k is a number of slots indicated by the PDSCH-to-HARQ_feedback timing indicator field in a corresponding DCI format or provided by *dl-DataToUL-ACK* if the PDSCH-to-HARQ_feedback timing indicator field is not present in the DCI format. If the UE reports HARQ-ACK information for the PDSCH reception in a slot other than slot $n+k$, the UE sets a value for each corresponding HARQ-ACK information bit to NACK.

If a UE reports HARQ-ACK information in a PUCCH only for

- a SPS PDSCH release indicated by DCI format 1_0 with counter DAI field value of 1 on the PCell, or
- a PDSCH reception scheduled by DCI format 1_0 with counter DAI field value of 1 on the PCell, or
- SPS PDSCH reception

within the $M_{A,c}$ occasions for candidate PDSCH receptions as determined in Clause 9.1.2.1, the UE determines a HARQ-ACK codebook only for the SPS PDSCH release or only for the PDSCH reception or only for the SPS PDSCH reception according to corresponding $M_{A,c}$ occasion(s) on respective serving cell(s), where the value of counter DAI in DCI format 1_0 is according to Table 9.1.3-1; otherwise, the procedures in Clause 9.1.2.1 and Clause 9.1.2.2 for a HARQ-ACK codebook determination apply.

9.1.2.1 Type-1 HARQ-ACK codebook in physical uplink control channel

For a serving cell c, an active DL BWP, and an active UL BWP, as described in Clause 12, the UE determines a set of $M_{A,c}$ occasions for candidate PDSCH receptions for which the UE can transmit corresponding HARQ-ACK information in a PUCCH in slot n_{U}. If serving cell c is deactivated, the UE uses as the active DL BWP for determining the set of $M_{A,c}$ occasions for candidate PDSCH receptions a DL BWP provided by *firstActiveDownlinkBWP-Id*. The determination is based:

a) on a set of slot timing values K_1 associated with the active UL BWP

   a) If the UE is configured to monitor PDCCH for DCI format 1_0 and is not configured to monitor PDCCH for DCI format 1_1 on serving cell c, K_1 is provided by the slot timing values {1, 2, 3, 4, 5, 6, 7, 8} for DCI format 1_0

   b) If the UE is configured to monitor PDCCH for DCI format 1_1 for serving cell c, K_1 is provided by *dl-DataToUL-ACK* for DCI format 1_1

b) on a set of row indexes R of a table that is provided either by a first set of row indexes of a table that is provided by *pdsch-TimeDomainAllocationList* in *pdsch-ConfigCommon* or by Default PDSCH time domain resource allocation A [6, TS 38.214], or by the union of the first set of row indexes and a second set of row indexes, if provided by *pdsch-TimeDomainAllocationList* in *pdsch-Config*, associated with the active DL BWP and defining respective sets of slot offsets K_0, start and length indicators *SLIV*, and PDSCH mapping types for PDSCH reception as described in [6, TS 38.214]

c) on the ratio $2^{\mu_{\text{DL}}-\mu_{\text{UL}}}$ between the downlink SCS configuration μ_{DL} and the uplink SCS configuration μ_{UL} provided by *subcarrierSpacing* in *BWP-Downlink* and *BWP-Uplink* for the active DL BWP and the active UL BWP, respectively

d) if provided, on *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* as described in Clause 11.1.

For the set of slot timing values K_1, the UE determines a set of $M_{A,c}$ occasions for candidate PDSCH receptions or SPS PDSCH releases according to the following pseudo-code. A location in the Type-1 HARQ-ACK codebook for HARQ-ACK information corresponding to a SPS PDSCH release is same as for a corresponding SPS PDSCH reception.

Set $j=0$ - index of occasion for candidate PDSCH reception or SPS PDSCH release

Set $B=\varnothing$

Set $M_{A,c}=\varnothing$

Set $\mathcal{O}(K_1)$ to the cardinality of set K_1

Set k =0 – index of slot timing values $K_{1,k}$, in descending order of the slot timing values, in set K_1 for serving cell c

while $k < \mathcal{O}(K_1)$

if $\text{mod}\left(n_{\text{U}} - K_{1,k} + 1, \max\left(2^{\mu_{\text{UL}}-\mu_{\text{DL}}}, 1\right)\right) = 0$

Set $n_{\text{D}} = 0$ – index of a DL slot within an UL slot

while $n_{\text{D}} < \max\left(2^{\mu_{\text{DL}}-\mu_{\text{UL}}}, 1\right)$

Set R to the set of rows

Set $\mathcal{O}(R)$ to the cardinality of R

Set $r=0$ – index of row in set R

if slot n_{U} starts at a same time as or after a slot for an active DL BWP change on serving cell c or an active UL BWP change on the PCell and slot $\left\lfloor \left(n_{\text{U}} - K_{1,k}\right) \cdot 2^{\mu_{\text{DL}}-\mu_{\text{UL}}} \right\rfloor + n_{\text{D}}$ is before the slot for the active DL BWP change on serving cell c or the active UL BWP change on the PCell

$n_D = n_D + 1;$

else

while $r < \mathcal{C}(R)$

if the UE is provided *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated* and, for each slot from slot $\left\lfloor (n_U - K_{1,k}) \cdot 2^{\mu_{DL}-\mu_{UL}} \right\rfloor + n_D - N_{PDSCH}^{repeat} + 1$ to slot $\left\lfloor (n_U - K_{1,k}) \cdot 2^{\mu_{DL}-\mu_{UL}} \right\rfloor + n_D$, at least one symbol of the PDSCH time resource derived by row r is configured as UL where $K_{1,k}$ is the k-th slot timing value in set K_1,

$R = R \backslash r$;

else

$r = r + 1$;

end if

end while

if the UE does not indicate a capability to receive more than one unicast PDSCH per slot and $R \neq \varnothing$,

$M_{A,c} = M_{A,c} \cup j$;

$j = j + 1$;

The UE does not expect to receive SPS PDSCH release and unicast PDSCH in a same slot;

else

Set $\mathcal{C}(R)$ to the cardinality of R

Set m to the smallest last OFDM symbol index, as determined by the *SLIV*, among all rows of R

while $R \neq \varnothing$

Set $r = 0$

while $r < \mathcal{C}(R)$

if $S \leq m$ for start OFDM symbol index S for row r

$b_{r,k,n_D} = j$; - index of occasion for candidate PDSCH reception or SPS PDSCH release associated with row r

$R = R \backslash r$;

$B = B \cup b_{r,k,n_D}$;

else

$r = r + 1$;

end if

end while

$M_{A,c} = M_{A,c} \cup j$;

$j = j + 1$;

Set m to the smallest last OFDM symbol index among all rows of R ;

end while

end if

$n_D = n_D + 1$;

end if

end while

end if

$k = k + 1$;

end while

If the UE indicates a capability to receive more than one PDSCH per slot, for occasions of candidate PDSCH receptions corresponding to rows of R associated with a same value of b_{r,k,n_D}, where $b_{r,k,n_D} \in B$, the UE does not expect to receive more than one PDSCH in a same DL slot.

If a UE receives a SPS PDSCH, or a SPS PDSCH release, or a PDSCH that is scheduled by a DCI format 1_0 and if

- the UE is configured with one serving cell, and
- $\mathcal{C}(M_{A,c})=1$, and
- *PDSCH-CodeBlockGroupTransmission* is provided to the UE

the UE generates HARQ-ACK information only for the transport block in the PDSCH or only for the SPS PDSCH release.

If a UE receives a SPS PDSCH, or a SPS PDSCH release, or a PDSCH that is scheduled by a DCI format 1_0 and if

- the UE is configured with more than one serving cells, or
- $\mathcal{C}(M_{A,c})>1$, and
- *PDSCH-CodeBlockGroupTransmission* is provided to the UE

the UE repeats $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ times the HARQ-ACK information for the transport block in the PDSCH or for the SPS PDSCH release.

A UE does not expect to detect a DCI format switching a DL BWP within N_3 symbols prior to a first symbol of a PUCCH transmission where the UE multiplexes HARQ-ACK information, where N_3 is defined in Clause 9.2.3.

If a UE is provided *dl-DataToUL-ACK*, the UE does not expect to be indicated by DCI format 1_0 a slot timing value for transmission of HARQ-ACK information that does not belong to the intersection of the set of slot timing values {1, 2, 3, 4, 5, 6, 7, 8} and the set of slot timing values provided by *dl-DataToUL-ACK* for the active DL BWP of a corresponding serving cell.

If an occasion for a candidate PDSCH reception can be in response to a PDCCH with DCI format 1_1 and if *maxNrofCodeWordsScheduledByDCI* indicates reception of two transport blocks, when the UE receives a PDSCH with one transport block, the HARQ-ACK information is associated with the first transport block and the UE generates a NACK for the second transport block if *harq-ACK-SpatialBundlingPUCCH* is not provided and generates HARQ-ACK information with value of ACK for the second transport block if *harq-ACK-SpatialBundlingPUCCH* is provided.

A UE determines $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$ HARQ-ACK information bits, for a total number of O_{ACK} HARQ-ACK information bits, of a HARQ-ACK codebook for transmission in a PUCCH according to the following pseudo-code. In the following pseudo-code, if the UE does not receive a transport block or a CBG, due to the UE not detecting a corresponding DCI format 1_0 or DCI format 1_1, the UE generates a NACK value for the transport block or the CBG. The cardinality of the set $M_{A,c}$ defines a total number M_c of occasions for PDSCH reception or SPS PDSCH release for serving cell c corresponding to the HARQ-ACK information bits.

Set $c=0$ – serving cell index: lower indexes correspond to lower RRC indexes of corresponding cell

Set $j=0$ - HARQ-ACK information bit index

Set $N_{\text{cells}}^{\text{DL}}$ to the number of serving cells configured by higher layers for the UE

while $c < N_{\text{cells}}^{\text{DL}}$

Set $m=0$ – index of occasion for candidate PDSCH reception or SPS PDSCH release

while $m < M_c$

if *harq-ACK-SpatialBundlingPUCCH* is not provided, *PDSCH-CodeBlockGroupTransmission* is not provided, and the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for the active DL BWP of serving cell c,

$\tilde{o}_j^{ACK}$ = HARQ-ACK information bit corresponding to a first transport block of this cell;

$j = j+1$;

$\tilde{o}_j^{ACK}$ = HARQ-ACK information bit corresponding to a second transport block of this cell;

$j = j+1$;

elseif *harq-ACK-SpatialBundlingPUCCH* is provided, and the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for the active DL BWP of serving cell c,

$\tilde{o}_j^{ACK}$ = binary AND operation of the HARQ-ACK information bits corresponding to first and second transport blocks of this cell - if the UE receives one transport block, the UE assumes ACK for the second transport block;

$j = j+1$;

elseif *PDSCH-CodeBlockGroupTransmission* is provided, and $N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$ CBGs are indicated by *maxCodeBlockGroupsPerTransportBlock* for serving cell c,

Set $n_{\text{CBG}} = 0$ - CBG index

while $n_{\text{CBG}} < N_{\text{HARQ-ACK},c}^{\text{CBG/TB, max}}$

$\tilde{o}_{j+n_{\text{CBG}}}^{ACK}$ = HARQ-ACK information bit corresponding to CBG n_{CBG} of the first transport block;

if the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for the active DL BWP of serving cell c

$\tilde{o}_{j+n_{\text{CBG}}+N_{\text{HARQ-ACK},c}^{\text{CBG/TBmax}}}^{ACK}$ = HARQ-ACK information bit corresponding to CBG n_{CBG} of the second transport block;

end if

$n_{\text{CBG}} = n_{\text{CBG}} + 1$;

end while

$j = j + N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$, where $N_{\text{TB},c}^{\text{DL}}$ is the value of *maxNrofCodeWordsScheduledByDCI* for the active DL BWP of serving cell c;

else

$\tilde{o}_j^{ACK}$ = HARQ-ACK information bit of serving cell c;

$j = j+1$;

end if

$m = m+1$;

end while

$c = c+1$;

end while

If $O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} \leq 11$, the UE determines a number of HARQ-ACK information bits $n_{\text{HARQ-ACK}}$ for obtaining a transmission power for a PUCCH, as described in Clause 7.2.1, as $n_{\text{HARQ-ACK}} = \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}-1} \sum_{m=0}^{M_c-1} N_{m,c}^{\text{received}} + \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}-1} \sum_{m=0}^{M_c-1} N_{m,c}^{\text{received,CBG}}$ where

- $N_{m,c}^{\text{received}}$ is the number of transport blocks the UE receives in PDSCH reception occasion m for serving cell c if *harq-ACK-SpatialBundlingPUCCH* and *PDSCH-CodeBlockGroupTransmission* are not provided, or the number of transport blocks the UE receives in PDSCH reception occasion m for serving cell c if *PDSCH-CodeBlockGroupTransmission* is provided and the PDSCH reception is scheduled by a DCI format 1_0, or the number of PDSCH receptions if *harq-ACK-SpatialBundlingPUCCH* is provided or SPS PDSCH release in PDSCH reception occasion m for serving cell c and the UE reports corresponding HARQ-ACK information in the PUCCH.

- $N_{m,c}^{\text{received, CBG}}$ is the number of CBGs the UE receives in a PDSCH reception occasion m for serving cell c if *PDSCH-CodeBlockGroupTransmission* is provided and the PDSCH reception is scheduled by a DCI format 1_1 and the UE reports corresponding HARQ-ACK information in the PUCCH.

9.1.2.2 Type-1 HARQ-ACK codebook in physical uplink shared channel

If a UE would multiplex HARQ-ACK information in a PUSCH transmission that is not scheduled by a DCI format or is scheduled by DCI format 0_0, then

- if the UE has not received any PDSCH or SPS PDSCH release that the UE transmits corresponding HARQ-ACK information in the PUSCH, based on a value of a respective PDSCH-to-HARQ_feedback timing indicator field in a DCI format scheduling the PDSCH reception or the SPS PDSCH release or on the value of *dl-DataToUL-ACK* if the PDSCH-to-HARQ_feedback timing indicator field is not present in the DCI format, in any of the M_c occasions for candidate PDSCH receptions by DCI format 1_0 or DCI format 1_1 or SPS PDSCH on any serving cell c, as described in Clause 9.1.2.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission;

- else the UE generates the HARQ-ACK codebook as described in Clause 9.1.2.1, except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*, unless the UE receives only a SPS PDSCH release, or only SPS PDSCH reception, or only a PDSCH that is scheduled by DCI format 1_0 with a counter DAI field value of 1 on the PCell in the M_c occasions for candidate PDSCH receptions in which case the UE generates HARQ-ACK information only for the SPS PDSCH release or only for the PDSCH reception as described in Clause 9.1.2.

A UE sets to NACK value in the HARQ-ACK codebook any HARQ-ACK information corresponding to PDSCH reception or SPS PDSCH release that the UE detects in a PDCCH monitoring occasion that starts after a PDCCH monitoring occasion where the UE detects a DCI format 0_0 or a DCI format 0_1 scheduling the PUSCH transmission.

A UE does not expect to detect a DCI format switching a DL BWP within N_2 symbols prior to a first symbol of a PUSCH transmission where the UE multiplexes HARQ-ACK information, where N_2 is defined in [6, TS 38.214].

If a UE multiplexes HARQ-ACK information in a PUSCH transmission that is scheduled by DCI format 0_1, the UE generates the HARQ-ACK codebook as described in Clause 9.1.2.1 when a value of the DAI field in DCI format 0_1 is $V_{\text{T-DAI}}^{\text{UL}} = 1$ except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*. The UE does not generate a HARQ-ACK codebook for multiplexing in the PUSCH transmission when $V_{\text{T-DAI}}^{\text{UL}} = 0$ unless the UE receives only a SPS PDSCH release, or only a SPS PDSCH, or only a PDSCH that is scheduled by DCI format 1_0 with a counter DAI field value of 1 on the PCell in the M_c occasions for candidate PDSCH receptions in which case the UE generates HARQ-ACK information only for the SPS PDSCH release or only for the PDSCH reception as described in Clause 9.1.2. $V_{\text{T-DAI}}^{\text{UL}} = 0$ if the DAI field in DCI format 0_1 is set to '0'; otherwise, $V_{\text{T-DAI}}^{\text{UL}} = 1$.

9.1.3 Type-2 HARQ-ACK codebook determination

This clause applies if the UE is configured with *pdsch-HARQ-ACK-Codebook = dynamic*.

9.1.3.1 Type-2 HARQ-ACK codebook in physical uplink control channel

A UE determines monitoring occasions for PDCCH with DCI format 1_0 or DCI format 1_1 for scheduling PDSCH receptions or SPS PDSCH release on an active DL BWP of a serving cell c, as described in Clause 10.1, and for which the UE transmits HARQ-ACK information in a same PUCCH in slot n based on

- PDSCH-to-HARQ_feedback timing indicator field values for PUCCH transmission with HARQ-ACK information in slot n in response to PDSCH receptions or SPS PDSCH release
- slot offsets K_0 [6, TS 38.214] provided by time domain resource assignment field in DCI format 1_0 or DCI format 1_1 for scheduling PDSCH receptions or SPS PDSCH release and by *pdsch-AggregationFactor*, when provided.

The set of PDCCH monitoring occasions for DCI format 1_0 or DCI format 1_1 for scheduling PDSCH receptions or SPS PDSCH release is defined as the union of PDCCH monitoring occasions across active DL BWPs of configured serving cells, ordered in ascending order of start time of the search space set associated with a PDCCH monitoring occasion. The cardinality of the set of PDCCH monitoring occasions defines a total number M of PDCCH monitoring occasions.

A value of the counter downlink assignment indicator (DAI) field in DCI format 1_0 or DCI format 1_1 denotes the accumulative number of {serving cell, PDCCH monitoring occasion}-pair(s) in which PDSCH reception(s) or SPS PDSCH release associated with DCI format 1_0 or DCI format 1_1 is present, up to the current serving cell and current PDCCH monitoring occasion, first in ascending order of serving cell index and then in ascending order of PDCCH monitoring occasion index m, where $0 \le m < M$.

The value of the total DAI, when present [5, TS 38.212], in DCI format 1_1 denotes the total number of {serving cell, PDCCH monitoring occasion}-pair(s) in which PDSCH reception(s) or SPS PDSCH release associated with DCI format 1_0 or DCI format 1_1 is present, up to the current PDCCH monitoring occasion m and is updated from PDCCH monitoring occasion to PDCCH monitoring occasion.

Denote by $V_{\text{C-DAI},c,m}^{\text{DL}}$ the value of the counter DAI in DCI format 1_0 or DCI format 1_1 for scheduling on serving cell c in PDCCH monitoring occasion m according to Table 9.1.3-1. Denote by $V_{\text{T-DAI},m}^{\text{DL}}$ the value of the total DAI in DCI format 1_1 in PDCCH monitoring occasion m according to Table 9.1.3-1. The UE assumes a same value of total DAI in all DCI formats 1_1 in PDCCH monitoring occasion m.

If the UE transmits HARQ-ACK information in a PUCCH in slot n and for any PUCCH format, the UE determines the $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \ldots, \tilde{o}_{O^{ACK}-1}^{ACK}$, for a total number of O_{ACK} HARQ-ACK information bits, according to the following pseudo-code:

Set $m=0$ – PDCCH with DCI format 1_0 or DCI format 1_1 monitoring occasion index: lower index corresponds to earlier PDCCH with DCI format 1_0 or DCI format 1_1 monitoring occasion

Set $j=0$

Set $V_{temp}=0$

Set $V_{temp2}=0$

Set $V_s=\varnothing$

Set $N_{\text{cells}}^{\text{DL}}$ to the number of serving cells configured by higher layers for the UE

Set M to the number of PDCCH monitoring occasion(s)

while $m<M$

Set $c=0$ – serving cell index: lower indexes correspond to lower RRC indexes of corresponding cell

while $c < N_{\text{cells}}^{\text{DL}}$

if PDCCH monitoring occasion m is before an active DL BWP change on serving cell c or an active UL BWP change on the PCell and an active DL BWP change is not triggered by a DCI format 1_1 in PDCCH monitoring occasion m

$c=c+1$;

else

if there is a PDSCH on serving cell c associated with PDCCH in PDCCH monitoring occasion m, or there is a PDCCH indicating SPS PDSCH release on serving cell c

if $V_{\text{C-DAI},c,m}^{\text{DL}} \le V_{temp}$

$j = j+1$

end if

$V_{temp}=V_{\text{C-DAI},c,m}^{\text{DL}}$

if $V_{\text{T-DAI},m}^{\text{DL}}=\varnothing$

$V_{temp2}=V_{\text{C-DAI},c,m}^{\text{DL}}$

else

$V_{temp\,2}=V_{\text{T-DAI},m}^{\text{DL}}$

end if

if *harq-ACK-SpatialBundlingPUCCH* is not provided and m is a monitoring occasion for PDCCH with DCI format 1_0 or DCI format 1_1 and the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for at least one configured DL BWP of at least one serving cell,

$\tilde{o}_{8j+2\left(V_{C-DAI,c,m}^{DL}-1\right)}^{ACK}$ = HARQ-ACK information bit corresponding to the first transport block of this cell

$\tilde{o}_{8j+2\left(V_{C-DAI,c,m}^{DL}-1\right)+1}^{ACK}$ = HARQ-ACK information bit corresponding to the second transport block of this cell

$V_s = V_s \cup \left\{8j+2\left(V_{\text{C-DAI},c,m}^{\text{DL}}-1\right), 8j+2\left(V_{\text{C-DAI},c,m}^{\text{DL}}-1\right)+1\right\}$

elseif *harq-ACK-SpatialBundlingPUCCH* is provided to the UE and m is a monitoring occasion for PDCCH with DCI format 1_1 and the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks in at least one configured DL BWP of a serving cell,

$\tilde{o}^{ACK}_{4j+V^{\mathrm{DL}}_{\mathrm{C-DAI},c,m}-1}$ = binary AND operation of the HARQ-ACK information bits corresponding to the first and second transport blocks of this cell

$V_s = V_s \cup \left\{4j + V^{\mathrm{DL}}_{\mathrm{C-DAI},c,m} - 1\right\}$

else

$\tilde{o}^{ACK}_{4j+V^{DL}_{C-DAI,c,m}-1}$ = HARQ-ACK information bit of this cell

$V_s = V_s \cup \left\{4j + V^{\mathrm{DL}}_{\mathrm{C-DAI},c,m} - 1\right\}$

end if

end if

$c = c+1$

end if

end while

$m = m+1$

end while

if $V_{temp2} < V_{temp}$

$j = j+1$

end if

if *harq-ACK-SpatialBundlingPUCCH* is not provided to the UE and the UE is configured by *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for at least one configured DL BWP of a serving cell,

$O^{ACK} = 2 \cdot \left(4 \cdot j + V_{temp2}\right)$

else

$O^{ACK} = 4 \cdot j + V_{temp\,2}$

end if

$\tilde{o}^{ACK}_i = \mathrm{NACK}$ for any $i \in \left\{0,1,\ldots, O^{ACK}-1\right\} \setminus V_s$

Set $c = 0$

while $c < N^{\mathrm{DL}}_{\mathrm{cells}}$

if SPS PDSCH reception is activated for a UE and the UE is configured to receive SPS PDSCH in a slot $n - K_{1,c}$ for serving cell c, where $K_{1,c}$ is the PDSCH-to-HARQ-feedback timing value for SPS PDSCH on serving cell c

$O^{ACK} = O^{ACK} + 1$

$o^{ACK}_{O^{ACK}-1}$ = HARQ-ACK information bit associated with the SPS PDSCH reception

end if

$c=c+1;$

end while

For a PDCCH monitoring occasion with DCI format 1_0 or DCI format 1_1 in the active DL BWP of a serving cell, when a UE receives a PDSCH with one transport block and the value of *maxNrofCodeWordsScheduledByDCI* is 2, the HARQ-ACK information is associated with the first transport block and the UE generates a NACK for the second transport block if *harq-ACK-SpatialBundlingPUCCH* is not provided and generates HARQ-ACK information with value of ACK for the second transport block if *harq-ACK-SpatialBundlingPUCCH* is provided.

If a UE is not provided *PDSCH-CodeBlockGroupTransmission* for each of the $N^{\mathrm{DL}}_{\mathrm{cells}}$ serving cells, or for PDSCH receptions scheduled by DCI format 1_0, or for SPS PDSCH reception, or for SPS PDSCH release, and if $O_{\mathrm{ACK}}+O_{\mathrm{SR}}+O_{\mathrm{CSI}}\leq 11$, the UE determines a number of HARQ-ACK information bits $n_{\mathrm{HARQ\text{-}ACK}}$ for obtaining a transmission power for a PUCCH, as described in Clause 7.2.1, as

$$n_{\mathrm{HARQ\text{-}ACK}}=n_{\mathrm{HARQ\text{-}ACK,TB}}=\left(\left(V^{\mathrm{DL}}_{\mathrm{DAI},m_{\mathrm{last}}}-\sum_{c=0}^{N^{\mathrm{DL}}_{\mathrm{cells}}-1}U_{\mathrm{DAI},c}\right)\bmod 4\right)N^{\mathrm{DL}}_{\mathrm{TB,max}}+\sum_{c=0}^{N^{\mathrm{DL}}_{\mathrm{cells}}-1}\left(\sum_{m=0}^{M-1}N^{\mathrm{received}}_{m,c}+N_{\mathrm{SPS},c}\right)$$

where

- if $N^{\mathrm{DL}}_{\mathrm{cells}}=1$, $V^{\mathrm{DL}}_{\mathrm{DAI},m_{\mathrm{last}}}$ is the value of the counter DAI in the last DCI format 1_0 or DCI format 1_1 scheduling PDSCH reception or indicating SPS PDSCH release for any serving cell c that the UE detects within the M PDCCH monitoring occasions.
- if $N^{\mathrm{DL}}_{\mathrm{cells}}>1$
  - if the UE does not detect any DCI format 1_1 in a last PDCCH monitoring occasion within the M PDCCH monitoring occasions where the UE detects at least one DCI format scheduling PDSCH reception or indicating SPS PDSCH release for any serving cell c, $V^{\mathrm{DL}}_{\mathrm{DAI},m_{\mathrm{last}}}$ is the value of the counter DAI in a last DCI format 1_0 the UE detects in the last PDCCH monitoring occasion
  - if the UE detects at least one DCI format 1_1 in a last PDCCH monitoring occasion within the M PDCCH monitoring occasions where the UE detects at least one DCI format scheduling PDSCH reception or indicating SPS PDSCH release for any serving cell c, $V^{\mathrm{DL}}_{\mathrm{DAI},m_{\mathrm{last}}}$ is the value of the total DAI in the at least one DCI format 1_1
- $V^{\mathrm{DL}}_{\mathrm{DAI},m_{\mathrm{last}}}=0$ if the UE does not detect any DCI format 1_0 or DCI format 1_1 scheduling PDSCH reception or indicating SPS PDSCH release for any serving cell c in any of the M PDCCH monitoring occasions.
- $U_{\mathrm{DAI},c}$ is the total number of DCI format 1_0 and DCI format 1_1 scheduling PDSCH receptions or indicating SPS PDSCH release that the UE detects within the M PDCCH monitoring occasions for serving cell c. $U_{\mathrm{DAI},c}=0$ if the UE does not detect any DCI format 1_0 or DCI format 1_1 scheduling PDSCH reception or indicating SPS PDSCH release for serving cell c in any of the M PDCCH monitoring occasions.
- $N^{\mathrm{DL}}_{\mathrm{TB,max}}=2$ if the value of *maxNrofCodeWordsScheduledByDCI* is 2 for any serving cell c and *harq-ACK-SpatialBundlingPUCCH* is not provided; otherwise, $N^{\mathrm{DL}}_{\mathrm{TB,max}}=1$.
- $N^{\mathrm{received}}_{m,c}$ is the number of transport blocks the UE receives in a PDSCH scheduled by DCI format 1_0 or DCI format 1_1 that the UE detects in PDCCH monitoring occasion m for serving cell c if *harq-ACK-*

SpatialBundlingPUCCH is not provided, or the number of PDSCH scheduled by DCI format 1_0 and DCI format 1_1 that the UE detects in PDCCH monitoring occasion m for serving cell c if *harq-ACK-SpatialBundlingPUCCH* is provided, or the number of DCI format 1_0 that the UE detects and indicate SPS PDSCH release in PDCCH monitoring occasion m for serving cell c.

- $N_{\text{SPS},c}$ is the number of SPS PDSCH receptions by the UE on serving cell c for which the UE transmits corresponding HARQ-ACK information in the same PUCCH as for HARQ-ACK information corresponding to PDSCH receptions within the M PDCCH monitoring occasions.

If a UE

- is provided *PDSCH-CodeBlockGroupTransmission* for $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells; and
- is not provided *PDSCH-CodeBlockGroupTransmission*, for $N_{\text{cells}}^{\text{DL,TB}}$ serving cells where $N_{\text{cells}}^{\text{DL,TB}} + N_{\text{cells}}^{\text{DL,CBG}} = N_{\text{cells}}^{\text{DL}}$

the UE determines the $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, ..., \tilde{o}_{O^{ACK}-1}^{ACK}$ according to the previous pseudo-code with the following modifications

- $N_{\text{cells}}^{\text{DL}}$ is used for the determination of a first HARQ-ACK sub-codebook for SPS PDSCH release, SPS PDSCH reception, and for TB-based PDSCH receptions scheduled by DCI formats 1_0 on the $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells and by DCI formats 1_0 and DCI formats 1_1 on the $N_{\text{cells}}^{\text{DL,TB}}$ serving cells
- $N_{\text{cells}}^{\text{DL}}$ is replaced by $N_{\text{cells}}^{\text{DL,CBG}}$ for the determination of a second HARQ-ACK sub-codebook corresponding to the $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells for CBG-based PDSCH receptions scheduled by DCI format 1_1, and
  - Instead of generating one HARQ-ACK information bit per transport block for a serving cell from the $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells, the UE generates $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$ HARQ-ACK information bits, where $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$ is the maximum value of $N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$ across all $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells and $N_{\text{TB},c}^{\text{DL}}$ is the value of *maxNrofCodeWordsScheduledByDCI* for serving cell c. If for a serving cell c it is $N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}} < N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$, the UE generates NACK for the last $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}} - N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$ HARQ-ACK information bits for serving cell c
  - The pseudo-code operation when *harq-ACK-SpatialBundlingPUCCH* is provided is not applicable
- The counter DAI value and the total DAI value apply separately for each HARQ-ACK sub-codebook
- The UE generates the HARQ-ACK codebook by appending the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook

If $O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}} \leq 11$, the UE also determines $n_{\text{HARQ-ACK}} = n_{\text{HARQ-ACK,TB}} + n_{\text{HARQ-ACK,CBG}}$ for obtaining a PUCCH transmission power, as described in Clause 7.2.1, with

$$n_{\text{HARQ-ACK,CBG}} = \left(\left(V_{\text{DAI},m_{\text{last}}}^{\text{DL}} - \sum_{c=0}^{N_{\text{cells}}^{\text{DL,CBG}}-1} U_{\text{DAI},c}^{\text{CBG}} \right) \bmod 4 \right) N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}} + \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}-1} \sum_{m=0}^{M-1} N_{m,c}^{\text{received,CBG}}$$

where

- if $N_{\text{cells}}^{\text{DL}} = 1$, $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$ is the value of the counter DAI in the last DCI format 1_1 scheduling CBG-based PDSCH reception for any serving cell c that the UE detects within the M PDCCH monitoring occasions
- if $N_{\text{cells}}^{\text{DL}} > 1$, $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$ is the value of the total DAI in the last DCI format 1_1 scheduling CBG-based PDSCH reception for any serving cell c that the UE detects within the M PDCCH monitoring occasions

- $V_{\text{DAI},m_{\text{last}}}^{\text{DL}} = 0$ if the UE does not detect any DCI format 1_1 scheduling CBG-based PDSCH reception for any serving cell c in any of the M PDCCH monitoring occasions

- $U_{\text{DAI},c}^{\text{CBG}}$ is the total number of DCI format 1_1 scheduling CBG-based PDSCH receptions that the UE detects within the M PDCCH monitoring occasions for serving cell c. $U_{\text{DAI},c}^{\text{CBG}} = 0$ if the UE does not detect any DCI format 1_1 scheduling CBG-based PDSCH reception for serving cell c in any of the M PDCCH monitoring occasions

- $N_{m,c}^{\text{received,CBG}}$ is the number of CBGs the UE receives in a PDSCH scheduled by DCI format 1_1 that the UE detects in PDCCH monitoring occasion m for serving cell c and the UE reports corresponding HARQ-ACK information in the PUCCH

Table 9.1.3-1: Value of counter DAI in DCI format 1_0 and of counter DAI or total DAI DCI format 1_1

DAI MSB, LSB	$V_{\text{C-DAI}}^{\text{DL}}$ or $V_{\text{T-DAI}}^{\text{DL}}$	Number of {serving cell, PDCCH monitoring occasion}-pair(s) in which PDSCH transmission(s) associated with PDCCH or PDCCH indicating SPS PDSCH release is present, denoted as Y and $Y \geq 1$
0,0	1	$(Y-1) \bmod 4 + 1 = 1$
0,1	2	$(Y-1) \bmod 4 + 1 = 2$
1,0	3	$(Y-1) \bmod 4 + 1 = 3$
1,1	4	$(Y-1) \bmod 4 + 1 = 4$

9.1.3.2 Type-2 HARQ-ACK codebook in physical uplink shared channel

If a UE would multiplex HARQ-ACK information in a PUSCH transmission that is not scheduled by a DCI format or is scheduled by DCI format 0_0, then

- if the UE has not received any PDCCH within the monitoring occasions for DCI format 1_0 or DCI format 1_1 for scheduling PDSCH receptions or SPS PDSCH release on any serving cell c and the UE does not have HARQ-ACK information in response to a SPS PDSCH reception to multiplex in the PUSCH, as described in Clause 9.1.3.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission;

- else, the UE generates the HARQ-ACK codebook as described in Clause 9.1.3.1, except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

If a UE multiplexes HARQ-ACK information in a PUSCH transmission that is scheduled by DCI format 0_1, the UE generates the HARQ-ACK codebook as described in Clause 9.1.3.1, with the following modifications:

- For the pseudo-code for the HARQ-ACK codebook generation in Clause 9.1.3.1, after the completion of the c and m loops, the UE sets $V_{temp2} = V_{\text{DAI}}^{\text{UL}}$ where $V_{\text{DAI}}^{\text{UL}}$ is the value of the DAI field in DCI format 0_1 according to Table 9.1.3-2

- For the case of first and second HARQ-ACK sub-codebooks, DCI format 0_1 includes a first DAI field corresponding to the first HARQ-ACK sub-codebook and a second DAI field corresponding to the second HARQ-ACK sub-codebook

- *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

If a UE is not provided *PDSCH-CodeBlockGroupTransmission* and the UE is scheduled for a PUSCH transmission by DCI format 0_1 with DAI field value $V_{\text{T-DAI}}^{\text{UL}} = 4$ and the UE has not received any PDCCH within the monitoring occasions for PDCCH with DCI format 1_0 or DCI format 1_1 for scheduling PDSCH receptions or SPS PDSCH release on any serving cell C and the UE does not have HARQ-ACK information in response to a SPS PDSCH reception to multiplex in the PUSCH, as described in Clause 9.1.3.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission.

If a UE is provided *PDSCH-CodeBlockGroupTransmission* and the UE is scheduled for a PUSCH transmission by DCI format 0_1 with first DAI field value $V_{\text{T-DAI}}^{\text{UL}} = 4$ or with second DAI field value $V_{\text{T-DAI}}^{\text{UL}} = 4$ and the UE has not received any PDCCH within the monitoring occasions for PDCCH with DCI format 1_0 or with DCI format 1_1, respectively, for scheduling PDSCH receptions or SPS PDSCH release on any serving cell C and the UE does not have HARQ-ACK information in response to a SPS PDSCH reception to multiplex in the PUSCH, as described in Clause 9.1.3.1, the UE does not multiplex HARQ-ACK information for the first sub-codebook or for the second sub-codebook, respectively, in the PUSCH transmission.

Table 9.1.3-2: Value of DAI in DCI format 0_1

DAI MSB, LSB	$V_{\text{T-DAI}}^{\text{UL}}$	Number of {serving cell, PDCCH monitoring occasion}-pair(s) in which PDSCH transmission(s) associated with PDCCH or PDCCH indicating SPS PDSCH release is present, denoted as X and $X \geq 1$
0,0	1	$(X-1) \bmod 4 + 1 = 1$
0,1	2	$(X-1) \bmod 4 + 1 = 2$
1,0	3	$(X-1) \bmod 4 + 1 = 3$
1,1	4	$(X-1) \bmod 4 + 1 = 4$

9.2 UCI reporting in physical uplink control channel

UCI types reported in a PUCCH include HARQ-ACK information, SR, and CSI. UCI bits include HARQ-ACK information bits, if any, SR information bits, if any, and CSI bits, if any. The HARQ-ACK information bits correspond to a HARQ-ACK codebook as described in Clause 9.1.

A UE may transmit one or two PUCCHs on a serving cell in different symbols within a slot of $N_{\text{symb}}^{\text{slot}}$ symbols as defined in [4, TS 38.211]. When the UE transmits two PUCCHs in a slot, at least one of the two PUCCHs uses PUCCH format 0 or PUCCH format 2.

In Clauses 9.2.3, 9.2.5.1 and 9.2.5.2, a UE assumes 11 CRC bits if a number of respective UCI bits is larger than or equal to 360; otherwise, the UE determines a number of CRC bits based on the number of respective UCI bits as described in [5, TS 38.212].

9.2.1 PUCCH Resource Sets

If a UE does not have dedicated PUCCH resource configuration, provided by *PUCCH-ResourceSet* in *PUCCH-Config*, a PUCCH resource set is provided by *pucch-ResourceCommon* through an index to a row of Table 9.2.1-1 for transmission of HARQ-ACK information on PUCCH in an initial UL BWP of $N_{\text{BWP}}^{\text{size}}$ PRBs. The PUCCH resource set includes sixteen resources, each corresponding to a PUCCH format, a first symbol, a duration, a PRB offset $RB_{\text{BWP}}^{\text{offset}}$, and a cyclic shift index set for a PUCCH transmission. The UE transmits a PUCCH using frequency hopping. An orthogonal cover code with index 0 is used for a PUCCH resource with PUCCH format 1 in Table 9.2.1-1. The UE transmits the PUCCH using the same spatial domain transmission filter as for a PUSCH transmission scheduled by a RAR UL grant as described in Clause 8.3.

If a UE is not provided *pdsch-HARQ-ACK-Codebook*, the UE generates at most one HARQ-ACK information bit.

If the UE provides HARQ-ACK information in a PUCCH transmission in response to detecting a DCI format 1_0 or DCI format 1_1, the UE determines a PUCCH resource with index r_{PUCCH}, $0 \leq r_{\text{PUCCH}} \leq 15$, as

$r_{\text{PUCCH}} = \left\lfloor \frac{2 \cdot n_{\text{CCE},0}}{N_{\text{CCE}}} \right\rfloor + 2 \cdot \Delta_{\text{PRI}}$, where N_{CCE} is a number of CCEs in a CORESET of a PDCCH reception with DCI format 1_0 or DCI format 1_1, as described in Clause 10.1, $n_{\text{CCE},0}$ is the index of a first CCE for the PDCCH reception, and Δ_{PRI} is a value of the PUCCH resource indicator field in the DCI format 1_0 or DCI format 1_1.

If $\lfloor r_{\text{PUCCH}} / 8 \rfloor = 0$

- the UE determines the PRB index of the PUCCH transmission in the first hop as $RB_{\text{BWP}}^{\text{offset}} + \lfloor r_{\text{PUCCH}} / N_{\text{CS}} \rfloor$ and the PRB index of the PUCCH transmission in the second hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \lfloor r_{\text{PUCCH}} / N_{\text{CS}} \rfloor$, where N_{CS} is the total number of initial cyclic shift indexes in the set of initial cyclic shift indexes
- the UE determines the initial cyclic shift index in the set of initial cyclic shift indexes as $r_{\text{PUCCH}} \bmod N_{\text{CS}}$

If $\lfloor r_{\text{PUCCH}} / 8 \rfloor = 1$

- the UE determines the PRB index of the PUCCH transmission in the first hop as $N_{\text{BWP}}^{\text{size}} - 1 - RB_{\text{BWP}}^{\text{offset}} - \lfloor (r_{\text{PUCCH}} - 8) / N_{\text{CS}} \rfloor$ and the PRB index of the PUCCH transmission in the second hop as $RB_{\text{BWP}}^{\text{offset}} + \lfloor (r_{\text{PUCCH}} - 8) / N_{\text{CS}} \rfloor$
- the UE determines the initial cyclic shift index in the set of initial cyclic shift indexes as $(r_{\text{PUCCH}} - 8) \bmod N_{\text{CS}}$

Table 9.2.1-1: PUCCH resource sets before dedicated PUCCH resource configuration

Index	PUCCH format	First symbol	Number of symbols	PRB offset $RB_{\text{BWP}}^{\text{offset}}$	Set of initial CS indexes
0	0	12	2	0	{0, 3}
1	0	12	2	0	{0, 4, 8}
2	0	12	2	3	{0, 4, 8}
3	1	10	4	0	{0, 6}
4	1	10	4	0	{0, 3, 6, 9}
5	1	10	4	2	{0, 3, 6, 9}
6	1	10	4	4	{0, 3, 6, 9}
7	1	4	10	0	{0, 6}
8	1	4	10	0	{0, 3, 6, 9}
9	1	4	10	2	{0, 3, 6, 9}
10	1	4	10	4	{0, 3, 6, 9}
11	1	0	14	0	{0, 6}
12	1	0	14	0	{0, 3, 6, 9}
13	1	0	14	2	{0, 3, 6, 9}
14	1	0	14	4	{0, 3, 6, 9}
15	1	0	14	$\lfloor N_{\text{BWP}}^{\text{size}} / 4 \rfloor$	{0, 3, 6, 9}

If a UE has dedicated PUCCH resource configuration, the UE is provided by higher layers with one or more PUCCH resources.

A PUCCH resource includes the following parameters:

- a PUCCH resource index provided by *pucch-ResourceId*
- an index of the first PRB prior to frequency hopping or for no frequency hopping by *startingPRB*
- an index of the first PRB after frequency hopping by *secondHopPRB*;
- an indication for intra-slot frequency hopping by *intraSlotFrequencyHopping*
- a configuration for a PUCCH format, from PUCCH format 0 through PUCCH format 4, provided by *format*

If the *format* indicates *PUCCH-format0*, the PUCCH format configured for a PUCCH resource is PUCCH format 0, where the PUCCH resource also includes an index for an initial cyclic shift provided by *initialCyclicShift*, a number of symbols for a PUCCH transmission provided by *nrofSymbols*, a first symbol for the PUCCH transmission provided by *startingSymbolIndex*.

If the *format* indicates *PUCCH-format1*, the PUCCH format configured for a PUCCH resource is PUCCH format 1, where the PUCCH resource also includes an index for an initial cyclic shift provided by *initialCyclicShift*, a number of symbols for a PUCCH transmission provided by *nrofSymbols*, a first symbol for the PUCCH transmission provided by *startingSymbolIndex*, and an index for an orthogonal cover code by *timeDomainOCC*.

If the *format* indicates *PUCCH-format2* or *PUCCH-format3*, the PUCCH format configured for a PUCCH resource is PUCCH format 2 or PUCCH format 3, respectively, where the PUCCH resource also includes a number of PRBs provided by *nrofPRBs*, a number of symbols for a PUCCH transmission provided by *nrofSymbols*, and a first symbol for the PUCCH transmission provided by *startingSymbolIndex*.

If the *format* indicates *PUCCH-format4*, the PUCCH format configured for a PUCCH resource is PUCCH format 4, where the PUCCH resource also includes a number of symbols for a PUCCH transmission provided by *nrofSymbols*, a length for an orthogonal cover code by *occ-Length*, an index for an orthogonal cover code by *occ-Index*, and a first symbol for the PUCCH transmission provided by *startingSymbolIndex*.

A UE can be configured up to four sets of PUCCH resources. A PUCCH resource set is provided by *PUCCH-ResourceSet* and is associated with a PUCCH resource set index provided by *pucch-ResourceSetId*, with a set of PUCCH resource indexes provided by *resourceList* that provides a set of *pucch-ResourceId* used in the PUCCH resource set, and with a maximum number of UCI information bits the UE can transmit using a PUCCH resource in the PUCCH resource set provided by *maxPayloadSize*. For the first PUCCH resource set, the maximum number of UCI information bits is 2. A maximum number of PUCCH resource indexes for a set of PUCCH resources is provided by *maxNrofPUCCH-ResourcesPerSet*. The maximum number of PUCCH resources in the first PUCCH resource set is 32 and the maximum number of PUCCH resources in the other PUCCH resource sets is 8.

If the UE transmits O_{UCI} UCI information bits, that include HARQ-ACK information bits, the UE determines a PUCCH resource set to be

- a first set of PUCCH resources with *pucch-ResourceSetId* = 0 if $O_{\text{UCI}} \leq 2$ including 1 or 2 HARQ-ACK information bits and a positive or negative SR on one SR transmission occasion if transmission of HARQ-ACK information and SR occurs simultaneously, or
- a second set of PUCCH resources with *pucch-ResourceSetId* = 1, if provided by higher layers, if $2 < O_{\text{UCI}} \leq N_2$ where N_2 is equal to *maxPayloadSize* if *maxPayloadSize* is provided for the PUCCH resource set with *pucch-ResourceSetId* = 1; otherwise N_2 is equal to 1706, or
- a third set of PUCCH resources with *pucch-ResourceSetId* = 2, if provided by higher layers, if $N_2 < O_{\text{UCI}} \leq N_3$ where N_3 is equal to *maxPayloadSize* if *maxPayloadSize* is provided for the PUCCH resource set with *pucch-ResourceSetId* = 2; otherwise N_3 is equal to 1706, or
- a fourth set of PUCCH resources with *pucch-ResourceSetId* = 3, if provided by higher layers, if $N_3 < O_{\text{UCI}} \leq 1706$.

9.2.2 PUCCH Formats for UCI transmission

If a UE is not transmitting PUSCH, and the UE is transmitting UCI, the UE transmits UCI in a PUCCH using

- PUCCH format 0 if
  - the transmission is over 1 symbol or 2 symbols,
  - the number of HARQ-ACK information bits with positive or negative SR (HARQ-ACK/SR bits) is 1 or 2
- PUCCH format 1 if
  - the transmission is over 4 or more symbols,
  - the number of HARQ-ACK/SR bits is 1 or 2
- PUCCH format 2 if
  - the transmission is over 1 symbol or 2 symbols,
  - the number of UCI bits is more than 2
- PUCCH format 3 if

- the transmission is over 4 or more symbols,
- the number of UCI bits is more than 2,
- the PUCCH resource does not include an orthogonal cover code

- PUCCH format 4 if
  - the transmission is over 4 or more symbols,
  - the number of UCI bits is more than 2,
  - the PUCCH resource includes an orthogonal cover code

A spatial setting for a PUCCH transmission is provided by *PUCCH-SpatialRelationInfo* if the UE is configured with a single value for *pucch-SpatialRelationInfoId*; otherwise, if the UE is provided multiple values for *PUCCH-SpatialRelationInfo*, the UE determines a spatial setting for the PUCCH transmission as described in [11, TS 38.321]. The UE applies corresponding actions in [11, TS 38.321] and a corresponding setting for a spatial domain filter to transmit PUCCH in the first slot that is after slot $k+3\cdot N_{\text{slot}}^{\text{subframe},\mu}$ where k is the slot where the UE would transmit a PUCCH with HARQ-ACK information with ACK value corresponding to a PDSCH reception providing the *PUCCH-SpatialRelationInfo* and μ is the SCS configuration for the PUCCH

- If *PUCCH-SpatialRelationInfo* provides *ssb-Index*, the UE transmits the PUCCH using a same spatial domain filter as for a reception of a SS/PBCH block with index provided by *ssb-Index* for a same serving cell or, if *servingCellId* is provided, for a serving cell indicated by *servingCellId*
- else if *PUCCH-SpatialRelationInfo* provides *csi-RS-Index*, the UE transmits the PUCCH using a same spatial domain filter as for a reception of a CSI-RS with resource index provided by *csi-RS-Index* for a same serving cell or, if *servingCellId* is provided, for a serving cell indicated by *servingCellId*
- else *PUCCH-SpatialRelationInfo* provides *srs*, the UE transmits the PUCCH using a same spatial domain filter as for a transmission of a SRS with resource index provided by *resource* for a same serving cell and/or active UL BWP or, if *servingCellId* and/or *uplinkBWP* are provided, for a serving cell indicated by *servingCellId* and/or for an UL BWP indicated by *uplinkBWP*

A number of DMRS symbols for a PUCCH transmission using PUCCH format 3 or 4 is provided by *additionalDMRS*.

Use of π/2-PBSK, instead of QPSK, for a PUCCH transmission using PUCCH format 3 or 4 is indicated by *pi2BPSK*.

9.2.3 UE procedure for reporting HARQ-ACK

A UE does not expect to transmit more than one PUCCH with HARQ-ACK information in a slot.

For DCI format 1_0, the PDSCH-to-HARQ_feedback timing indicator field values map to {1, 2, 3, 4, 5, 6, 7, 8}. For DCI format 1_1, if present, the PDSCH-to-HARQ_feedback timing indicator field values map to values for a set of number of slots provided by *dl-DataToUL-ACK* as defined in Table 9.2.3-1.

For a SPS PDSCH reception ending in slot n, the UE transmits the PUCCH in slot $n+k$ where k is provided by the PDSCH-to-HARQ_feedback timing indicator field in DCI format 1_0 or, if present, in DCI format 1_1 activating the SPS PDSCH reception.

If the UE detects a DCI format 1_1 that does not include a PDSCH-to-HARQ_feedback timing indicator field and schedules a PDSCH reception or activates a SPS PDSCH reception ending in slot n, the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot $n+k$ where k is provided by *dl-DataToUL-ACK*.

With reference to slots for PUCCH transmissions, if the UE detects a DCI format 1_0 or a DCI format 1_1 scheduling a PDSCH reception ending in slot n or if the UE detects a DCI format 1_0 indicating a SPS PDSCH release through a PDCCH reception ending in slot n, the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot $n+k$, where k is a number of slots and is indicated by the PDSCH-to-HARQ_feedback timing indicator field in the DCI format, if present, or provided by *dl-DataToUL-ACK*. $k=0$ corresponds to the last slot of the PUCCH transmission that overlaps with the PDSCH reception or with the PDCCH reception in case of SPS PDSCH release.

A PUCCH transmission with HARQ-ACK information is subject to the limitations for UE transmissions described in Clause 11.1 and Clause 11.1.1.

Table 9.2.3-1: Mapping of PDSCH-to-HARQ_feedback timing indicator field values to numbers of slots

PDSCH-to-HARQ_feedback timing indicator			Number of slots k
1 bit	2 bits	3 bits	
'0'	'00'	'000'	1st value provided by *dl-DataToUL-ACK*
'1'	'01'	'001'	2nd value provided by *dl-DataToUL-ACK*
	'10'	'010'	3rd value provided by *dl-DataToUL-ACK*
	'11'	'011'	4th value provided by *dl-DataToUL-ACK*
		'100'	5th value provided by *dl-DataToUL-ACK*
		'101'	6th value provided by *dl-DataToUL-ACK*
		'110'	7th value provided by *dl-DataToUL-ACK*
		'111'	8th value provided by *dl-DataToUL-ACK*

For a PUCCH transmission with HARQ-ACK information, a UE determines a PUCCH resource after determining a set of PUCCH resources for O_{UCI} HARQ-ACK information bits, as described in Clause 9.2.1. The PUCCH resource determination is based on a PUCCH resource indicator field [5, TS 38.212] in a last DCI format 1_0 or DCI format 1_1, among the DCI formats 1_0 or DCI formats 1_1 that have a value of a PDSCH-to-HARQ_feedback timing indicator field indicating a same slot for the PUCCH transmission, that the UE detects and for which the UE transmits corresponding HARQ-ACK information in the PUCCH where, for PUCCH resource determination, detected DCI formats are first indexed in an ascending order across serving cells indexes for a same PDCCH monitoring occasion and are then indexed in an ascending order across PDCCH monitoring occasion indexes.

The PUCCH resource indicator field values map to values of a set of PUCCH resource indexes, as defined in Table 9.2.3-2, provided by *resourceList* for PUCCH resources from a set of PUCCH resources provided by *PUCCH-ResourceSet* with a maximum of eight PUCCH resources.

For the first set of PUCCH resources and when the size R_{PUCCH} of *resourceList* is larger than eight, when a UE provides HARQ-ACK information in a PUCCH transmission in response to detecting a last DCI format 1_0 or DCI format 1_1 in a PDCCH reception, among DCI formats 1_0 or DCI formats 1_1 with a value of the PDSCH-to-HARQ_feedback timing indicator field indicating a same slot for the PUCCH transmission, the UE determines a PUCCH resource with index r_{PUCCH}, $0 \le r_{\text{PUCCH}} \le R_{\text{PUCCH}} - 1$, as

$$r_{\text{PUCCH}} = \begin{cases} \left\lfloor \frac{n_{\text{CCE},p} \cdot \lceil R_{\text{PUCCH}}/8 \rceil}{N_{\text{CCE},p}} \right\rfloor + \Delta_{\text{PRI}} \cdot \left\lceil \frac{R_{\text{PUCCH}}}{8} \right\rceil & \text{if} \quad \Delta_{\text{PRI}} < R_{\text{PUCCH}} \bmod 8 \\ \left\lfloor \frac{n_{\text{CCE},p} \cdot \lfloor R_{\text{PUCCH}}/8 \rfloor}{N_{\text{CCE},p}} \right\rfloor + \Delta_{\text{PRI}} \cdot \left\lceil \frac{R_{\text{PUCCH}}}{8} \right\rceil + R_{\text{PUCCH}} \bmod 8 & \text{if} \quad \Delta_{\text{PRI}} \ge R_{\text{PUCCH}} \bmod 8 \end{cases}$$

where $N_{\text{CCE},p}$ is a number of CCEs in CORESET p of the PDCCH reception for the DCI format 1_0 or DCI format 1_1 as described in Clause 10.1, $n_{\text{CCE},p}$ is the index of a first CCE for the PDCCH reception, and Δ_{PRI} is a value of the PUCCH resource indicator field in the DCI format 1_0 or DCI format 1_1.

Table 9.2.3-2: Mapping of PUCCH resource indication field values to a PUCCH resource in a PUCCH resource set with maximum 8 PUCCH resources

PUCCH resource indicator	PUCCH resource
'000'	1st PUCCH resource provided by *pucch-ResourceId* obtained from the 1st value of *resourceList*
'001'	2nd PUCCH resource provided by *pucch-ResourceId* obtained from the 2nd value of *resourceList*
'010'	3rd PUCCH resource provided by *pucch-ResourceId* obtained from the 3rd value of *resourceList*
'011'	4th PUCCH resource provided by *pucch-ResourceId* obtained from the 4th value of *resourceList*
'100'	5th PUCCH resource provided by *pucch-ResourceId* obtained from the 5th value of *resourceList*
'101'	6th PUCCH resource provided by *pucch-ResourceId* obtained from the 6th value of *resourceList*
'110'	7th PUCCH resource provided by *pucch-ResourceId* obtained from the 7th value of *resourceList*
'111'	8th PUCCH resource provided by *pucch-ResourceId* obtained from the 8th value of *resourceList*

If a UE detects a first DCI format 1_0 or DCI format 1_1 indicating a first resource for a PUCCH transmission with corresponding HARQ-ACK information in a slot and also detects at a later time a second DCI format 1_0 or DCI format 1_1 indicating a second resource for a PUCCH transmission with corresponding HARQ-ACK information in the slot, the UE does not expect to multiplex HARQ-ACK information corresponding to the second DCI format in a PUCCH resource in the slot if the PDCCH reception that includes the second DCI format is not earlier than $N_3 \cdot (2048+144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$ from the beginning of a first symbol of the first resource for PUCCH transmission in the slot where, κ and T_c are defined in clause 4.1 of [4, TS 38.211] and μ corresponds to the smallest SCS configuration among the SCS configurations of the PDCCHs providing the DCI formats and the SCS configuration of the PUCCH. If *processingType2Enabled* of *PDSCH-ServingCellConfig* is set to *enable* for the serving cell with the second DCI format and for all serving cells with corresponding HARQ-ACK information multiplexed in the PUCCH transmission in the slot, $N_3 = 3$ for $\mu = 0$, $N_3 = 4.5$ for $\mu = 1$, $N_3 = 9$ for $\mu = 2$; otherwise, $N_3 = 8$ for $\mu = 0$, $N_3 = 10$ for $\mu = 1$, $N_3 = 17$ for $\mu = 2$, $N_3 = 20$ for $\mu = 3$.

If a UE transmits HARQ-ACK information corresponding only to a PDSCH reception without a corresponding PDCCH, a PUCCH resource for corresponding PUCCH transmission with HARQ-ACK information is provided by *n1PUCCH-AN*.

If a UE transmits a PUCCH with HARQ-ACK information using PUCCH format 0, the UE determines values m_0 and m_{CS} for computing a value of cyclic shift α [4, TS 38.211] where m_0 is provided by *initialCyclicShift* of *PUCCH-format0* or, if *initialCyclicShift* is not provided, by the initial cyclic shift index as described in Clause 9.2.1 and m_{CS} is determined from the value of one HARQ-ACK information bit or from the values of two HARQ-ACK information bits as in Table 9.2.3-3 and Table 9.2.3-4, respectively.

Table 9.2.3-3: Mapping of values for one HARQ-ACK information bit to sequences for PUCCH format 0

HARQ-ACK Value	0	1
Sequence cyclic shift	$m_{CS} = 0$	$m_{CS} = 6$

Table 9.2.3-4: Mapping of values for two HARQ-ACK information bits to sequences for PUCCH format 0

HARQ-ACK Value	{0, 0}	{0, 1}	{1, 1}	{1, 0}
Sequence cyclic shift	$m_{CS} = 0$	$m_{CS} = 3$	$m_{CS} = 6$	$m_{CS} = 9$

If a UE transmits a PUCCH with HARQ-ACK information using PUCCH format 1, the UE is provided a value for m_0 by *initialCyclicShift* of *PUCCH-format1* or, if *initialCyclicShift* is not provided, by the initial cyclic shift index as described in Clause 9.2.1.

If a UE transmits a PUCCH with O_{ACK} HARQ-ACK information bits and O_{CRC} bits using PUCCH format 2 or PUCCH format 3 in a PUCCH resource that includes $M_{\text{RB}}^{\text{PUCCH}}$ PRBs, the UE determines a number of PRBs $M_{\text{RB,min}}^{\text{PUCCH}}$ for the PUCCH transmission to be the minimum number of PRBs, that is smaller than or equal to a number of PRBs $M_{\text{RB}}^{\text{PUCCH}}$ provided respectively by *nrofPRBs* of *PUCCH-format2* or *nrofPRBs* of *PUCCH-format3* and start from the first PRB from the number of PRBs, that results to $(O_{\text{ACK}}+O_{\text{CRC}}) \le M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ and, if $M_{\text{RB}}^{\text{PUCCH}} > 1$, $(O_{\text{ACK}}+O_{\text{CRC}}) > (M_{\text{RB,min}}^{\text{PUCCH}}-1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$, where $N_{\text{sc,ctrl}}^{\text{RB}}$, $N_{\text{symb-UCI}}^{\text{PUCCH}}$, Q_m, and r are defined in Clause 9.2.5.2. For PUCCH format 3, if $M_{\text{RB,min}}^{\text{PUCCH}}$ is not equal $2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5}$ according to [4, TS 38.211], $M_{\text{RB,min}}^{\text{PUCCH}}$ is increased to the nearest allowed value of *nrofPRBs* for *PUCCH-format3* [12, TS 38.331]. If $(O_{\text{ACK}}+O_{\text{CRC}}) > (M_{\text{RB}}^{\text{PUCCH}}-1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$, the UE transmits the PUCCH over $M_{\text{RB}}^{\text{PUCCH}}$ PRBs.

9.2.4 UE procedure for reporting SR

A UE is configured by higher layer paremater *SchedulingRequestResourceConfig* a set of configurations for SR in a PUCCH transmission using either PUCCH format 0 or PUCCH format 1.

The UE is configured a PUCCH resource by *SchedulingRequestResourceId* providing a PUCCH format 0 resource or a PUCCH format 1 resource as described in Clause 9.2.1. The UE is also configured a periodicity $SR_{\text{PERIODICITY}}$ in symbols or slots and an offset SR_{OFFSET} in slots by *periodicityAndOffset* for a PUCCH transmission conveying SR. If $SR_{\text{PERIODICITY}}$ is larger than one slot, the UE determines a SR transmission occasion in a PUCCH to be in a slot with number $n_{s,f}^{\mu}$ [4, TS 38.211] in a frame with number n_f if $\left(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - SR_{\text{OFFSET}}\right) \bmod SR_{\text{PERIODICITY}} = 0$.

If $SR_{\text{PERIODICITY}}$ is one slot, the UE expects that $SR_{\text{OFFSET}} = 0$ and every slot is a SR transmission occasion in a PUCCH.

If $SR_{\text{PERIODICITY}}$ is smaller than one slot, the UE determines a SR transmission occasion in a PUCCH to start in a symbol with index l [4, TS 38.211] if $(l - l_0 \bmod SR_{\text{PERIODICITY}}) \bmod SR_{\text{PERIODICITY}} = 0$ where l_0 is the value of *startingSymbolIndex*.

If the UE determines that, for a SR transmission occasion in a PUCCH, the number of symbols available for the PUCCH transmission in a slot is smaller than the value provided by *nrofSymbols*, the UE does not transmit the PUCCH in the slot.

SR transmission occasions in a PUCCH are subject to the limitations for UE transmissions described in Clause 11.1 and Clause 11.1.1.

The UE transmits a PUCCH in the PUCCH resource for the corresponding SR configuration only when the UE transmits a positive SR. For a positive SR transmission using PUCCH format 0, the UE transmits the PUCCH as described in [4, TS 38.211] by obtaining m_0 as described for HARQ-ACK information in Clause 9.2.3 and by setting $m_{\text{cs}} = 0$. For a positive SR transmission using PUCCH format 1, the UE transmits the PUCCH as described in [4, TS 38.211] by setting $b(0) = 0$.

9.2.5 UE procedure for reporting multiple UCI types

This Clause is applicable to the case that a UE has overlapping resources for PUCCH transmissions or for PUCCH and PUSCH transmissions and each PUCCH transmission is over a single slot without repetition. Any case that a PUCCH transmission is with repetitions over multiple slots is described in Clause 9.2.6. If a UE is configured with multiple PUCCH resources in a slot to transmit CSI reports

- if the UE is not provided *multi-CSI-PUCCH-ResourceList* or if PUCCH resources for transmissions of CSI reports do not overlap in the slot, the UE determines a first resource corresponding to a CSI report with the highest priority [6, TS 38.214]

- if the first resource includes PUCCH format 2, and if there are remaining resources in the slot that do not overlap with the first resource, the UE determines a CSI report with the highest priority, among the CSI reports with corresponding resources from the remaining resources, and a corresponding second resource as an additional resource for CSI reporting

- if the first resource includes PUCCH format 3 or PUCCH format 4, and if there are remaining resources in the slot that include PUCCH format 2 and do not overlap with the first resource, the UE determines a CSI report with the highest priority, among the CSI reports with corresponding resources from the remaining resources, and a corresponding second resource as an additional resource for CSI reporting

- if the UE is provided *multi-CSI-PUCCH-ResourceList* and if any of the multiple PUCCH resources overlap, the UE multiplexes all CSI reports in a resource from the resources provided by *multi-CSI-PUCCH-ResourceList*, as described in Clause 9.2.5.2.

A UE multiplexes HARQ-ACK information, with or without SR, and CSI resport(s) in a same PUCCH if the UE is provided *simultaneousHARQ-ACK-CSI*; otherwise, the UE drops the CSI report(s) and includes only HARQ-ACK information, with or without SR, in the PUCCH. If the UE would transmit multiple PUCCHs in a slot that include HARQ-ACK information and CSI report(s), the UE expects to be provided a same configuration for *simultaneousHARQ-ACK-CSI* each of PUCCH formats 2, 3, and 4.

If a UE would multiplex CSI reports that include Part 2 CSI reports in a PUCCH resource, the UE determines the PUCCH resource and a number of PRBs for the PUCCH resource or a number of Part 2 CSI reports assuming that each of the CSI reports indicates rank 1.

If a UE would transmit multiple overlapping PUCCHs in a slot or overlapping PUCCH(s) and PUSCH(s) in a slot and, when applicable as described in Clauses 9.2.5.1 and 9.2.5.2, the UE is configured to multiplex different UCI types in one PUCCH, and at least one of the multiple overlapping PUCCHs or PUSCHs is in response to a DCI format detection by the UE, the UE multiplexes all corresponding UCI types if the following conditions are met. If one of the PUCCH transmissions or PUSCH transmissions is in response to a DCI format detection by the UE, the UE expects that the first symbol S_0 of the earliest PUCCH or PUSCH, among a group overlapping PUCCHs and PUSCHs in the slot, satisfies the following timeline conditions

- S_0 is not before a symbol with CP starting after $T_{proc,1}^{mux}$ after a last symbol of any corresponding PDSCH, $T_{proc,1}^{mux}$ is given by maximum of $\left\{T_{proc,1}^{mux,1}, \cdots, T_{proc,1}^{mux,i}, \cdots\right\}$ where for the i-th PDSCH with corresponding HARQ-ACK transmission on a PUCCH which is in the group of overlapping PUCCHs and PUSCHs, $T_{proc,1}^{mux,i} = \left(N_1 + d_{1,1} + 1\right) \cdot \left(2048 + 144\right) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$, $d_{1,1}$ is selected for the i-th PDSCH following [6, TS 38.214], N_1 is selected based on the UE PDSCH processing capability of the i-th PDSCH and SCS configuration μ, where μ corresponds to the smallest SCS configuration among the SCS configurations used for the PDCCH scheduling the i-th PDSCH (if any), the i-th PDSCH, the PUCCH with corresponding HARQ-ACK transmission for i-th PDSCH, and all PUSCHs in the group of overlapping PUCCHs and PUSCHs.

- S_0 is not before a symbol with CP starting after $T_{proc,release}^{mux}$ after a last symbol of any corresponding SPS PDSCH release. $T_{proc,release}^{mux}$ is given by maximum of $\left\{T_{proc,release}^{mux,1}, \cdots, T_{proc,release}^{mux,i}, \cdots\right\}$ where for the i-th PDCCH providing the SPS PDSCH release with corresponding HARQ-ACK transmission on a PUCCH which is in the group of overlapping PUCCHs and PUSCHs, $T_{proc,release}^{mux,i} = \left(N + 1\right) \cdot \left(2048 + 144\right) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$, N is described in Clause 10.2 and is selected based on the UE PDSCH processing capability of the i-th SPS PDSCH release and SCS configuration μ, where μ corresponds to the smallest SCS configuration among the SCS configurations used for the PDCCH providing the i-th SPS PDSCH release, the PUCCH with corresponding HARQ-ACK transmission for i-th SPS PDSCH release, and all PUSCHs in the group of overlapping PUCCHs and PUSCHs.

- if there is no aperiodic CSI report multiplexed in a PUSCH in the group of overlapping PUCCHs and PUSCHs, S_0 is not before a symbol with CP starting after $T_{proc,2}^{mux}$ after a last symbol of

  - any PDCCH with the DCI format scheduling an overlapping PUSCH, and

  - any PDCCH scheduling a PDSCH or SPS PDSCH release with corresponding HARQ-ACK information in an overlapping PUCCH in the slot

If there is at least one PUSCH in the group of overlapping PUCCHs and PUSCHs, $T_{proc,2}^{mux}$ is given by maximum of $\{T_{proc,2}^{mux,1}, \cdots, T_{proc,2}^{mux,i}, \cdots\}$ where for the i-th PUSCH which is in the group of overlapping PUCCHs and PUSCHs, $T_{proc,2}^{mux,i} = max\left(\left(N_2 + d_{2,1} + 1\right) \cdot (2048 + 144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C, d_{2,2}\right)$, $d_{2,1}$ and $d_{2,2}$ are selected for the i-th PUSCH following [6, TS 38.214], N_2 is selected based on the UE PUSCH processing capability of the i-th PUSCH and SCS configuration μ, where μ corresponds to the smallest SCS configuration among the SCS configurations used for the PDCCH scheduling the i-th PUSCH (if any), the PDCCHs scheduling the PDSCHs with corresponding HARQ-ACK transmission on a PUCCH which is in the group of overlapping PUCCHs/PUSCHs, and all PUSCHs in the group of overlapping PUCCHs and PUSCHs.

If there is no PUSCH in the group of overlapping PUCCHs and PUSCHs, $T_{proc,2}^{mux}$ is given by maximum of $\{T_{proc,2}^{mux,1}, \cdots, T_{proc,2}^{mux,i}, \cdots\}$ where for the i-th PDSCH with corresponding HARQ-ACK transmission on a PUCCH which is in the group of overlapping PUCCHs, $T_{proc,2}^{mux,i} = (N_2 + 1) \cdot (2048 + 144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$, N_2 is selected based on the UE PUSCH processing capability of the PUCCH serving cell if configured. N_2 is selected based on the UE PUSCH processing capability 1, if PUSCH processing capability is not configured for the PUCCH serving cell. μ is selected based on the smallest SCS configuration between the SCS configuration used for the PDCCH scheduling the i-th PDSCH (if any) with corresponding HARQ-ACK transmission on a PUCCH which is in the group of overlapping PUCCHs, and the SCS configuration for the PUCCH serving cell.

- if there is an aperiodic CSI report multiplexed in a PUSCH in the group of overlapping PUCCHs and PUSCHs, S_0 is not before a symbol with CP starting after $T_{\text{proc,CSI}}^{\text{mux}} = \max\left(\left(Z + d\right) \cdot \left(2048 + 144\right) \cdot \kappa \cdot 2^{-\mu} \cdot T_C, d_{2,2}\right)$ after a last symbol of

  - any PDCCH with the DCI format scheduling an overlapping PUSCH, and

  - any PDCCH scheduling a PDSCH or SPS PDSCH release with corresponding HARQ-ACK information in an overlapping PUCCH in the slot

  where μ corresponds to the smallest SCS configuration among the SCS configuration of the PDCCHs, the smallest SCS configuration for the group of the overlapping PUSCHs, and the smallest SCS configuration of CSI-RS associated with the DCI format scheduling the PUSCH with the multiplexed aperiodic CSI report, and $d = 2$ for $\mu = 0,1$, $d = 3$ for $\mu = 2$ and $d = 4$ for $\mu = 3$

- N_1, N_2, $d_{1,1}$, $d_{2,1}$, $d_{2,2}$, and Z are defined in [6, TS 38.214], and κ and T_C are defined in [4, TS 38.211].

If a UE would transmit multiple overlapping PUCCHs in a slot or overlapping PUCCH(s) and PUSCH(s) in a slot, one of the PUCCHs includes HARQ-ACK information in response to an SPS PDSCH reception, and any PUSCH is not in response to a DCI format detection, the UE expects that the first symbol S_0 of the earliest PUCCH or PUSCH satisfies the first of the previous timeline conditions with the exception that components associated to a SCS configuration for a PDCCH scheduling a PDSCH or a PUSCH are absent from the timeline conditions.

A UE does not expect a PUCCH or a PUSCH that is in response to a DCI format detection to overlap with any other PUCCH or PUSCH that does not satisfy the above timing conditions.

If there is one or more aperiodic CSI reports multiplexed on PUSCHs in the group of overlapping PUCCHs and PUSCHs and if symbol S_0 is before symbol $Z'^{\text{mux}}_{\text{ref}}$ that is a next uplink symbol with CP starting after $Z'^{\text{mux}}_{\text{proc,CSI}} = \left(Z' + d\right) \cdot \left(2048 + 144\right) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$ after the end of the last symbol of

- the last symbol of aperiodic CSI-RS resource for channel measurements, and

- the last symbol of aperiodic CSI-IM used for interference measurements, and

- the last symbol of aperiodic NZP CSI-RS for interference measurements, when aperiodic CSI-RS is used for channel measurement for triggered CSI report n

the UE is not required to update the CSI report for the triggered CSI report n. Z' is defined in [6, TS 38.214] and μ corresponds to the smallest SCS configuration among the SCS configurations of the PDCCHs scheduling the PUSCHs, the smallest SCS configuration of aperiodic CSI-RSs associated with DCI formats provided by the PDCCHs triggering the aperiodic CSI reports, and the smallest SCS configuration of the overlapping PUCCHs and PUSCHs and $d = 2$ for $\mu = 0,1$, $d = 3$ for $\mu = 2$ and $d = 4$ for $\mu = 3$.

If a UE would transmit multiple PUCCHs in a slot that include HARQ-ACK information, SR, and CSI reports and any PUCCH with HARQ-ACK information in the slot satisfies the above timing conditions and does not overlap with any other PUCCH or PUSCH in the slot that does not satisfy the above timing conditions, the UE multiplexes HARQ-ACK information, SR, and CSI reports and determines corresponding PUCCH(s) for transmission in the slot according to the following pseudo-code. If the multiple PUCCHs do not include HARQ-ACK information and do not overlap with any PUSCH transmission by the UE in response to a DCI format detection by the UE, the timing conditions do not apply.

If

- a UE is not provided *multi-CSI-PUCCH-ResourceList*, and
- a resource for a PUCCH transmission with HARQ-ACK information in response to SPS PDSCH reception and/or a resource for a PUCCH associated with a SR occasion overlap in time with two resources for respective PUCCH transmissions with two CSI reports, and
- there is no resource for a PUCCH transmission with HARQ-ACK information in response to a DCI format detection that overlaps in time with any of the previous resources, and
- the following pseudo code results to the UE attempting to determine a single PUCCH resource from the HARQ-ACK and/or the SR resource and the two PUCCH resources with CSI reports

the UE

- multiplexes the HARQ-ACK information and/or the SR in the resource for the PUCCH transmission with the CSI report having the higher priority, and
- does not transmit the PUCCH with the CSI report having the lower priority

Set Q to the set of resources for transmission of corresponding PUCCHs in a single slot without repetitions where

- a resource with earlier first symbol is placed before a resource with later first symbol
- for two resources with same first symbol, the resource with longer duration is placed before the resource with shorter duration
- for two resources with same first symbol and same duration, the placement is arbitrary
  - the above three steps for the set Q are according to a subsequent pseudo-code for a function $\text{order}(Q)$
- a resource for negative SR transmission that does not overlap with a resource for HARQ-ACK or CSI transmission is excluded from set Q
- if the UE is not provided *simultaneousHARQ-ACK-CSI* and resources for transmission of HARQ-ACK information include PUCCH format 0 or PUCCH format 2, resources that include PUCCH format 2, or PUCCH format 3, or PUCCH format 4 for transmission of CSI reports are excluded from the set Q if they overlap with any resource from the resources for transmission of HARQ-ACK information
- if the UE is not provided *simultaneousHARQ-ACK-CSI* and at least one of the resources for transmission of HARQ-ACK information includes PUCCH format 1, PUCCH format 3, or PUCCH format 4
  - resources that include PUCCH format 3 or PUCCH format 4 for transmission of CSI reports are excluded from the set Q
  - resources that include PUCCH format 2 for transmission of CSI reports are excluded from the set Q if they overlap with any resource from the resources for transmission of HARQ-ACK information

Set $\mathcal{O}(Q)$ to the cardinality of Q

Set $Q(j,0)$ to be the first symbol of resource $Q(j)$ in the slot

Set $L(Q(j))$ to be the number of symbols of resource $Q(j)$ in the slot

Set $j = 0$ - index of first resource in set Q

Set $o=0$ - counter of overlapped resources

while $j \le \mathcal{C}(Q)-1$

if $j < \mathcal{C}(Q)-1$ and resource $Q(j-o)$ overlaps with resource $Q(j+1)$

$o=o+1$

$j=j+1$

else

if $o>0$

determine a single resource for multiplexing UCI associated with resources $\{Q(j-o), Q(j-o+1),..., Q(j)\}$ as described in Clauses 9.2.5.1 and 9.2.5.2

set the index of the single resource to j

$Q = Q \setminus \{Q(j-o), Q(j-o+1),..., Q(j-1)\}$

$j=0$ % start from the beginning after reordering unmerged resources at next step

$o=0$

order(Q) % function that re-orders resources in current set Q

Set $\mathcal{C}(Q)$ to the cardinality of Q

else

$j=j+1$

end if

end if

end while

The function order(Q) performs the following pseudo-code

{

$k=0$

while $k < \mathcal{C}(Q)-1$ % the next two while loops are to re-order the unmerged resources

$l=0$

while $l < \mathcal{C}(Q)-1-k$

if $Q(l,0) > Q(l+1,0)$ OR $(Q(l,0) = Q(l+1,0) \& L(Q(l)) < L(Q(l+1)))$

temp$=Q(l)$

$Q(l) = Q(l+1)$

$Q(l+1) =$ temp

end if

$l=l+1$

end while

$k=k+1$

end while

}

For each PUCCH resource in the set Q that satisfies the aforementioned timing conditions, when applicable,

- the UE transmits a PUCCH using the PUCCH resource if the PUCCH resource does not overlap in time with a PUSCH transmission after multiplexing UCI following the procedures described in Clauses 9.2.5.1 and 9.2.5.2
- the UE multiplexes HARQ-ACK information and/or CSI reports in a PUSCH if the PUCCH resource overlaps in time with a PUSCH transmission, as described in Clause 9.3, and does not transmit SR. In case the PUCCH resource overlaps in time with multiple PUSCH transmissions, the PUSCH for multiplexing HARQ-ACK information and/or CSI is selected as described in Clause 9. If the PUSCH transmission by the UE is not in response to a DCI format detection and the UE multiplexes only CSI reports, the timing conditions are not applicable
- the UE does not expect the resource to overlap with a second resource of a PUCCH transmission over multiple slots if the resource is obtained from a group of resources that do not overlap with the second resource.

Clauses 9.2.5.1 and 9.2.5.2 assume the following

- resources for transmissions of UCI types, prior to multiplexing or dropping, overlap in a slot
- multiplexing conditions of corresponding UCI types in a single PUCCH are satisfied, and
- the UE does not transmit any PUSCH time-overlapping with PUCCH in the slot.

9.2.5.1 UE procedure for multiplexing HARQ-ACK or CSI and SR in a PUCCH

In the following, a UE is configured to transmit K PUCCHs for respective K SRs in a slot, as determined by a set of *schedulingRequestResourceId*, with SR transmission occasions that would overlap with a transmission of a PUCCH with HARQ-ACK information from the UE in the slot or with a transmission of a PUCCH with CSI report(s) from the UE in the slot.

If a UE would transmit a PUCCH with positive SR and at most two HARQ-ACK information bits in a resource using PUCCH format 0, the UE transmits the PUCCH in the resource using PUCCH format 0 in PRB(s) for HARQ-ACK information as described in Clause 9.2.3. The UE determines a value of m_0 and m_{CS} for computing a value of cyclic shift α [4, TS 38.211] where m_0 is provided by *initialcyclicshift* of *PUCCH-format0*, and m_{CS} is determined from the value of one HARQ-ACK information bit or from the values of two HARQ-ACK information bits as in Table 9.2.5-1 and Table 9.2.5-2, respectively.

If the UE would transmit negative SR and a PUCCH with at most two HARQ-ACK information bits in a resource using PUCCH format 0, the UE transmits the PUCCH in the resource using PUCCH format 0 for HARQ-ACK information as described in Clause 9.2.3.

Table 9.2.5-1: Mapping of values for one HARQ-ACK information bit and positive SR to sequences for PUCCH format 0

HARQ-ACK Value	0	1
Sequence cyclic shift	$m_{\text{CS}}=3$	$m_{\text{CS}}=9$

Table 9.2.5-2: Mapping of values for two HARQ-ACK information bits and positive SR to sequences for PUCCH format 0

HARQ-ACK Value	{0, 0}	{0, 1}	{1, 1}	{1, 0}
Sequence cyclic shift	$m_{\text{CS}}=1$	$m_{\text{CS}}=4$	$m_{\text{CS}}=7$	$m_{\text{CS}}=10$

If a UE would transmit positive or negative SR in a resource using PUCCH format 0 and HARQ-ACK information bits in a resource using PUCCH format 1 in a slot, the UE transmits only a PUCCH with the HARQ-ACK information bits in the resource using PUCCH format 1.

If the UE would transmit positive SR in a first resource using PUCCH format 1 and at most two HARQ-ACK information bits in a second resource using PUCCH format 1 in a slot, the UE transmits a PUCCH with HARQ-ACK information bits in the first resource using PUCCH format 1 as described in Clause 9.2.3. If a UE would transmit negative SR in a resource using PUCCH format 1 and at most two HARQ-ACK information bits in a resource using PUCCH format 1 in a slot, the UE transmits a PUCCH in the resource using PUCCH format 1 for HARQ-ACK information as described in Clause 9.2.3.

If a UE would transmit a PUCCH with O_{ACK} HARQ-ACK information bits in a resource using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 in a slot, as described in Clause 9.2.3, $\lceil \log_2(K+1) \rceil$ bits representing a negative or positive SR, in ascending order of the values of *schedulingRequestResourceId*, are appended to the HARQ-ACK information bits and the UE transmits the combined $O_{\text{UCI}} = O_{\text{ACK}} + \lceil \log_2(K+1) \rceil$ UCI bits in a PUCCH using a resource with PUCCH format 2 or PUCCH format 3 or PUCCH format 4 that the UE determines as described in Clauses 9.2.1 and 9.2.3. An all-zero value for the $\lceil \log_2(K+1) \rceil$ bits represents a negative SR value across all K SRs.

If a UE would transmit a PUCCH with O_{CSI} CSI report bits in a resource using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 in a slot, $\lceil \log_2(K+1) \rceil$ bits representing corresponding negative or positive SR, in ascending order of the values of *schedulingRequestResourceId*, are prepended to the CSI information bits as described in Clause 9.2.5.2 and the UE transmits a PUCCH with the combined $O_{\text{UCI}} = \lceil \log_2(K+1) \rceil + O_{\text{CSI}}$ UCI bits in a resource using the PUCCH format 2 or PUCCH format 3 or PUCCH format 4 for CSI reporting. An all-zero value for the $\lceil \log_2(K+1) \rceil$ bits represents a negative SR value across all K SRs.

If a UE transmits a PUCCH with O_{ACK} HARQ-ACK information bits, $O_{\text{SR}} = \lceil \log_2(K+1) \rceil$ SR bits, and O_{CRC} CRC bits using PUCCH format 2 or PUCCH format 3 in a PUCCH resource that includes $M_{\text{RB}}^{\text{PUCCH}}$ PRBs, the UE determines a number of PRBs $M_{\text{RB,min}}^{\text{PUCCH}}$ for the PUCCH transmission to be the minimum number of PRBs, that is smaller than or equal to a number of PRBs provided respectively by *nrofPRBs* in *PUCCH-format2* or *nrofPRBs* in *PUCCH-format3* and starts from the first PRB from the number of PRBs, that results to $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) \le M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ and, if $M_{\text{RB}}^{\text{PUCCH}} > 1$, $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) > (M_{\text{RB,min}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$, where $N_{\text{sc,ctrl}}^{\text{RB}}$, $N_{\text{symb-UCI}}^{\text{PUCCH}}$, Q_m, and r are defined in Clause 9.2.5.2. For PUCCH format 3, if $M_{\text{RB,min}}^{\text{PUCCH}}$ is not equal $2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5}$ according to [4, TS 38.211], $M_{\text{RB,min}}^{\text{PUCCH}}$ is increased to the nearest allowed value of *nrofPRBs* for *PUCCH-format3* [12, TS 38.331]. If $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) > (M_{\text{RB}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$, the UE transmits the PUCCH over the $M_{\text{RB}}^{\text{PUCCH}}$ PRBs.

9.2.5.2 UE procedure for multiplexing HARQ-ACK/SR/CSI in a PUCCH

For a transmission occasion of a single CSI report, a PUCCH resource is provided by *pucch-CSI-ResourceList*. For a transmission occasion of multiple CSI reports, corresponding PUCCH resources can be provided by *multi-CSI-PUCCH-ResourceList*.

If a UE is provided only one PUCCH resource set for transmission of HARQ-ACK information in response to PDSCH reception scheduled by a DCI format or in response to a SPS PDSCH release, the UE does not expect to be provided *simultaneousHARQ-ACK-CSI*.

A UE is configured by *maxCodeRate* a code rate for multiplexing HARQ-ACK, SR, and CSI report(s) in a PUCCH transmission using PUCCH format 2, PUCCH format 3, or PUCCH format 4.

If a UE transmits CSI reports using PUCCH format 2, the UE transmits only wideband CSI for each CSI report [6, TS 38.214]. In the following, a Part 1 CSI report refers either to a CSI report with only wideband CSI or to a Part 1 CSI report with wideband CSI and sub-band CSI.

Denote as

- O_{ACK} a total number of HARQ-ACK information bits, if any

- O_{SR} a total number of SR bits. $O_{\text{SR}} = 0$ if there is no scheduling request bit; otherwise, $O_{\text{SR}} = \lceil \log_2(K+1) \rceil$ as described in Clause 9.2.5.1

- $O_{\text{CSI}} = \sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} \left(O_{\text{CSI-part1},n} + O_{\text{CSI-part2},n} \right)$, where $O_{\text{CSI-part1},n}$ is a number of Part 1 CSI report bits for CSI report with priority value n, $O_{\text{CSI-part2},n}$ is a number of Part 2 CSI report bits, if any, for CSI report with priority value n [6, TS 38.214], and $N_{\text{CSI}}^{\text{total}}$ is a number of CSI reports that include overlapping CSI reports

- $O_{\text{CRC}} = O_{\text{CRC,CSI-part1}} + O_{\text{CRC,CSI-part2}}$, where $O_{\text{CRC,CSI-part1}}$ is a number of CRC bits, if any, for encoding HARQ-ACK, SR and Part 1 CSI report bits and $O_{\text{CRC,CSI-part2}}$ is a number of CRC bits, if any, for encoding Part 2 CSI report bits

In the following

- r is a code rate given by *maxCodeRate* as in Table 9.2.5.2-1.

- $M_{\text{RB}}^{\text{PUCCH}}$ is a number of PRBs for PUCCH format 2, or PUCCH format 3, or PUCCH format 4, respectively, where $M_{\text{RB}}^{\text{PUCCH}}$ is provided by *nrofPRBs* in *PUCCH-format2* for PUCCH format 2 or by *nrofPRBs* in *PUCCH-format3* for PUCCH format 3, and $M_{\text{RB}}^{\text{PUCCH}} = 1$ for PUCCH format 4

- $N_{\text{sc,ctrl}}^{\text{RB}} = N_{\text{sc}}^{\text{RB}} - 4$ for PUCCH format 2, $N_{\text{sc,ctrl}}^{\text{RB}} = N_{\text{sc}}^{\text{RB}}$ for PUCCH format 3, and $N_{\text{sc,ctrl}}^{\text{RB}} = N_{\text{sc}}^{\text{RB}} / N_{\text{SF}}^{\text{PUCCH,4}}$ for PUCCH format 4, where $N_{\text{sc}}^{\text{RB}}$ is a number of subcarriers per resource block [4, TS 38.211]

- $N_{\text{symb-UCI}}^{\text{PUCCH}}$ is equal to a number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,2}}$ for PUCCH format 2 provided by *nrofSymbols* in *PUCCH-format2*. For PUCCH format 3 or for PUCCH format 4, $N_{\text{symb-UCI}}^{\text{PUCCH}}$ is equal to a number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,3}}$ for PUCCH format 3 or equal to a number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,4}}$ for PUCCH format 4 provided by *nrofSymbols* in *PUCCH-format3* or *nrofSymbols* in *PUCCH-format4*, respectively, after excluding a number of symbols used for DM-RS transmission for PUCCH format 3 or for PUCCH format 4, respectively [4, TS 38.211]

- $Q_m = 1$ if pi/2-BPSK is the modulation scheme and $Q_m = 2$ if QPSK is the modulation scheme as indicated by *pi2BPSK* for PUCCH format 3 or PUCCH format 4. For PUCCH format 2, $Q_m = 2$

If a UE has one or more CSI reports and zero or more HARQ-ACK/SR information bits to transmit in a PUCCH where the HARQ-ACK, if any, is in response to a PDSCH reception without a corresponding PDCCH

- if any of the CSI reports are overlapping and the UE is provided by *multi-CSI-PUCCH-ResourceList* with $J \le 2$ PUCCH resources in a slot, for PUCCH format 2 and/or PUCCH format 3 and/or PUCCH format 4, as described in Clause 9.2.1, where the resources are indexed according to an ascending order for the product of a number of corresponding REs, modulation order Q_m, and configured code rate r;

  - if $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}) \le \left(M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r \right)_0$, the UE uses PUCCH format 2 resource 0, or the PUCCH format 3 resource 0, or the PUCCH format 4 resource 0

  - else if $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}) > \left(M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r \right)_j$ and $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}) \le \left(M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r \right)_{j+1}$, $0 \le j < J-1$, the UE transmits a PUCCH conveying HARQ-ACK information, SR and CSI report(s) in a respective PUCCH where the UE uses the PUCCH format 2 resource $j+1$, or the PUCCH format 3 resource $j+1$, or the PUCCH format 4 resource $j+1$

  - else the UE uses the PUCCH format 2 resource $J-1$, or the PUCCH format 3 resource $J-1$, or the PUCCH format 4 resource $J-1$ and the UE selects $N_{\text{CSI}}^{\text{reported}}$ CSI report(s) for transmission together with HARQ-ACK information and SR, when any, in ascending priority value as described in [6, TS 38.214]

- else, the UE transmits the $O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}$ bits in a PUCCH resource provided by *pucch-CSI-ResourceList* and determined as described in Clause 9.2.5

If a UE has HARQ-ACK, SR and wideband or sub-band CSI reports to transmit and the UE determines a PUCCH resource with PUCCH format 2, or the UE has HARQ-ACK, SR and wideband CSI reports [6, TS 38.214] to transmit and the UE determines a PUCCH resource with PUCCH format 3 or PUCCH format 4, where

- the UE determines the PUCCH resource using the PUCCH resource indicator field [5, TS 38.212] in a last DCI format 1_0 or DCI format 1_1, from DCI formats 1_0 or DCI formats 1_1 that have a value of a PDSCH-to-HARQ_feedback timing indicator field indicating a same slot for the PUCCH transmission, from a PUCCH resource set provided to the UE for HARQ-ACK transmission, and

- the UE determines the PUCCH resource set as described in Clause 9.2.1 and Clause 9.2.3 for O_{UCI} UCI bits

and

- if $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI-part1}}+O_{\text{CRC,CSI-part1}}\right)\le M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$, the UE transmits the HARQ-ACK, SR, and CSI reports bits by selecting the minimum number $M_{\text{RB,min}}^{\text{PUCCH}}$ of the $M_{\text{RB}}^{\text{PUCCH}}$ PRBs satisfying $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI-part1}}+O_{\text{CRC,CSI-part1}}\right)\le M_{\text{RB,min}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$ as described in Clauses 9.2.3 and 9.2.5.1;

- else, the UE selects $N_{\text{CSI}}^{\text{reported}}$ CSI report(s), from the $N_{\text{CSI}}^{\text{total}}$ CSI reports, for transmission together with HARQ-ACK and SR in ascending priority value [6, TS 38.214], where the value of $N_{\text{CSI}}^{\text{reported}}$ satisfies $\left(O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}}O_{\text{CSI-part1},n}+O_{\text{CRC,CSI-part1},N}\right)\le M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$ and $\left(O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}+1}O_{\text{CSI-part1},n}+O_{\text{CRC,CSI-part1},N+1}\right)> M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$, where $O_{\text{CRC,CSI-part1},N}$ is a number of CRC bits corresponding to $O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}}O_{\text{CSI-part1},n}$ UCI bits, and $O_{\text{CRC,CSI-part1},N+1}$ is a number of CRC bits corresponding to $O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}+1}O_{\text{CSI-part1},n}$ UCI bits.

If a UE has HARQ-ACK, SR and sub-band CSI reports to transmit and the UE determines a PUCCH resource with PUCCH format 3 or PUCCH format 4, where

- the UE determines the PUCCH resource using the PUCCH resource indicator field [5, TS 38.212] in a last DCI format 1_0 or DCI format 1_1, from DCI formats 1_0 or DCI formats 1_1 that have a value of a PDSCH-to-HARQ_feedback timing indicator field indicating a same slot for the PUCCH transmission, from a PUCCH resource set provided to the UE for HARQ-ACK transmission, and

- the UE determines the PUCCH resource set as described in Clause 9.2.1 and Clause 9.2.3 for O_{UCI} UCI bits

and

- if $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)\le M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$, the UE transmits the HARQ-ACK, SR and the $N_{\text{CSI}}^{\text{total}}$ CSI report bits by selecting the minimum number $M_{\text{RB,min}}^{\text{PUCCH}}$ of PRBs from the $M_{\text{RB}}^{\text{PUCCH}}$ PRBs satisfying $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)\le M_{\text{RB,min}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$ as described in Clauses 9.2.3 and 9.2.5.1

- else,

  - if for $N_{\text{CSI-part2}}^{\text{reported}}>0$ Part 2 CSI report priority value(s), it is

$$\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}} O_{\text{CSI-part2},n} + O_{\text{CRC,CSI-part2},N} \le \left(M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} - \left\lceil \left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} O_{\text{CSI-part1},n} + O_{\text{CRC,CSI-part1}} \right) \Big/ \left(Q_m \cdot r \right) \right\rceil \right) \cdot Q_m \cdot r$$

and

$$\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}+1} O_{\text{CSI-part2},n} + O_{\text{CRC,CSI-part2,N+1}} > \left(M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} - \left\lceil \left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} O_{\text{CSI-part1},n} + O_{\text{CRC,CSI-part1}} \right) \Big/ \left(Q_m \cdot r \right) \right\rceil \right) \cdot Q_m \cdot r$$

,

the UE selects the first $N_{\text{CSI-part2}}^{\text{reported}}$ Part 2 CSI reports, according to respective priority value(s) [6, TS 38.214], for transmission together with the HARQ-ACK, SR and $N_{\text{CSI}}^{\text{total}}$ Part 1 CSI reports , where $O_{\text{CSI-part1},n}$ is the number of Part 1 CSI report bits for the n_{th} CSI report and $O_{\text{CSI-part2},n}$ is the number of Part 2 CSI report bits for the n_{th} CSI report priority value, $O_{\text{CRC,CSI-part2},N}$ is a number of CRC bits corresponding to $\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}} O_{\text{CSI-part2},n}$, and $O_{\text{CRC,CSI-part2},N+1}$ is a number of CRC bits corresponding to $\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}+1} O_{\text{CSI-part2},n}$

- else, the UE drops all Part 2 CSI reports and selects $N_{\text{CSI-part1}}^{\text{reported}}$ Part 1 CSI report(s), from the $N_{\text{CSI}}^{\text{total}}$ CSI reports in ascending priority value [6, TS 38.214], for transmission together with the HARQ-ACK and SR information bits where the value of $N_{\text{CSI-part1}}^{\text{reported}}$ satisfies

$\left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}} O_{\text{CSI-part1},n} + O_{\text{CRC,CSI-part1},N} \right) \le M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ and

$\left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}+1} O_{\text{CSI-part1},n} + O_{\text{CRC,CSI-part1},N+1} \right) > M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$, where $O_{\text{CRC,CSI-part1},N}$ is a number of CRC bits corresponding to $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}} O_{\text{CSI-part1},n}$ UCI bits, and $O_{\text{CRC,CSI-part1},N+1}$ is a number of CRC bits corresponding to $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}+1} O_{\text{CSI-part1},n}$ UCI bits.

Table 9.2.5.2-1: Code rate r corresponding to value of *maxCodeRate*

maxCodeRate	**Code rate** r
0	0.08
1	0.15
2	0.25
3	0.35
4	0.45
5	0.60
6	0.80
7	Reserved

9.2.6 PUCCH repetition procedure

For PUCCH formats 1, 3, or 4, a UE can be configured a number of slots, $N_{\text{PUCCH}}^{\text{repeat}}$, for repetitions of a PUCCH transmission by respective *nrofSlots*.

For $N_{\text{PUCCH}}^{\text{repeat}} > 1$,

- the UE repeats the PUCCH transmission with the UCI over N_{PUCCH}^{repeat} slots

- a PUCCH transmission in each of the N_{PUCCH}^{repeat} slots has a same number of consecutive symbols, as provided by *nrofSymbols* in *PUCCH-format1*, *nrofSymbols* in *PUCCH-format3*, or *nrofSymbols* in *PUCCH-format4*

- a PUCCH transmission in each of the N_{PUCCH}^{repeat} slots has a same first symbol, as provided by *startingSymbolIndex* in *PUCCH-format1*, *startingSymbolIndex* in *PUCCH-format3*, or *startingSymbolIndex* in *PUCCH-format4*

- the UE is configured by *interslotFrequencyHopping* whether or not to perform frequency hopping for PUCCH transmissions in different slots

  - if the UE is configured to perform frequency hopping for PUCCH transmissions across different slots

    - the UE performs frequency hopping per slot

    - the UE transmits the PUCCH starting from a first PRB, provided by *startingPRB*, in slots with even number and starting from the second PRB, provided by *secondHopPRB*, in slots with odd number. The slot indicated to the UE for the first PUCCH transmission has number 0 and each subsequent slot until the UE transmits the PUCCH in N_{PUCCH}^{repeat} slots is counted regardless of whether or not the UE transmits the PUCCH in the slot

    - the UE does not expect to be configured to perform frequency hopping for a PUCCH transmission within a slot

  - If the UE is not configured to perform frequency hopping for PUCCH transmissions across different slots and if the UE is configured to perform frequency hopping for PUCCH transmissions within a slot, the frequency hopping pattern between the first PRB and the second PRB is same within each slot

If the UE determines that, for a PUCCH transmission in a slot, the number of symbols available for the PUCCH transmission is smaller than the value provided by *nrofSymbols* for the corresponding PUCCH format, the UE does not transmit the PUCCH in the slot.

A SS/PBCH block symbol is a symbol indicated to a UE by *ssb-PositionsInBurst* in *SIB1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon*.

For unpaired spectrum, the UE determines the N_{PUCCH}^{repeat} slots for a PUCCH transmission starting from a slot indicated to the UE as described in Clause 9.2.3 and having

- an UL symbol, as described in Clause 11.1, or flexible symbol that is not SS/PBCH block symbol provided by *startingSymbolIndex* in *PUCCH-format1*, or in *PUCCH-format3*, or in *PUCCH-format4* as a first symbol, and

- consecutive UL symbols, as described in Clause 11.1, or flexible symbols that are not SS/PBCH block symbols, starting from the first symbol, equal to or larger than a number of symbols provided by *nrofsymbols* in *PUCCH-format1*, or in *PUCCH-format3*, or in *PUCCH-format4*

For paired spectrum, the UE determines the N_{PUCCH}^{repeat} slots for a PUCCH transmission as the N_{PUCCH}^{repeat} consecutive slots starting from a slot indicated to the UE as described in Clause 9.2.3.

If a UE would transmit a PUCCH over a first number $N_{PUCCH}^{repeat}>1$ of slots and the UE would transmit a PUSCH over a second number of slots, and the PUCCH transmission would overlap with the PUSCH transmission in one or more slots, and the conditions in Clause 9.2.5 for multiplexing the UCI in the PUSCH are satisfied in the overlapping slots, the UE transmits the PUCCH and does not transmit the PUSCH in the overlapping slots.

A UE does not multiplex different UCI types in a PUCCH transmission with repetitions over $N_{PUCCH}^{repeat}>1$ slots. If a UE would transmit a first PUCCH over more than one slot and at least a second PUCCH over one or more slots, and the transmissions of the first PUCCH and the second PUCCH would overlap in a number of slots then, for each slot of the number of slots and with UCI type priority of HARQ-ACK > SR > CSI with higher priority > CSI with lower priority

- the UE does not expect the first PUCCH and any of the second PUCCHs to start at a same slot and include a UCI type with same priority

- if the first PUCCH and any of the second PUCCHs include a UCI type with same priority, the UE transmits the PUCCH starting at an earlier slot and does not transmit the PUCCH starting at a later slot
- if the first PUCCH and any of the second PUCCHs do not include a UCI type with same priority, the UE transmits the PUCCH that includes the UCI type with higher priority and does not transmit the PUCCH that include the UCI type with lower priority

A UE does not expect a PUCCH that is in response to a DCI format detection to overlap with any other PUCCH that does not satisfy the corresponding timing conditions in Clause 9.2.5.

If a UE would transmit a PUCCH over $N_{\text{PUCCH}}^{\text{repeat}}$ slots and the UE does not transmit the PUCCH in a slot from the $N_{\text{PUCCH}}^{\text{repeat}}$ slots due to overlapping with another PUCCH transmission in the slot, the UE counts the slot in the number of $N_{\text{PUCCH}}^{\text{repeat}}$ slots.

9.3 UCI reporting in physical uplink shared channel

Offset values are defined for a UE to determine a number of resources for multiplexing HARQ-ACK information and for multiplexing CSI reports in a PUSCH. The offset values are signalled to a UE either by a DCI format scheduling the PUSCH transmission or by higher layers.

If DCI format 0_0, or DCI format 0_1 that does not include a beta_offset indicator field, schedules the PUSCH transmission from the UE and the UE is provided *betaOffsets = 'semiStatic'*, the UE applies the $\beta_{\text{offset}}^{\text{HARQ-ACK}}$, $\beta_{\text{offset}}^{\text{CSI-1}}$, and $\beta_{\text{offset}}^{\text{CSI-2}}$ values that are provided by *betaOffsets = 'semiStatic'* for the corresponding HARQ-ACK information, Part 1 CSI reports and Part 2 CSI reports.

If the PUSCH transmission is with a configured grant and the UE is provided *CG-UCI-OnPUSCH= 'semiStatic'*, the UE applies the $\beta_{\text{offset}}^{\text{HARQ-ACK}}$, $\beta_{\text{offset}}^{\text{CSI-1}}$, and $\beta_{\text{offset}}^{\text{CSI-2}}$ values that are provided by *CG-UCI-OnPUSCH = 'semiStatic'* for the corresponding HARQ-ACK information, Part 1 CSI reports and Part 2 CSI reports.

If the PUSCH is scheduled by DCI format 0_0 and the UE is provided *betaOffsets = 'dynamic'*, the UE applies the $\beta_{\text{offset}}^{\text{HARQ-ACK}}$, $\beta_{\text{offset}}^{\text{CSI-1}}$, and $\beta_{\text{offset}}^{\text{CSI-2}}$ values that are determined from the first value of *betaOffsets = 'dynamic'*.

If the PUSCH is a configured grant Type 2 PUSCH activated by DCI format 0_0 and the UE is provided *CG-UCI-OnPUSCH ='dynamic'*, the UE applies the $\beta_{\text{offset}}^{\text{HARQ-ACK}}$, $\beta_{\text{offset}}^{\text{CSI-1}}$, and $\beta_{\text{offset}}^{\text{CSI-2}}$ values that are determined from the first value of *CG-UCI-OnPUSCH = 'dynamic'*.

HARQ-ACK information offsets $\beta_{\text{offset}}^{\text{HARQ-ACK}}$ are configured to values according to Table 9.3-1. The *betaOffsetACK-Index1*, *betaOffsetACK-Index2*, and *betaOffsetACK-Index3* respectively provide indexes $I_{\text{offset},0}^{\text{HARQ-ACK}}$, $I_{\text{offset},1}^{\text{HARQ-ACK}}$, and $I_{\text{offset},2}^{\text{HARQ-ACK}}$ for the UE to use if the UE multiplexes up to 2 HARQ-ACK information bits, more than 2 and up to 11 HARQ-ACK information bits, and more than 11 bits in the PUSCH, respectively.

Part 1 CSI report and Part 2 CSI report offsets $\beta_{\text{offset}}^{\text{CSI-1}}$ and $\beta_{\text{offset}}^{\text{CSI-2}}$, respectively, are configured to values according to Table 9.3-2. The *betaOffsetCSI-Part1-Index1* and *betaOffsetCSI-Part2-Index1* respectively provide indexes $I_{\text{offset},0}^{\text{CSI-1}}$ and $I_{\text{offset},0}^{\text{CSI-2}}$ for the UE to use if the UE multiplexes up to 11 bits for Part 1 CSI reports or Part 2 CSI reports in the PUSCH. The *betaOffsetCSI-Part1-Index2* and *betaOffsetCSI-Part2-Index2* respectively provide indexes $I_{\text{offset},1}^{\text{CSI-1}}$ or $I_{\text{offset},1}^{\text{CSI-2}}$ for the UE to use if the UE multiplexes more than 11 bits for Part 1 CSI reports or Part 2 CSI reports in the PUSCH.

If a DCI format 0_1 schedules the PUSCH transmission from the UE and if DCI format 0_1 includes a beta_offset indicator field, as configured by *uci-OnPUSCH*, the UE is provided by each of {*betaOffsetACK-Index1*, *betaOffsetACK-Index2*, *betaOffsetACK-Index3*} a set of four $I_{\text{offset}}^{\text{HARQ-ACK}}$ indexes, by each of {*betaOffsetCSI-Part1-Index1*, *betaOffsetCSI-Part1-Index2*} a set of four $I_{\text{offset}}^{\text{CSI-1}}$ indexes and by each of {*betaOffsetCSI-Part2-Index1*, *betaOffsetCSI-Part2-Index2*} a set of four $I_{\text{offset}}^{\text{CSI-2}}$ indexes from Table 9.3-1 and 9.3-2, respectively, for multiplexing HARQ-ACK information, Part 1 CSI reports, and Part 2 CSI reports, respectively, in the PUSCH transmission. The

beta_offset indicator field indicates a $I_{\text{offset}}^{\text{HARQ–ACK}}$ value, a $I_{\text{offset}}^{\text{CSI-1}}$ value and a $I_{\text{offset}}^{\text{CSI-2}}$ value from the respective sets of values, with the mapping defined in Table 9.3-3.

Table 9.3-1: Mapping of beta_offset values for HARQ-ACK information and the index signalled by higher layers

$I_{offset,0}^{HARQ-ACK}$ or $I_{offset,1}^{HARQ-ACK}$ or $I_{offset,2}^{HARQ-ACK}$	$\beta_{offset}^{HARQ-ACK}$
0	1.000
1	2.000
2	2.500
3	3.125
4	4.000
5	5.000
6	6.250
7	8.000
8	10.000
9	12.625
10	15.875
11	20.000
12	31.000
13	50.000
14	80.000
15	126.000
16	Reserved
17	Reserved
18	Reserved
19	Reserved
20	Reserved
21	Reserved
22	Reserved
23	Reserved
24	Reserved
25	Reserved
26	Reserved
27	Reserved
28	Reserved
29	Reserved
30	Reserved
31	Reserved

Table 9.3-2: Mapping of beta_offset values for CSI and the index signalled by higher layers

$I_{offset,0}^{CSI-1}$ **or** $I_{offset,1}^{CSI-1}$ $I_{offset,0}^{CSI-2}$ **or** $I_{offset,1}^{CSI-2}$	β_{offset}^{CSI-1} β_{offset}^{CSI-2}
0	1.125
1	1.250
2	1.375
3	1.625
4	1.750
5	2.000
6	2.250
7	2.500
8	2.875
9	3.125
10	3.500
11	4.000
12	5.000
13	6.250
14	8.000
15	10.000
16	12.625
17	15.875
18	20.000
19	Reserved
20	Reserved
21	Reserved
22	Reserved
23	Reserved
24	Reserved
25	Reserved
26	Reserved
27	Reserved
28	Reserved
29	Reserved
30	Reserved
31	Reserved

Table 9.3-3: Mapping of beta_offset indicator values to offset indexes

beta_offset indicator	($I_{\text{offset},0}^{\text{HARQ-ACK}}$ or $I_{\text{offset},1}^{\text{HARQ-ACK}}$ or $I_{\text{offset},2}^{\text{HARQ-ACK}}$), ($I_{\text{offset},0}^{\text{CSI-1}}$ or $I_{\text{offset},0}^{\text{CSI-2}}$), ($I_{\text{offset},1}^{\text{CSI-1}}$ or $I_{\text{offset},1}^{\text{CSI-2}}$)
'00'	1st offset index provided by higher layers
'01'	2nd offset index provided by higher layers
'10'	3rd offset index provided by higher layers
'11'	4th offset index provided by higher layers

10 UE procedure for receiving control information

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG except for PDCCH monitoring in Type0/0A/2-PDCCH CSS sets where the UE is not required to apply the procedures in this clause for the SCG

- When the procedures are applied for MCG, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term 'primary cell' in this clause refers to the PSCell of the SCG.

A UE monitors a set of PDCCH candidates in one or more CORESETs on the active DL BWP on each activated serving cell configured with PDCCH monitoring according to corresponding search space sets where monitoring implies decoding each PDCCH candidate according to the monitored DCI formats.

For monitoring of a PDCCH candidate in a slot

- If the UE has received *ssb-PositionsInBurst* in *SIB1* and has not received *ssb-PositionsInBurst* in *ServingCellConfigCommon* for a serving cell and if the UE does not monitor PDCCH candidates in a Type0-PDCCH CSS set and at least one RE for a PDCCH candidate overlaps with at least one RE corresponding to a SS/PBCH block index provided by *ssb-PositionsInBurst* in *SIB1*, the UE is not required to monitor the PDCCH candidate.
- If a UE has received *ssb-PositionsInBurst* in *ServingCellConfigCommon* for a serving cell and if the UE does not monitor PDCCH candidates in a Type0-PDCCH CSS set and at least one RE for a PDCCH candidate overlaps with at least one RE corresponding to a SS/PBCH block index provided by *ssb-PositionsInBurst* in *ServingCellConfigCommon*, the UE is not required to monitor the PDCCH candidate.
- If the UE monitors the PDCCH candidate for a Type0-PDCCH CSS set on the serving cell according to the procedure described in Clause 13, the UE may assume that no SS/PBCH block is transmitted in REs used for monitoring the PDCCH candidate on the serving cell.
- If at least one RE of a PDCCH candidate on the serving cell overlaps with at least one RE of *lte-CRS-ToMatchAround*, the UE is not required to monitor the PDCCH candidate.

If a UE indicates in *UE-NR-Capability* a carrier aggregation capability larger than 4 serving cells, the UE includes in *UE-NR-Capability* an indication for a maximum number of PDCCH candidates the UE can monitor per slot when the UE is configured for carrier aggregation operation over more than 4 cells. When a UE is not configured for NR-DC operation, the UE determines a capability to monitor a maximum number of PDCCH candidates per slot that corresponds to $N_{\text{cells}}^{\text{cap}}$ downlink cells, where

- $N_{\text{cells}}^{\text{cap}}$ is the number of configured downlink cells if the UE does not provide *pdcch-BlindDetectionCA*
- otherwise, $N_{\text{cells}}^{\text{cap}}$ is the value of *pdcch-BlindDetectionCA*

When a UE is configured for NR-DC operation, the UE determines a capability to monitor a maximum number of PDCCH candidates per slot that corresponds to $N_{cells}^{cap}=N_{cells}^{MCG}$ downlink cells for the MCG where N_{cells}^{MCG} is provided by *pdcch-BlindDetection* for the MCG and determines a capability to monitor a maximum number of PDCCH candidates per slot that corresponds to $N_{cells}^{cap}=N_{cells}^{SCG}$ downlink cells for the SCG where N_{cells}^{SCG} is provided by *pdcch-BlindDetection* for the SCG. When the UE is configured for carrier aggregation operation over more than 4 cells, or for a cell group when the UE is configured for NR-DC operation, the UE does not expect to monitor per slot a number of PDCCH candidates that is larger than the maximum number as derived from the corresponding value of N_{cells}^{cap}.

When a UE is configured for NR-DC operation with a total of $N_{NR-DC}^{DL,cells}$ downlink cells on both the MCG and the SCG, the UE expects to be provided *pdcch-BlindDetection* for the MCG and *pdcch-BlindDetection* for the SCG with values that satisfy

- *pdcch-BlindDetection* for the MCG + *pdcch-BlindDetection* for the SCG <= *pdcch-BlindDetectionCA*, if the UE reports *pdcch-BlindDetectionCA*, or

- *pdcch-BlindDetection* for the MCG + *pdcch-BlindDetection* for the SCG <= $N_{NR-DC}^{DL,cells}$, if the UE does not report *pdcch-BlindDetectionCA*.

For NR-DC operation, the UE may indicate, through *pdcch-BlindDetectionMCG-UE* and *pdcch-BlindDetectionSCG-UE*, respective maximum values for *pdcch-BlindDetection* for the MCG and *pdcch-BlindDetection* for the SCG.

If the UE reports *pdcch-BlindDetectionCA*,

- the value range of *pdcch-BlindDetectionMCG-UE* or of *pdcch-BlindDetectionSCG-UE* is [1, …, *pdcch-BlindDetectionCA*-1], and

- *pdcch-BlindDetectionMCG-UE* + *pdcch-BlindDetectionSCG-UE* >= *pdcch-BlindDetectionCA*.

Otherwise, if $N_{NR-DC,max}^{DL,cells}$ is a maximum total number of downlink cells that the UE can be configured on both the MCG and the SCG for NR-DC as indicated in *UE-NR-Capability*,

- the value range of *pdcch-BlindDetectionMCG-UE* or of *pdcch-BlindDetectionSCG-UE* is [1, 2, 3], and

- *pdcch-BlindDetectionMCG-UE* + *pdcch-BlindDetectionSCG-UE* >= $N_{NR-DC,max}^{DL,cells}$.

10.1 UE procedure for determining physical downlink control channel assignment

A set of PDCCH candidates for a UE to monitor is defined in terms of PDCCH search space sets. A search space set can be a CSS set or a USS set. A UE monitors PDCCH candidates in one or more of the following search spaces sets

- a Type0-PDCCH CSS set configured by *pdcch-ConfigSIB1* in *MIB* or by *searchSpaceSIB1* in *PDCCH-ConfigCommon* or by *searchSpaceZero* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG

- a Type0A-PDCCH CSS set configured by *searchSpaceOtherSystemInformation* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell of the MCG

- a Type1-PDCCH CSS set configured by *ra-SearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a RA-RNTI or a TC-RNTI on the primary cell

- a Type2-PDCCH CSS set configured by *pagingSearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a P-RNTI on the primary cell of the MCG

- a Type3-PDCCH CSS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = common* for DCI formats with CRC scrambled by INT-RNTI, SFI-RNTI, TPC-PUSCH-RNTI, TPC-PUCCH-RNTI, or TPC-SRS-RNTI and, only for the primary cell, C-RNTI, MCS-C-RNTI, or CS-RNTI(s), and

- a USS set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = ue-Specific* for DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or CS-RNTI(s).

For a DL BWP, if a UE is not provided *searchSpaceSIB1* for Type0-PDCCH CSS set by *PDCCH-ConfigCommon*, the UE does not monitor PDCCH candidates for a Type0-PDCCH CSS set on the DL BWP. The Type0-PDCCH CSS set is defined by the CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level given in Table 10.1-1. If the active DL BWP and the initial DL BWP have same SCS and same CP length and the active DL BWP includes all RBs of the CORESET with index 0, or the active DL BWP is the initial DL BWP, the CORESET configured for Type0-PDCCH CSS set has CORESET index 0 and the Type0-PDCCH CSS set has search space set index 0.

For a DL BWP, if a UE is not provided *searchSpaceOtherSystemInformation* for Type0A-PDCCH CSS set, the UE does not monitor PDCCH for Type0A-PDCCH CSS set on the DL BWP. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level for Type0A-PDCCH CSS set are given in Table 10.1-1.

For a DL BWP, if a UE is not provided *ra-SearchSpace* for Type1-PDCCH CSS set, the UE does not monitor PDCCH for Type1-PDCCH CSS set on the DL BWP. If the UE has not been provided a Type3-PDCCH CSS set or a USS set and the UE has received a C-RNTI and has been provided a Type1-PDCCH CSS set, the UE monitors PDCCH candidates for DCI format 0_0 and DCI format 1_0 with CRC scrambled by the C-RNTI in the Type1-PDCCH CSS set.

If a UE is not provided *pagingSearchSpace* for Type2-PDCCH CSS set, the UE does not monitor PDCCH for Type2-PDCCH CSS set on the DL BWP. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level for Type2-PDCCH CSS set are given in Table 10.1-1.

If a UE is provided a zero value for *searchSpaceID* in *PDCCH-ConfigCommon* for a Type0/0A/2-PDCCH CSS set, the UE determines monitoring occasions for PDCCH candidates of the Type0/0A/2-PDCCH CSS set as described in Clause 13, and the UE is provided a C-RNTI, the UE monitors PDCCH candidates only at monitoring occasions associated with a SS/PBCH block, where the SS/PBCH block is determined by the most recent of

- a MAC CE activation command indicating a TCI state of the active BWP that includes a CORESET with index 0, as described in [6, TS 38.214], where the TCI-state includes a CSI-RS which is quasi-co-located with the SS/PBCH block, or

- a random access procedure that is not initiated by a PDCCH order that triggers a contention-free random access procedure

If a UE monitors PDCCH candidates for DCI formats with CRC scrambled by a C-RNTI and the UE is provided a non-zero value for *searchSpaceID* in *PDCCH-ConfigCommon* for a Type0/0A/2-PDCCH CSS set, the UE determines monitoring occasions for PDCCH candidates of the Type0/0A/2-PDCCH CSS set based on the search space set associated with the value of *searchSpaceID*.

The UE may assume that the DM-RS antenna port associated with PDCCH receptions in the CORESET configured by *pdcch-ConfigSIB1* in *MIB*, the DM-RS antenna port associated with corresponding PDSCH receptions, and the corresponding SS/PBCH block are quasi co-located with respect to average gain, QCL-TypeA, and QCL-TypeD properties, when applicable [6, TS 38.214], if the UE is not provided a TCI state indicating quasi co-location information of the DM-RS antenna port for PDCCH reception in the CORESET. The value for the DM-RS scrambling sequence initialization is the cell ID. A SCS is provided by *subCarrierSpacingCommon* in *MIB*.

For single cell operation or for operation with carrier aggregation in a same frequency band, a UE does not expect to monitor a PDCCH in a Type0/0A/2/3-PDCCH CSS set or in a USS set if a DM-RS for monitoring a PDCCH in a Type1-PDCCH CSS set does not have same QCL-TypeD properties [6, TS 38.214] with a DM-RS for monitoring the PDCCH in the Type0/0A/2/3-PDCCH CSS set or in the USS set, and if the PDCCH or an associated PDSCH overlaps in at least one symbol with a PDCCH the UE monitors in a Type1-PDCCH CSS set or with an associated PDSCH.

If a UE is provided

- one or more search space sets by corresponding one or more of *searchSpaceZero*, *searchSpaceSIB1*, *searchSpaceOtherSystemInformation*, *pagingSearchSpace*, *ra-SearchSpace*, and

- a C-RNTI, an MCS-C-RNTI, or a CS-RNTI,

the UE monitors PDCCH candidates for DCI format 0_0 and DCI format 1_0 with CRC scrambled by the C-RNTI, the MCS-C-RNTI, or the CS-RNTI in the one or more search space sets in a slot where the UE monitors PDCCH candidates for at least a DCI format 0_0 or a DCI format 1_0 with CRC scrambled by SI-RNTI, RA-RNTI or P-RNTI.

If a UE is provided

- one or more search space sets by corresponding one or more of *searchSpaceZero, searchSpaceSIB1*, *searchSpaceOtherSystemInformation, pagingSearchSpace, ra-SearchSpace*, or a CSS set by *PDCCH-Config*, and

- a SI-RNTI, a P-RNTI, a RA-RNTI, a SFI-RNTI, an INT-RNTI, a TPC-PUSCH-RNTI, a TPC-PUCCH-RNTI, or a TPC-SRS-RNTI

then, for a RNTI from any of these RNTIs, the UE does not expect to process information from more than one DCI format with CRC scrambled with the RNTI per slot.

Table 10.1-1: CCE aggregation levels and maximum number of PDCCH candidates per CCE aggregation level for CSS sets configured by *searchSpaceSIB1*

CCE Aggregation Level	Number of Candidates
4	4
8	2
16	1

For each DL BWP configured to a UE in a serving cell, a UE can be provided by higher layer signalling with $P \leq 3$ CORESETs. For each CORESET, the UE is provided the following by *ControlResourceSet*:

- a CORESET index p , $0 < p < 12$, by *controlResourceSetId*;

- a DM-RS scrambling sequence initialization value by *pdcch-DMRS-ScramblingID*;

- a precoder granularity for a number of REGs in the frequency domain where the UE can assume use of a same DM-RS precoder by *precoderGranularity*;

- a number of consecutive symbols provided by *duration*;

- a set of resource blocks provided by *frequencyDomainResources*;

- CCE-to-REG mapping parameters provided by *cce-REG-MappingType*;

- an antenna port quasi co-location, from a set of antenna port quasi co-locations provided by *TCI-State*, indicating quasi co-location information of the DM-RS antenna port for PDCCH reception in a respective CORESET;

- an indication for a presence or absence of a transmission configuration indication (TCI) field for DCI format 1_1 transmitted by a PDCCH in CORESET p , by *tci-PresentInDCI*.

When *precoderGranularity* = *allContiguousRBs*, a UE does not expect

- to be configured a set of resource blocks of a CORESET that includes more than four sub-sets of resource blocks that are not contiguous in frequency

- any RE of a CORESET to overlap with any RE determined from *lte-CRS-ToMatchAround* or with any RE of a SS/PBCH block.

For each CORESET in a DL BWP of a serving cell, a respective *frequencyDomainResources* provides a bitmap. The bits of the bitmap have a one-to-one mapping with non-overlapping groups of 6 consecutive PRBs, in ascending order of the PRB index in the DL BWP bandwidth of $N_{\text{RB}}^{\text{BWP}}$ PRBs with starting common RB position $N_{\text{BWP}}^{\text{start}}$ where the first common RB of the first group of 6 PRBs has common RB index $6 \cdot \left\lceil N_{\text{BWP}}^{\text{start}} / 6 \right\rceil$.

For a CORESET other than a CORESET with index 0,

- if a UE has not been provided a configuration of TCI state(s) by *tci-StatesPDCCH-ToAddList* and *tci-StatesPDCCH-ToReleaseList* for the CORESET, or has been provided initial configuration of more than one TCI states for the CORESET by *tci-StatesPDCCH-ToAddList* and *tci-StatesPDCCH-ToReleaseList* but has not received a MAC CE activation command for one of the TCI states as described in [11, TS 38.321], the UE assumes that the DM-RS antenna port associated with PDCCH receptions is quasi co-located with the SS/PBCH block the UE identified during the initial access procedure;

- if a UE has been provided a configuration of more than one TCI states by *tci-StatesPDCCH-ToAddList* and *tci-StatesPDCCH-ToReleaseList* for the CORESET as part of Reconfiguration with sync procedure as described in [12, TS 38.331] but has not received a MAC CE activation command for one of the TCI states as described in [11, TS 38.321], the UE assumes that the DM-RS antenna port associated with PDCCH receptions is quasi co-located with the SS/PBCH block or the CSI-RS resource the UE identified during the random access procedure initiated by the Reconfiguration with sync procedure as described in [12, TS 38.331].

For a CORESET with index 0, the UE assumes that a DM-RS antenna port for PDCCH receptions in the CORESET is quasi co-located with

- the one or more DL RS configured by a TCI state, where the TCI state is indicated by a MAC CE activation command for the CORESET, if any, or

- a SS/PBCH block the UE identified during a most recent random access procedure not initiated by a PDCCH order that triggers a contention-free random access procedure, if no MAC CE activation command indicating a TCI state for the CORESET is received after the most recent random access procedure.

For a CORESET other than a CORESET with index 0, if a UE is provided a single TCI state for a CORESET, or if the UE receives a MAC CE activation command for one of the provided TCI states for a CORESET, the UE assumes that the DM-RS antenna port associated with PDCCH receptions in the CORESET is quasi co-located with the one or more DL RS configured by the TCI state. For a CORESET with index 0, the UE expects that QCL-TypeD of a CSI-RS in a TCI state indicated by a MAC CE activation command for the CORESET is provided by a SS/PBCH block

- if the UE receives a MAC CE activation command for one of the TCI states, the UE applies the activation command in the first slot that is after slot $k+3\cdot N_{\text{slot}}^{\text{subframe},\mu}$ where k is the slot where the UE would transmit a PUCCH with HARQ-ACK information for the PDSCH providing the activation command and μ is the SCS configuration for the PUCCH. The active BWP is defined as the active BWP in the slot when the activation command is applied.

For each DL BWP configured to a UE in a serving cell, the UE is provided by higher layers with $S \le 10$ search space sets where, for each search space set from the S search space sets, the UE is provided the following by *SearchSpace*:

- a search space set index s, $0 < s < 40$, by *searchSpaceId*

- an association between the search space set s and a CORESET p by *controlResourceSetId*

- a PDCCH monitoring periodicity of k_s slots and a PDCCH monitoring offset of o_s slots, by *monitoringSlotPeriodicityAndOffset*

- a PDCCH monitoring pattern within a slot, indicating first symbol(s) of the CORESET within a slot for PDCCH monitoring, by *monitoringSymbolsWithinSlot*

- a duration of $T_s < k_s$ slots indicating a number of slots that the search space set s exists by *duration*

- a number of PDCCH candidates $M_s^{(L)}$ per CCE aggregation level L by *aggregationLevel1*, *aggregationLevel2*, *aggregationLevel4*, *aggregationLevel8*, and *aggregationLevel16*, for CCE aggregation level 1, CCE aggregation level 2, CCE aggregation level 4, CCE aggregation level 8, and CCE aggregation level 16, respectively

- an indication that search space set s is either a CSS set or a USS set by *searchSpaceType*

- if search space set s is a CSS set

  - an indication by *dci-Format0-0-AndFormat1-0* to monitor PDCCH candidates for DCI format 0_0 and DCI format 1_0

  - an indication by *dci-Format2-0* to monitor one or two PDCCH candidates for DCI format 2_0 and a corresponding CCE aggregation level

  - an indication by *dci-Format2-1* to monitor PDCCH candidates for DCI format 2_1

  - an indication by *dci-Format2-2* to monitor PDCCH candidates for DCI format 2_2

  - an indication by *dci-Format2-3* to monitor PDCCH candidates for DCI format 2_3

- if search space set s is a USS set, an indication by *dci-Formats* to monitor PDCCH candidates either for DCI format 0_0 and DCI format 1_0, or for DCI format 0_1 and DCI format 1_1

If the *monitoringSymbolsWithinSlot* indicates to a UE to monitor PDCCH in a subset of up to three consecutive symbols that are same in every slot where the UE monitors PDCCH for all search space sets, the UE does not expect to be configured with a PDCCH SCS other than 15 kHz if the subset includes at least one symbol after the third symbol.

A UE does not expect to be provided a first symbol and a number of consecutive symbols for a CORESET that results to a PDCCH candidate mapping to symbols of different slots.

A UE does not expect any two PDCCH monitoring occasions on an active DL BWP, for a same search space set or for different search space sets, in a same CORESET to be separated by a non-zero number of symbols that is smaller than the CORESET duration.

A UE determines a PDCCH monitoring occasion on an active DL BWP from the PDCCH monitoring periodicity, the PDCCH monitoring offset, and the PDCCH monitoring pattern within a slot. For search space set s, the UE determines that a PDCCH monitoring occasion(s) exists in a slot with number $n_{s,f}^{\mu}$ [4, TS 38.211] in a frame with number n_f if $\left(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - o_s\right) \text{mod} k_s = 0$. The UE monitors PDCCH candidates for search space set s for T_s consecutive slots, starting from slot $n_{s,f}^{\mu}$, and does not monitor PDCCH candidates for search space set s for the next $k_s - T_s$ consecutive slots.

A USS at CCE aggregation level $L \in \{1, 2, 4, 8, 16\}$ is defined by a set of PDCCH candidates for CCE aggregation level L.

If a UE is configured with *CrossCarrierSchedulingConfig* for a serving cell the carrier indicator field value corresponds to the value indicated by *CrossCarrierSchedulingConfig.*

For an active DL BWP of a serving cell on which a UE monitors PDCCH candidates in a USS, if the UE is not configured with a carrier indicator field, the UE monitors the PDCCH candidates without carrier indicator field. For an active DL BWP of a serving cell on which a UE monitors PDCCH candidates in a USS, if a UE is configured with a carrier indicator field, the UE monitors the PDCCH candidates with carrier indicator field.

A UE does not expect to monitor PDCCH candidates on an active DL BWP of a secondary cell if the UE is configured to monitor PDCCH candidates with carrier indicator field corresponding to that secondary cell in another serving cell. For the active DL BWP of a serving cell on which the UE monitors PDCCH candidates, the UE monitors PDCCH candidates at least for the same serving cell.

For a search space set s associated with CORESET p, the CCE indexes for aggregation level L corresponding to PDCCH candidate $m_{s,n_{CI}}$ of the search space set in slot $n_{s,f}^{\mu}$ for an active DL BWP of a serving cell corresponding to carrier indicator field value n_{CI} are given by

$$L \cdot \left\{ \left(Y_{p,n_{s,f}^{\mu}} + \left\lfloor \frac{m_{s,n_{CI}} \cdot N_{\text{CCE},p}}{L \cdot M_{s,\max}^{(L)}} \right\rfloor + n_{CI} \right) \text{mod} \left\lfloor N_{\text{CCE},p} / L \right\rfloor \right\} + i$$

where

for any CSS, $Y_{p,n_{s,f}^{\mu}} = 0$;

for a USS, $Y_{p,n_{s,f}^{\mu}} = \left(A_p \cdot Y_{p,n_{s,f}^{\mu}-1}\right) \text{mod} D$, $Y_{p,-1} = n_{\text{RNTI}} \neq 0$, $A_p = 39827$ for $p \text{mod} 3 = 0$, $A_p = 39829$ for $p \text{mod} 3 = 1$, $A_p = 39839$ for $p \text{mod} 3 = 2$, and $D = 65537$;

$i = 0, \cdots, L-1$;

$N_{\text{CCE},p}$ is the number of CCEs, numbered from 0 to $N_{\text{CCE},p} - 1$, in CORESET p;

n_{CI} is the carrier indicator field value if the UE is configured with a carrier indicator field by *CrossCarrierSchedulingConfig* for the serving cell on which PDCCH is monitored; otherwise, including for any CSS, $n_{CI}=0$;

$m_{s,n_{CI}}=0,...,M_{s,n_{CI}}^{(L)}-1$, where $M_{s,n_{CI}}^{(L)}$ is the number of PDCCH candidates the UE is configured to monitor for aggregation level L of a search space set s for a serving cell corresponding to n_{CI};

for any CSS, $M_{s,\max}^{(L)}=M_{s,0}^{(L)}$;

for a USS, $M_{s,\max}^{(L)}$ is the maximum of $M_{s,n_{CI}}^{(L)}$ over all configured n_{CI} values for a CCE aggregation level L of search space set s;

the RNTI value used for n_{RNTI} is the C-RNTI.

A UE that

- is configured for operation with carrier aggregation, and
- indicates support of search space sharing through *searchSpaceSharingCA-UL* or through *searchSpaceSharingCA-DL*, and
- has a PDCCH candidate with CCE aggregation level L in CORESET p for a DCI format 0_1 or a DCI format 1_1 having a first size and associated with serving cell $n_{CI,2}$,

can receive a corresponding PDCCH through a PDCCH candidate with CCE aggregation level L in CORESET p for a DCI format 0_1 or a DCI format 1_1, respectively, having a second size and associated with serving cell $n_{CI,1}$ if the first size and the second size are same.

A UE expects to monitor PDCCH candidates for up to 4 sizes of DCI formats that include up to 3 sizes of DCI formats with CRC scrambled by C-RNTI per serving cell. The UE counts a number of sizes for DCI formats per serving cell based on a number of configured PDCCH candidates in respective search space sets for the corresponding active DL BWP.

A PDCCH candidate with index $m_{s_j,n_{CI}}$ for a search space set s_j using a set of CCEs in a CORESET p on the active DL BWP for serving cell n_{CI} is not counted for monitoring if there is a PDCCH candidate with index $m_{s_i,n_{CI}}$ for a search space set $s_i<s_j$, or if there is a PDCCH candidate with index $n_{s_j,n_{CI}}$ and $n_{s_j,n_{CI}}<m_{s_j,n_{CI}}$, in the CORESET p on the active DL BWP for serving cell n_{CI} using a same set of CCEs, the PDCCH candidates have identical scrambling, and the corresponding DCI formats for the PDCCH candidates have a same size; otherwise, the PDCCH candidate with index $m_{s_j,n_{CI}}$ is counted for monitoring.

Table 10.1-2 provides the maximum number of monitored PDCCH candidates, $M_{\text{PDCCH}}^{\max,\text{slot},\mu}$, for a DL BWP with SCS configuration μ for a UE per slot for operation with a single serving cell.

Table 10.1-2: Maximum number $M_{\text{PDCCH}}^{\max,\text{slot},\mu}$ of monitored PDCCH candidates per slot for a DL BWP with SCS configuration $\mu\in\{0,1,2,3\}$ for a single serving cell

μ	Maximum number of monitored PDCCH candidates per slot and per serving cell $M_{\text{PDCCH}}^{\max,\text{slot},\mu}$
0	44
1	36
2	22
3	20

Table 10.1-3 provides the maximum number of non-overlapped CCEs, $C_{\text{PDCCH}}^{\text{max,slot},\mu}$, for a DL BWP with SCS configuration μ that a UE is expected to monitor corresponding PDCCH candidates per slot for operation with a single serving cell.

CCEs for PDCCH candidates are non-overlapped if they correspond to

- different CORESET indexes, or
- different first symbols for the reception of the respective PDCCH candidates.

Table 10.1-3: Maximum number $C_{\text{PDCCH}}^{\text{max,slot},\mu}$ of non-overlapped CCEs per slot for a DL BWP with SCS configuration $\mu \in \{0, 1, 2, 3\}$ for a single serving cell

μ	Maximum number of non-overlapped CCEs per slot and per serving cell $C_{\text{PDCCH}}^{\text{max,slot},\mu}$
0	56
1	56
2	48
3	32

If a UE is configured with $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with DL BWPs having SCS configuration μ where $\sum_{\mu=0}^{3} N_{\text{cells}}^{\text{DL},\mu} \le N_{\text{cells}}^{\text{cap}}$, the UE is not required to monitor, on the active DL BWP of the scheduling cell, more than $M_{\text{PDCCH}}^{\text{total,slot},\mu} = M_{\text{PDCCH}}^{\text{max,slot},\mu}$ PDCCH candidates or more than $C_{\text{PDCCH}}^{\text{total,slot},\mu} = C_{\text{PDCCH}}^{\text{max,slot},\mu}$ non-overlapped CCEs per slot for each scheduled cell.

If a UE is configured with $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with DL BWPs having SCS configuration μ, where $\sum_{\mu=0}^{3} N_{\text{cells}}^{\text{DL},\mu} > N_{\text{cells}}^{\text{cap}}$, a DL BWP of an activated cell is the active DL BWP of the activated cell, and a DL BWP of a deactivated cell is the DL BWP with index provided by *firstActiveDownlinkBWP-Id* for the deactivated cell, the UE is not required to monitor more than $M_{\text{PDCCH}}^{\text{total,slot},\mu} = \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} \Big/ \sum_{j=0}^{3} N_{\text{cells}}^{\text{DL},j} \right\rfloor$ PDCCH candidates or more than $C_{\text{PDCCH}}^{\text{total,slot},\mu} = \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} \Big/ \sum_{j=0}^{3} N_{\text{cells}}^{\text{DL},j} \right\rfloor$ non-overlapped CCEs per slot on the active DL BWP(s) of scheduling cell(s) from the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells.

For each scheduled cell, the UE is not required to monitor on the active DL BWP with SCS configuration μ of the scheduling cell more than $\min\left(M_{\text{PDCCH}}^{\text{max,slot},\mu}, M_{\text{PDCCH}}^{\text{total,slot},\mu}\right)$ PDCCH candidates or more than $\min\left(C_{\text{PDCCH}}^{\text{max,slot},\mu}, C_{\text{PDCCH}}^{\text{total,slot},\mu}\right)$ non-overlapped CCEs per slot.

A UE does not expect to be configured CSS sets that result to corresponding total, or per scheduled cell, numbers of monitored PDCCH candidates and non-overlapped CCEs per slot that exceed the corresponding maximum numbers per slot.

For same cell scheduling or for cross-carrier scheduling where a scheduling cell and scheduled cell(s) have DL BWPs with same SCS configuration μ, a UE does not expect a number of PDCCH candidates, and a number of corresponding non-overlapped CCEs per slot on a secondary cell to be larger than the corresponding numbers that the UE is capable of monitoring on the secondary cell per slot.

For cross-carrier scheduling, the number of PDCCH candidates for monitoring and the number of non-overlapped CCEs per slot are separately counted for each scheduled cell.

For all search space sets within a slot n, denote by S_{css} a set of CSS sets with cardinality of I_{css} and by S_{uss} a set of USS sets with cardinality of J_{uss}. The location of USS sets s_j, $0 \le j < J_{\text{uss}}$, in S_{uss} is according to an ascending order of the search space set index.

Denote by $M^{(L)}_{S_{\text{css}}(i)}$, $0 \le i < I_{\text{css}}$, the number of counted PDCCH candidates for monitoring for CSS set $S_{\text{css}}(i)$ and by $M^{(L)}_{S_{\text{uss}}(j)}$, $0 \le j < J_{\text{uss}}$, the number of counted PDCCH candidates for monitoring for USS set $S_{\text{uss}}(j)$.

For the CSS sets, a UE monitors $M^{\text{CSS}}_{\text{PDCCH}} = \sum_{i=0}^{I_{\text{css}}-1} \sum_{L} M^{(L)}_{S_{\text{css}}(i)}$ PDCCH candidates requiring a total of $C^{\text{CSS}}_{\text{PDCCH}}$ non-overlapping CCEs in a slot.

The UE allocates PDCCH candidates for monitoring to USS sets for the primary cell having an active DL BWP with SCS configuration μ in slot n according to the following pseudocode. A UE does not expect to monitor PDCCH in a USS set without allocated PDCCH candidates for monitoring.

Denote by $V_{\text{CCE}}(S_{\text{uss}}(j))$ the set of non-overlapping CCEs for search space set $S_{\text{uss}}(j)$ and by $\mathcal{C}\left(V_{\text{CCE}}(S_{\text{uss}}(j))\right)$ the cardinality of $V_{\text{CCE}}(S_{\text{uss}}(j))$ where the non-overlapping CCEs for search space set $S_{\text{uss}}(j)$ are determined considering the allocated PDCCH candidates for monitoring for the CSS sets and the allocated PDCCH candidates for monitoring for all search space sets $S_{\text{uss}}(k)$, $0 \le k \le j$.

Set $M^{\text{uss}}_{\text{PDCCH}} = \min\left(M^{\text{max,slot},\mu}_{\text{PDCCH}}, M^{\text{total,slot},\mu}_{\text{PDCCH}}\right) - M^{\text{css}}_{\text{PDCCH}}$

Set $C^{\text{uss}}_{\text{PDCCH}} = \min\left(C^{\text{max,slot},\mu}_{\text{PDCCH}}, C^{\text{total,slot},\mu}_{\text{PDCCH}}\right) - C^{\text{css}}_{\text{PDCCH}}$

Set $j = 0$

while $\sum_{L} M^{(L)}_{S_{\text{uss}}(j)} \le M^{\text{uss}}_{\text{PDCCH}}$ AND $\mathcal{C}\left(V_{\text{CCE}}(S_{\text{uss}}(j))\right) \le C^{\text{uss}}_{\text{PDCCH}}$

allocate $\sum_{L} M^{(L)}_{S_{\text{uss}}(j)}$ PDCCH candidates for monitoring to USS set $S_{\text{uss}}(j)$

$M^{\text{uss}}_{\text{PDCCH}} = M^{\text{uss}}_{\text{PDCCH}} - \sum_{L} M^{(L)}_{S_{\text{uss}}(j)}$;

$C^{\text{uss}}_{\text{PDCCH}} = C^{\text{uss}}_{\text{PDCCH}} - \mathcal{C}\left(V_{\text{CCE}}(S_{\text{uss}}(j))\right)$;

$j = j + 1$;

end while

If a UE

- is configured for single cell operation or for operation with carrier aggregation in a same frequency band, and
- monitors PDCCH candidates in overlapping PDCCH monitoring occasions in multiple CORESETs that have same or different QCL-TypeD properties on active DL BWP(s) of one or more cells

the UE monitors PDCCHs only in a CORESET, and in any other CORESET from the multiple CORESETs having same QCL-TypeD properties as the CORESET, on the active DL BWP of a cell from the one or more cells

- the CORESET corresponds to the CSS set with the lowest index in the cell with the lowest index containing CSS, if any; otherwise, to the USS set with the lowest index in the cell with lowest index
- the lowest USS set index is determined over all USS sets with at least one PDCCH candidate in overlapping PDCCH monitoring occasions
- for the purpose of determining the CORESET, a SS/PBCH block is considered to have different QCL-TypeD properties than a CSI-RS

- for the purpose of determining the CORESET, a first CSI-RS associated with a SS/PBCH block in a first cell and a second CSI-RS in a second cell that is also associated with the SS/PBCH block are assumed to have same QCL-TypeD properties
- the allocation of non-overlapping CCEs and of PDCCH candidates for PDCCH monitoring is according to all search space sets associated with the multiple CORESETs on the active DL BWP(s) of the one or more cells
- the number of active TCI states is determined from the multiple CORESETs

If a UE

- is configured for single cell operation or for operation with carrier aggregation in a same frequency band, and
- monitors PDCCH candidates in overlapping PDCCH monitoring occasions in multiple CORESETs where none of the CORESETs has TCI-states with 'QCL-TypeD',

the UE is required to monitor PDCCH candidates in overlapping PDCCH monitoring occasions for search space sets associated with different CORESETs.

For a scheduled cell and at any time, a UE expects to have received at most 16 PDCCHs for DCI formats 1_0 or 1_1 with CRC scrambled by C-RNTI, CS-RNTI, or MCS-C-RNTI scheduling 16 PDSCH receptions for which the UE has not received any corresponding PDSCH symbol and at most 16 PDCCHs for DCI formats 0_0 or 0_1 with CRC scrambled by C-RNTI, CS-RNTI, or MCS-C-RNTI scheduling 16 PUSCH transmissions for which the UE has not transmitted any corresponding PUSCH symbol.

If a UE

- is not configured for NR-DC operation and indicates through *pdcch-BlindDetectionCA* a capability to monitor PDCCH candidates for $N_{\text{cells}}^{\text{cap}} \geq 4$ downlink cells and the UE is configured with $N_{\text{cells}}^{\text{DL}} > 4$ downlink cells or $N_{\text{cells}}^{\text{UL}} > 4$ uplink cells, or
- is configured with NR-DC operation and for a cell group with $N_{\text{cells}}^{\text{DL}}$ downlink cells or $N_{\text{cells}}^{\text{UL}}$ uplink cells

the UE expects to have respectively received at most $16 \cdot N_{\text{cells}}^{\text{cap}}$ PDCCHs for

- DCI formats 1_0 or 1_1 with CRC scrambled by a C-RNTI, or a CS-RNTI, or a MCS-C-RNTI scheduling $16 \cdot N_{\text{cells}}^{\text{cap}}$ PDSCH receptions for which the UE has not received any corresponding PDSCH symbol over all $N_{\text{cells}}^{\text{DL}}$ downlink cells
- DCI formats 0_0 or 0_1 with CRC scrambled by a C-RNTI, or a CS-RNTI, or a MCS-C-RNTI scheduling $16 \cdot N_{\text{cells}}^{\text{cap}}$ PUSCH transmissions for which the UE has not transmitted any corresponding PUSCH symbol over all $N_{\text{cells}}^{\text{UL}}$ uplink cells

If a UE

- is configured to monitor a first PDCCH candidate for a DCI format 0_0 and a DCI format 1_0 from a CSS set and a second PDCCH candidate for a DCI format 0_0 and a DCI format 1_0 from a USS set in a CORESET with index zero on an active DL BWP, and
- the DCI formats 0_0/1_0 associated with the first PDCCH candidate and the DCI formats 0_0/1_0 associated with the second PDCCH candidate have same size, and
- the UE receives the first PDCCH candidate and the second PDCCH candidate over a same set of CCEs, and
- the first PDCCH candidate and the second PDCCH candidate have identical scrambling, and
- the DCI formats 0_0/1_0 for the first PDCCH candidate and the DCI formats 0_0/1_0 for the second PDCCH candidate have CRC scrambled by either C-RNTI, or MCS-C-RNTI, or CS-RNTI

the UE decodes only the DCI formats 0_0/1_0 associated with the first PDCCH candidate.

If a UE detects a DCI format with inconsistent information, the UE discards all the information in the DCI format.

A UE configured with a bandwidth part indicator in DCI formats 0_1 or 1_1 determines, in case of an active DL BWP or of an active UL BWP change, the DCI information applicable to the new active DL BWP or UL BWP, respectively, as described in Clause 12.

For unpaired spectrum operation, if a UE is not configured for PUSCH/PUCCH transmission on serving cell c_2, the UE does not expect to monitor PDCCH on serving cell c_1 if the PDCCH overlaps in time with SRS transmission (including any interruption due to uplink or downlink RF retuning time [10, TS 38.133]) on serving cell c_2 and if the UE is not capable of simultaneous reception and transmission on serving cell c_1 and serving cell c_2.

If a UE is provided *resourceBlocks* and s*ymbolsInResourceBlock* in *RateMatchPattern*, or if the UE is additionally provided *periodicityAndPattern* in *RateMatchPattern*, the UE can determine a set of RBs in symbols of a slot that are not available for PDSCH reception as described in [6, TS 38.214]. If a PDCCH candidate in a slot is mapped to one or more REs that overlap with REs of any RB in the set of RBs in symbols of the slot, the UE does not expect to monitor the PDCCH candidate.

10.2 PDCCH validation for DL SPS and UL grant Type 2

A UE validates, for scheduling activation or scheduling release, a DL SPS assignment PDCCH or configured UL grant Type 2 PDCCH if

- the CRC of a corresponding DCI format is scrambled with a CS-RNTI provided by *cs-RNTI*, and
- the new data indicator field for the enabled transport block is set to '0'.

Validation of the DCI format is achieved if all fields for the DCI format are set according to Table 10.2-1 or Table 10.2-2.

If validation is achieved, the UE considers the information in the DCI format as a valid activation or valid release of DL SPS or configured UL grant Type 2. If validation is not achieved, the UE discards all the information in the DCI format.

Table 10.2-1: Special fields for DL SPS and UL grant Type 2 scheduling activation PDCCH validation

	DCI format 0_0/0_1	DCI format 1_0	DCI format 1_1
HARQ process number	set to all '0's	set to all '0's	set to all '0's
Redundancy version	set to '00'	set to '00'	For the enabled transport block: set to '00'

Table 10.2-2: Special fields for DL SPS and UL grant Type 2 scheduling release PDCCH validation

	DCI format 0_0	DCI format 1_0
HARQ process number	set to all '0's	set to all '0's
Redundancy version	set to '00'	set to '00'
Modulation and coding scheme	set to all '1's	set to all '1's
Frequency domain resource assignment	set to all '1's	set to all '1's

A UE is expected to provide HARQ-ACK information in response to a SPS PDSCH release after N symbols from the last symbol of a PDCCH providing the SPS PDSCH release. If *processingType2Enabled* of *PDSCH-ServingCellConfig* is set to *enable* for the serving cell with the PDCCH providing the SPS PDSCH release, N=5 for $\mu = 0$, N=5.5 for $\mu = 1$, and N=11 for $\mu = 2$, otherwise, N=10 for $\mu = 0$, N=12 for $\mu = 1$, N=22 for $\mu = 2$, and N=25 for $\mu = 3$, wherein μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH providing the SPS PDSCH release and the SCS configuration of a PUCCH carrying the HARQ-ACK information in response to a SPS PDSCH release.

11 UE-group common signalling

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG

- When the procedures are applied for MCG, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term 'primary cell' in this clause refers to the PSCell of the SCG.

11.1 Slot configuration

A slot format includes downlink symbols, uplink symbols, and flexible symbols.

The following are applicable for each serving cell.

If a UE is provided *tdd-UL-DL-ConfigurationCommon*, the UE sets the slot format per slot over a number of slots as indicated by *tdd-UL-DL-ConfigurationCommon*.

The *tdd-UL-DL-ConfigurationCommon* provides

- a reference SCS configuration μ_{ref} by *referenceSubcarrierSpacing*
- a *pattern1*.

The *pattern1* provides

- a slot configuration period of P msec by *dl-UL-TransmissionPeriodicity*
- a number of slots d_{slots} with only downlink symbols by *nrofDownlinkSlots*
- a number of downlink symbols d_{sym} by *nrofDownlinkSymbols*
- a number of slots u_{slots} with only uplink symbols by *nrofUplinkSlots*
- a number of uplink symbols u_{sym} by *nrofUplinkSymbols*

A value $P = 0.625$ msec is valid only for $\mu_{\text{ref}} = 3$. A value $P = 1.25$ msec is valid only for $\mu_{\text{ref}} = 2$ or $\mu_{\text{ref}} = 3$. A value $P = 2.5$ msec is valid only for $\mu_{\text{ref}} = 1$, or $\mu_{\text{ref}} = 2$, or $\mu_{\text{ref}} = 3$.

A slot configuration period of P msec includes $S = P \cdot 2^{\mu_{\text{ref}}}$ slots with SCS configuration μ_{ref} . From the S slots, a first d_{slots} slots include only downlink symbols and a last u_{slots} slots include only uplink symbols. The d_{sym} symbols after the first d_{slots} slots are downlink symbols. The u_{sym} symbols before the last u_{slots} slots are uplink symbols. The remaining $\left(S - d_{\text{slots}} - u_{\text{slots}}\right) \cdot N_{\text{symb}}^{\text{slot}} - d_{\text{sym}} - u_{\text{sym}}$ are flexible symbols.

The first symbol every $20/P$ periods is a first symbol in an even frame.

If *tdd-UL-DL-ConfigurationCommon* provides both *pattern1* and *pattern2*, the UE sets the slot format per slot over a first number of slots as indicated by *pattern1* and the UE sets the slot format per slot over a second number of slots as indicated by *pattern2*.

The *pattern2* provides

- a slot configuration period of P_2 msec by *dl-UL-TransmissionPeriodicity*

- a number of slots $d_{\text{slots},2}$ with only downlink symbols by *nrofDownlinkSlots*
- a number of downlink symbols $d_{\text{sym},2}$ by *nrofDownlinkSymbols*
- a number of slots $u_{\text{slots},2}$ with only uplink symbols by *nrofUplinkSlots*
- a number of uplink symbols $u_{\text{sym},2}$ by *nrofUplinkSymbols*

The applicable values of P_2 are same as the applicable values for P .

A slot configuration period of $P + P_2$ msec includes first $S = P \cdot 2^{\mu_{\text{ref}}}$ slots and second $S_2 = P_2 \cdot 2^{\mu_{\text{ref}}}$ slots.

From the S_2 slots, a first $d_{\text{slots},2}$ slots include only downlink symbols and a last $u_{\text{slots},2}$ include only uplink symbols. The $d_{\text{sym},2}$ symbols after the first $d_{\text{slots},2}$ slots are downlink symbols. The $u_{\text{sym},2}$ symbols before the last $u_{\text{slots},2}$ slots are uplink symbols. The remaining $\left(S_2 - d_{\text{slots},2} - u_{\text{slots},2}\right) \cdot N_{\text{symb}}^{\text{slot}} - d_{\text{sym},2} - u_{\text{sym},2}$ are flexible symbols.

A UE expects that $P + P_2$ divides 20 msec.

The first symbol every $20/\left(P + P_2\right)$ periods is a first symbol in an even frame.

A UE expects that the reference SCS configuration μ_{ref} is smaller than or equal to a SCS configuration μ for any configured DL BWP or UL BWP. Each slot provided by *pattern1* or *pattern2* is applicable to $2^{(\mu-\mu_{\text{ref}})}$ consecutive slots in the active DL BWP or the active UL BWP where the first slot starts at a same time as a first slot for the reference SCS configuration μ_{ref} and each downlink or flexible or uplink symbol for the reference SCS configuration μ_{ref} corresponds to $2^{(\mu-\mu_{\text{ref}})}$ consecutive downlink or flexible or uplink symbols for the SCS configuration μ .

If the UE is additionally provided *tdd-UL-DL-ConfigurationDedicated*, the parameter *tdd-UL-DL-ConfigurationDedicated* overrides only flexible symbols per slot over the number of slots as provided by *tdd-UL-DL-ConfigurationCommon*.

The *tdd-UL-DL-ConfigurationDedicated* provides

- a set of slot configurations by *slotSpecificConfigurationsToAddModList*
- for each slot configuration from the set of slot configurations
- a slot index for a slot provided by *slotIndex*
- a set of symbols for a slot by *symbols* where
  - if *symbols* = *allDownlink*, all symbols in the slot are downlink
  - if *symbols* = *allUplink*, all symbols in the slot are uplink
  - if *symbols* = *explicit*, *nrofDownlinkSymbols* provides a number of downlink first symbols in the slot and *nrofUplinkSymbols* provides a number of uplink last symbols in the slot. If *nrofDownlinkSymbols* is not provided, there are no downlink first symbols in the slot and if *nrofUplinkSymbols* is not provided, there are no uplink last symbols in the slot. The remaining symbols in the slot are flexible

For each slot having a corresponding index provided by *slotIndex*, the UE applies a format provided by a corresponding *symbols*. The UE does not expect *tdd-UL-DL-ConfigurationDedicated* to indicate as uplink or as downlink a symbol that *tdd-UL-DL-ConfigurationCommon* indicates as a downlink or as an uplink symbol, respectively.

For each slot configuration provided by *tdd-UL-DL-ConfigurationDedicated*, a reference SCS configuration is the reference SCS configuration μ_{ref} provided by *tdd-UL-DL-ConfigurationCommon*.

A slot configuration period and a number of downlink symbols, uplink symbols, and flexible symbols in each slot of the slot configuration period are determined from *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* and are common to each configured BWP.

A UE considers symbols in a slot indicated as downlink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated* to be available for receptions and considers symbols in a slot indicated as uplink by *tdd-UL-DL-ConfigurationCommon*, or by *tdd-UL-DL-ConfigurationDedicated* to be available for transmissions.

If a UE is not configured to monitor PDCCH for DCI format 2_0, for a set of symbols of a slot that are indicated as flexible by *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* if provided, or when *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* are not provided to the UE

- the UE receives PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 1_0, DCI format 1_1, or DCI format 0_1
- the UE transmits PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant

For operation on a single carrier in unpaired spectrum, if a UE is configured by higher layers to receive a PDCCH, or a PDSCH, or a CSI-RS in a set of symbols of a slot, the UE receives the PDCCH, the PDSCH, or the CSI-RS if the UE does not detect a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, or DCI format 2_3 that indicates to the UE to transmit a PUSCH, a PUCCH, a PRACH, or a SRS in at least one symbol of the set of symbols of the slot; otherwise, the UE does not receive the PDCCH, or the PDSCH, or the CSI-RS in the set of symbols of the slot.

For operation on a single carrier in unpaired spectrum, if a UE is configured by higher layers to transmit SRS, or PUCCH, or PUSCH, or PRACH in a set of symbols of a slot and the UE detects a DCI format 1_0, DCI format 1_1, or DCI format 0_1 indicating to the UE to receive CSI-RS or PDSCH in a subset of symbols from the set of symbols, then

- the UE does not expect to cancel the transmission in symbols from the set of symbols that occur, relative to a last symbol of a CORESET where the UE detects the DCI format 1_0 or the DCI format 1_1 or the DCI format 0_1, after a number of symbols that is smaller than the PUSCH preparation time $T_{\text{proc},2}$ for the corresponding UE processing capability [6, TS 38.214] assuming $d_{2,1}=1$ and μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH carrying the DCI format 1_0, DCI format 1_1 or DCI format 0_1 and the SCS configuration of the SRS, PUCCH, PUSCH or μ_r, where μ_r corresponds to the SCS configuration of the PRACH if it is 15kHz or higher; otherwise μ_r=0
- the UE cancels the PUCCH, or PUSCH, or PRACH transmission in remaining symbols from the set of symbols and cancels the SRS transmission in remaining symbols from the subset of symbols

For a set of symbols of a slot that are indicated to a UE as uplink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, the UE does not receive PDCCH, PDSCH, or CSI-RS when the PDCCH, PDSCH, or CSI-RS overlaps, even partially, with the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE as downlink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, the UE does not transmit PUSCH, PUCCH, PRACH, or SRS when the PUSCH, PUCCH, PRACH, or SRS overlaps, even partially, with the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE as flexible by *tdd-UL-DL-ConfigurationCommon*, and *tdd-UL-DL-ConfigurationDedicated* if provided, the UE does not expect to receive both dedicated higher layer parameters configuring transmission from the UE in the set of symbols of the slot and dedicated higher layer parameters configuring reception by the UE in the set of symbols of the slot.

For operation on a single carrier in unpaired spectrum, for a set of symbols of a slot that are indicated to a UE by *ssb-PositionsInBurst* in *SIB1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon*, for reception of SS/PBCH blocks, the UE does not transmit PUSCH, PUCCH, PRACH in the slot if a transmission would overlap with any symbol from the set of symbols and the UE does not transmit SRS in the set of symbols of the slot. The UE does not expect the set of symbols of the slot to be indicated as uplink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, when provided to the UE.

For a set of symbols of a slot corresponding to a valid PRACH occasion and N_{gap} symbols before the valid PRACH occasion, as described in Sublcause 8.1, the UE does not receive PDCCH, PDSCH, or CSI-RS in the slot if a reception would overlap with any symbol from the set of symbols. The UE does not expect the set of symbols of the slot to be indicated as downlink by *tdd-UL-DL-ConfigurationCommon* or *tdd-UL-DL-ConfigurationDedicated*.

For a set of symbols of a slot indicated to a UE by *pdcch-ConfigSIB1* in *MIB* for a CORESET for Type0-PDCCH CSS set, the UE does not expect the set of symbols to be indicated as uplink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*.

If a UE is scheduled by a DCI format 1_1 to receive PDSCH over multiple slots, and if *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, indicate that, for a slot from the multiple slots, at least one symbol from a set of symbols where the UE is scheduled PDSCH reception in the slot is an uplink symbol, the UE does not receive the PDSCH in the slot.

If a UE is scheduled by a DCI format 0_1 to transmit PUSCH over multiple slots, and if *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, indicates that, for a slot from the multiple slots, at least one symbol from a set of symbols where the UE is scheduled PUSCH transmission in the slot is a downlink symbol, the UE does not transmit the PUSCH in the slot.

11.1.1 UE procedure for determining slot format

This clause applies for a serving cell that is included in a set of serving cells configured to a UE by *slotFormatCombToAddModList* and *slotFormatCombToReleaseList*.

If a UE is configured by higher layers with parameter *SlotFormatIndicator*, the UE is provided a SFI-RNTI by *sfi-RNTI* and with a payload size of DCI format 2_0 by *dci-PayloadSize*.

The UE is also provided in one or more serving cells with a configuration for a search space set s and a corresponding CORESET p for monitoring $M_{p,s}^{(L_{\text{SFI}})}$ PDCCH candidates for DCI format 2_0 with a CCE aggregation level of L_{SFI} CCEs as described in Clause 10.1. The $M_{p,s}^{(L_{\text{SFI}})}$ PDCCH candidates are the first $M_{p,s}^{(L_{\text{SFI}})}$ PDCCH candidates for CCE aggregation level L_{SFI} for search space set s in CORESET p.

For each serving cell in the set of serving cells, the UE can be provided:

- an identity of the serving cell by *servingCellId*
- a location of a SFI-index field in DCI format 2_0 by *positionInDCI*
- a set of slot format combinations by *slotFormatCombinations*, where each slot format combination in the set of slot format combinations includes
  - one or more slot formats indicated by a respective *slotFormats* for the slot format combination, and
  - a mapping for the slot format combination provided by *slotFormats* to a corresponding SFI-index field value in DCI format 2_0 provided by *slotFormatCombinationId*
- for unpaired spectrum operation, a reference SCS configuration μ_{SFI} by *subcarrierSpacing* and, when a supplementary UL carrier is configured for the serving cell, a reference SCS configuration $\mu_{\text{SFI,SUL}}$ by *subcarrierSpacing2* for the supplementary UL carrier
- for paired spectrum operation, a reference SCS configuration $\mu_{\text{SFI,DL}}$ for a DL BWP by *subcarrierSpacing* and a reference SCS configuration $\mu_{\text{SFI,UL}}$ for an UL BWP by *subcarrierSpacing2*

A SFI-index field value in a DCI format 2_0 indicates to a UE a slot format for each slot in a number of slots for each DL BWP or each UL BWP starting from a slot where the UE detects the DCI format 2_0. The number of slots is equal to or larger than a PDCCH monitoring periodicity for DCI format 2_0. The SFI-index field includes $\max\{\lceil \log_2(\text{maxSFIindex}+1) \rceil, 1\}$ bits where maxSFIindex is the maximum value of the values provided by corresponding *slotFormatCombinationId*. A slot format is identified by a corresponding format index as provided in Table 11.1.1-1 where 'D' denotes a downlink symbol, 'U' denotes an uplink symbol, and 'F' denotes a flexible symbol.

If a PDCCH monitoring periodicity for DCI format 2_0, provided to a UE for the search space set S by *monitoringSlotPeriodicityAndOffset*, is smaller than a duration of a slot format combination the UE obtains at a PDCCH monitoring occasion for DCI format 2_0 by a corresponding SFI-index field value, and the UE detects more than one DCI formats 2_0 indicating a slot format for a slot, the UE expects each of the more than one DCI formats 2_0 to indicate a same format for the slot.

A UE does not expect to be configured to monitor PDCCH for DCI format 2_0 on a second serving cell that uses larger SCS than the serving cell.

Table 11.1.1-1: Slot formats for normal cyclic prefix

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	F	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	F	U	U	U	U	U	U	U	U	U	U
37	D	F	F	U	U	U	U	U	U	U	U	U	U	U
38	D	D	F	F	U	U	U	U	U	U	U	U	U	U
39	D	D	D	F	F	U	U	U	U	U	U	U	U	U
40	D	F	F	F	U	U	U	U	U	U	U	U	U	U
41	D	D	F	F	F	U	U	U	U	U	U	U	U	U
42	D	D	D	F	F	F	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	F	F	F	F	U
44	D	D	D	D	D	D	F	F	F	F	F	F	U	U
45	D	D	D	D	D	D	F	F	U	U	U	U	U	U
46	D	D	D	D	D	F	U	D	D	D	D	D	F	U
47	D	D	F	U	U	U	U	D	D	F	U	U	U	U
48	D	F	U	U	U	U	U	D	F	U	U	U	U	U
49	D	D	D	D	F	F	U	D	D	D	D	F	F	U
50	D	D	F	F	U	U	U	D	D	F	F	U	U	U
51	D	F	F	U	U	U	U	D	F	F	U	U	U	U
52	D	F	F	F	F	F	U	D	F	F	F	F	F	U
53	D	D	F	F	F	F	U	D	D	F	F	F	F	U
54	F	F	F	F	F	F	F	D	D	D	D	D	D	D
55	D	D	F	F	F	U	U	U	D	D	D	D	D	D
56 – 254	Reserved													
255	UE determines the slot format for the slot based on *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated* and, if any, on detected DCI formats													

For unpaired spectrum operation for a UE on a serving cell, the UE is provided by *subcarrierSpacing* a reference SCS configuration μ_{SFI} for each slot format in a combination of slot formats indicated by a SFI-index field value in DCI format 2_0. The UE expects that for a reference SCS configuration μ_{SFI} and for an active DL BWP or an active UL BWP with SCS configuration μ, it is $\mu \geq \mu_{\text{SFI}}$. Each slot format in the combination of slot formats indicated by the SFI-index field value in DCI format 2_0 is applicable to $2^{(\mu-\mu_{\text{SFI}})}$ consecutive slots in the active DL BWP or the active UL BWP where the first slot starts at a same time as a first slot for the reference SCS configuration μ_{SFI} and each downlink or flexible or uplink symbol for the reference SCS configuration μ_{SFI} corresponds to $2^{(\mu-\mu_{\text{SFI}})}$ consecutive downlink or flexible or uplink symbols for the SCS configuration μ.

For paired spectrum operation for a UE on a serving cell, the SFI-index field in DCI format 2_0 indicates a combination of slot formats that includes a combination of slot formats for a reference DL BWP and a combination of slot formats for a reference UL BWP of the serving cell. The UE is provided by *subcarrierSpacing* a reference SCS configuration $\mu_{\text{SFI,DL}}$ for the combination of slot formats indicated by the SFI-index field value in DCI format 2_0 for the reference DL BWP of the serving cell. The UE is provided by *subcarrierSpacing2* a reference SCS configuration $\mu_{\text{SFI,UL}}$ for the combination of slot formats indicated by the SFI-index field value in DCI format 2_0 for the reference UL BWP of the serving cell. If $\mu_{\text{SFI,DL}} \geq \mu_{\text{SFI,UL}}$ and for each $2^{(\mu_{\text{SFI,DL}}-\mu_{\text{SFI,UL}})}+1$ values provided by a value of *slotFormats*, where the value of *slotFormats* is determined by a value of *slotFormatCombinationId* in *slotFormatCombination* and the value of *slotFormatCombinationId* is set by the value of the SFI-index field value in DCI format 2_0, the first $2^{(\mu_{\text{SFI,DL}}-\mu_{\text{SFI,UL}})}$ values for the combination of slot formats are applicable to the reference DL BWP and the next value is applicable to the reference UL BWP. If $\mu_{\text{SFI,DL}} < \mu_{\text{SFI,UL}}$ and for each $2^{(\mu_{\text{SFI,UL}}-\mu_{\text{SFI,DL}})}+1$ values provided by *slotFormats*, the first value for the combination of slot formats is applicable to the reference DL BWP and the next $2^{(\mu_{\text{SFI,UL}}-\mu_{\text{SFI,DL}})}$ values are applicable to the reference UL BWP.

The UE is provided a reference SCS configuration $\mu_{\text{SFI,DL}}$ so that for an active DL BWP with SCS configuration μ_{DL}, it is $\mu_{\text{DL}} \geq \mu_{\text{SFI,DL}}$. The UE is provided a reference SCS configuration $\mu_{\text{SFI,UL}}$ so that for an active UL BWP with SCS configuration μ_{UL}, it is $\mu_{\text{UL}} \geq \mu_{\text{SFI,UL}}$. Each slot format for a combination of slot formats indicated by the SFI-index field value in DCI format 2_0 for the reference DL BWP, by indicating a value for *slotFormatCombinationId* that is mapped to a value of *slotFormats* in *slotFormatCombination*, is applicable to $2^{(\mu_{\text{DL}}-\mu_{\text{SFI,DL}})}$ consecutive slots for the active DL BWP where the first slot starts at a same time as a first slot in the reference DL BWP and each downlink or flexible symbol for the reference SCS configuration $\mu_{\text{SFI,DL}}$ corresponds to $2^{(\mu_{\text{DL}}-\mu_{\text{SFI,DL}})}$ consecutive downlink or flexible symbols for the SCS configuration μ_{DL}. Each slot format for the combination of slot formats for the reference UL BWP is applicable to $2^{(\mu_{\text{UL}}-\mu_{\text{SFI,UL}})}$ consecutive slots for the active UL BWP where the first slot starts at a same time as a first slot in the reference UL BWP and each uplink or flexible symbol for the reference SCS configuration $\mu_{\text{SFI,UL}}$ corresponds to $2^{(\mu_{\text{UL}}-\mu_{\text{SFI,UL}})}$ consecutive uplink or flexible symbols for the SCS configuration μ_{UL}.

For unpaired spectrum operation with a second UL carrier for a UE on a serving cell, the SFI-index field value in DCI format 2_0 indicates a combination of slot formats that includes a combination of slot formats for a reference first UL carrier of the serving cell and a combination of slot formats for a reference second UL carrier of the serving cell. The UE is provided by *subcarrierSpacing* a reference SCS configuration μ_{SFI} for the combination of slot formats indicated by the SFI-index field in DCI format 2_0 for the reference first UL carrier of the serving cell. The UE is provided by *subcarrierSpacing2* a reference SCS configuration $\mu_{\text{SFI,SUL}}$ for the combination of slot formats indicated by the SFI-index field value in DCI format 2_0 for the reference second UL carrier of the serving cell. For each $2^{(\mu_{\text{SFI}}-\mu_{\text{SFI,SUL}})}+1$ values of *slotFormats*, the first $2^{(\mu_{\text{SFI}}-\mu_{\text{SFI,SUL}})}$ values for the combination of slot formats are applicable to the reference first UL carrier and the next value is applicable to the reference second UL carrier.

The UE expects to be provided a reference SCS configuration $\mu_{\text{SFI,SUL}}$ so that for an active UL BWP in the second UL carrier with SCS configuration μ_{SUL}, it is $\mu_{\text{SUL}} \geq \mu_{\text{SFI,SUL}}$. Each slot format for a combination of slot formats indicated by the SFI-index field in DCI format 2_0 for the reference first UL carrier is applicable to $2^{(\mu-\mu_{\text{SFI}})}$ consecutive slots for the active DL BWP and the active UL BWP in the first UL carrier where the first slot starts at a same time as a first slot in the reference first UL carrier. Each slot format for the combination of slot formats for the reference second UL

carrier is applicable to $2^{(\mu_{SUL}-\mu_{SFI,SUL})}$ consecutive slots for the active UL BWP in the second UL carrier where the first slot starts at a same time as a first slot in the reference second UL carrier.

If a BWP in the serving cell is configured with $\mu = 2$ and with extended CP, the UE expects $\mu_{SFI} = 0$, $\mu_{SFI} = 1$, or $\mu_{SFI} = 2$. A format for a slot with extended CP is determined from a format for a slot with normal CP. A UE determines an extended CP symbol to be a downlink/uplink/flexible symbol if the overlapping normal CP symbols that are downlink/uplink/flexible symbols, respectively. A UE determines an extended CP symbol to be a flexible symbol if one of the overlapping normal CP symbols is flexible. A UE determines an extended CP symbol to be a flexible symbol if the pair of the overlapping normal CP symbols includes a downlink and an uplink symbol.

A reference SCS configuration μ_{SFI}, or $\mu_{SFI,DL}$, or $\mu_{SFI,UL}$, or $\mu_{SFI,SUL}$ is either 0, or 1, or 2 for FR1 and is either 2 or 3 for FR2.

For a set of symbols of a slot, a UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols of the slot as uplink and to detect a DCI format 1_0, a DCI format 1_1, or DCI format 0_1 indicating to the UE to receive PDSCH or CSI-RS in the set of symbols of the slot.

For a set of symbols of a slot, a UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols in the slot as downlink and to detect a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot.

For a set of symbols of a slot that are indicated as downlink/uplink by *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationDedicated*, the UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols of the slot as uplink/downlink, respectively, or as flexible.

For a set of symbols of a slot indicated to a UE by *ssb-PositionsInBurst* in *SIB1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon* for reception of SS/PBCH blocks, the UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols of the slot as uplink.

For a set of symbols of a slot corresponding to a valid PRACH occasion and N_{gap} symbols before the valid PRACH occasion, as described in Sublcause 8.1, the UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols of the slot as downlink.

For a set of symbols of a slot indicated to a UE by *pdcch-ConfigSIB1* in *MIB* for a CORESET for Type0-PDCCH CSS set, the UE does not expect to detect a DCI format 2_0 with an SFI-index field value indicating the set of symbols of the slot as uplink.

For a set of symbols of a slot indicated to a UE as flexible by *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* if provided, or when *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationDedicated* are not provided to the UE, and if the UE detects a DCI format 2_0 providing a format for the slot using a slot format value other than 255

- if one or more symbols from the set of symbols are symbols in a CORESET configured to the UE for PDCCH monitoring, the UE receives PDCCH in the CORESET only if an SFI-index field value in DCI format 2_0 indicates that the one or more symbols are downlink symbols
- if an SFI-index field value in DCI format 2_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format 1_0, DCI format 1_1, or DCI format 0_1 indicating to the UE to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE receives PDSCH or CSI-RS in the set of symbols of the slot
- if an SFI-index field value in DCI format 2_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot the UE transmits the PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot
- if an SFI-index field value in DCI format 2_0 indicates the set of symbols of the slot as flexible, and the UE does not detect a DCI format 1_0, DCI format 1_1, or DCI format 0_1 indicating to the UE to receive PDSCH or CSI-RS, or the UE does not detect a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot, the UE does not transmit or receive in the set of symbols of the slot

- if the UE is configured by higher layers to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE receives the PDSCH or the CSI-RS in the set of symbols of the slot only if an SFI-index field value in DCI format 2_0 indicates the set of symbols of the slot as downlink

- if the UE is configured by higher layers to transmit PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE transmits the PUCCH, or the PUSCH, or the PRACH in the slot only if an SFI-index field value in DCI format 2_0 indicates the set of symbols of the slot as uplink

- if the UE is configured by higher layers to transmit SRS in the set of symbols of the slot, the UE transmits the SRS only in a subset of symbols from the set of symbols of the slot indicated as uplink symbols by an SFI-index field value in DCI format 2_0

- a UE does not expect to detect an SFI-index field value in DCI format 2_0 indicating the set of symbols of the slot as downlink and also detect a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant indicating to the UE to transmit SRS, PUSCH, PUCCH, or PRACH, in one or more symbols from the set of symbols of the slot

- a UE does not expect to detect an SFI-index field value in DCI format 2_0 indicating the set of symbols of the slot as downlink or flexible if the set of symbols of the slot includes symbols corresponding to any repetition of a PUSCH transmission activated by an UL Type 2 grant PDCCH as described in Clause 10.2

- a UE does not expect to detect an SFI-index field value in DCI format 2_0 indicating the set of symbols of the slot as uplink and also detect a DCI format 1_0 or DCI format 1_1 or DCI format 0_1 indicating to the UE to receive PDSCH or CSI-RS in one or more symbols from the set of symbols of the slot

If a UE is configured by higher layers to receive a CSI-RS or a PDSCH in a set of symbols of a slot and the UE detects a DCI format 2_0 with a slot format value other than 255 that indicates a slot format with a subset of symbols from the set of symbols as uplink or flexible, or the UE detects a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, or DCI format 2_3 indicating to the UE to transmit PUSCH, PUCCH, SRS, or PRACH in at least one symbol in the set of the symbols, the UE cancels the CSI-RS reception in the set of symbols of the slot or cancels the PDSCH reception in the slot.

If a UE is configured by higher layers to transmit SRS, or PUCCH, or PUSCH, or PRACH in a set of symbols of a slot and the UE detects a DCI format 2_0 with a slot format value other than 255 that indicates a slot format with a subset of symbols from the set of symbols as downlink or flexible, or the UE detects a DCI format 1_0, DCI format 1_1, or DCI format 0_1 indicating to the UE to receive CSI-RS or PDSCH in a subset of symbols from the set of symbols, then

- the UE does not expect to cancel the transmission in symbols from the set of symbols that occur, relative to a last symbol of a CORESET where the UE detects the DCI format 2_0 or the DCI format 1_0 or the DCI format 1_1 or the DCI format 0_1, after a number of symbols that is smaller than the PUSCH preparation time $T_{\text{proc},2}$ for the corresponding PUSCH processing capability [6, TS 38.214] assuming $d_{2,1}=1$ and μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH carrying the DCI format 2_0, DCI format 1_0, DCI format 1_1 or DCI format 0_1 and the SCS configuration of the SRS, PUCCH, PUSCH or μ_r, where μ_r corresponds to the SCS configuration of the PRACH if it is 15kHz or higher; otherwise μ_r=0

- the UE cancels the PUCCH, or PUSCH, or PRACH transmission in remaining symbols from the set of symbols and cancels the SRS transmission in remaining symbols from the subset of symbols.

A UE assumes that flexible symbols in a CORESET configured to the UE for PDCCH monitoring are downlink symbols if the UE does not detect an SFI-index field value in DCI format 2_0 indicating the set of symbols of the slot as flexible or uplink and the UE does not detect a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, or DCI format 2_3 indicating to the UE to transmit SRS, PUSCH, PUCCH, or PRACH in the set of symbols.

For a set of symbols of a slot that are indicated as flexible by *tdd-UL-DL-ConfigurationCommon*, and *tdd-UL-DL-ConfigurationDedicated* if provided, or when *tdd-UL-DL-ConfigurationCommon*, and *tdd-UL-DL-ConfigurationDedicated* are not provided to the UE, and if the UE does not detect a DCI format 2_0 providing a slot format for the slot

- the UE receives PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 1_0, DCI format 1_1, or DCI format 0_1

- the UE transmits PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, DCI format 2_3, or a RAR UL grant

- the UE receives PDCCH as described in Clause 10.1
- if the UE is configured by higher layers to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE does not receive the PDSCH or the CSI-RS in the set of symbols of the slot
- if the UE is configured by higher layers to transmit SRS, or PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE
  - does not transmit the PUCCH, or the PUSCH, or the PRACH in the slot and does not transmit the SRS in symbols from the set of symbols in the slot, if any, starting from a symbol that is after PUSCH preparation time $T_{\text{proc,2}}$ for the corresponding PUSCH timing capability [6, TS 38.214] assuming $d_{2,1}=1$ after a last symbol of a CORESET where the UE is configured to monitor PDCCH for DCI format 2_0 and μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH carrying the DCI format 2_0 and the SCS configuration of the SRS, PUCCH, PUSCH or μ_r, where μ_r corresponds to the SCS configuration of the PRACH if it is 15kHz or higher; otherwise μ_r=0
  - does not expect to cancel the transmission of the SRS, or the PUCCH, or the PUSCH, or the PRACH in symbols from the set of symbols in the slot, if any, starting before a symbol that is after the PUSCH preparation time $T_{\text{proc,2}}$ for the corresponding PUSCH timing capability [6, TS 38.214] assuming $d_{2,1}=1$ after a last symbol of a CORESET where the UE is configured to monitor PDCCH for DCI format 2_0 and μ corresponds to the smallest SCS configuration between the SCS configuration of the PDCCH carrying the DCI format 2_0 and the SCS configuration of the SRS, PUCCH, PUSCH or μ_r, where μ_r corresponds to the SCS configuration of the PRACH if it is 15kHz or higher; otherwise μ_r=0

For unpaired spectrum operation for a UE on a cell in a frequency band of FR1, and when the scheduling restrictions due to RRM measurements [10, TS 38.133] are not applicable, if the UE detects a DCI format 0_0, DCI format 0_1, DCI format 1_0, DCI format 1_1, or DCI format 2_3 indicating to the UE to transmit in a set of symbols, the UE is not required to perform RRM measurements [10, TS 38.133] based on a SS/PBCH block or CSI-RS reception on a different cell in the frequency band if the SS/PBCH block or CSI-RS reception includes at least one symbol from the set of symbols.

11.2 Interrupted transmission indication

If a UE is provided *DownlinkPreemption*, the UE is configured with an INT-RNTI provided by *int-RNTI* for monitoring PDCCH conveying DCI format 2_1 [5, TS 38.212]. The UE is additionally configured with

- a set of serving cells by *int-ConfigurationPerServingCell* that includes a set of serving cell indexes provided by corresponding *servingCellId* and a corresponding set of locations for fields in DCI format 2_1 by *positionInDCI*
- an information payload size for DCI format 2_1 by *dci-PayloadSize*
- an indication granularity for time-frequency resources by *timeFrequencySet*

If a UE detects a DCI format 2_1 for a serving cell from the configured set of serving cells, the UE may assume that no transmission to the UE is present in PRBs and in symbols that are indicated by the DCI format 2_1, from a set of PRBs and a set of symbols of the last monitoring period. The indication by the DCI format 2_1 is not applicable to receptions of SS/PBCH blocks.

The set of PRBs is equal to the active DL BWP as defined in Clause 12 and includes B_{INT} PRBs.

If a UE detects a DCI format 2_1 in a PDCCH transmitted in a CORESET in a slot, the set of symbols is the last $N_{\text{symb}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$ symbols prior to the first symbol of the CORESET in the slot where T_{INT} is the PDCCH monitoring periodicity provided by the value of *monitoringSlotPeriodicityAndOffset*, as described in Clause 10.1, $N_{\text{symb}}^{\text{slot}}$ is the number of symbols per slot, μ is the SCS configuration for a serving cell with mapping to a respective field in the DCI format 2_1, μ_{INT} is the SCS configuration of the DL BWP where the UE receives the PDCCH with the DCI format 2_1. If the UE is provided *tdd-UL-DL-ConfigurationCommon*, symbols indicated as uplink by *tdd-UL-DL-ConfigurationCommon* are excluded from the last $N_{\text{symb}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$ symbols prior to the first symbol of the CORESET in the slot. The resulting set of symbols includes a number of symbols that is denoted as N_{INT}.

The UE does not expect to be provided values of μ, μ_{INT}, and T_{INT} resulting to a value of $N_{\text{symb}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$ that is not an integer. The UE does not expect to be configured by *monitoringSymbolsWithinSlot* with more than one PDCCH monitoring occasion for DCI format 2_1 in a slot.

A UE is provided the indication granularity for the set of PRBs and for the set of symbols by *timeFrequencySet*.

If the value of *timeFrequencySet* is 'set0', 14 bits from MSB of a field in DCI format 2_1 have a one-to-one mapping with 14 groups of consecutive symbols from the set of symbols where each of the first $N_{\text{INT}} - \lfloor N_{\text{INT}} / 14 \rfloor \cdot 14$ symbol groups includes $\lceil N_{\text{INT}} / 14 \rceil$ symbols, each of the last $14 - N_{\text{INT}} + \lfloor N_{\text{INT}} / 14 \rfloor \cdot 14$ symbol groups includes $\lfloor N_{\text{INT}} / 14 \rfloor$ symbols, a bit value of 0 indicates transmission to the UE in the corresponding symbol group and a bit value of 1 indicates no transmission to the UE in the corresponding symbol group.

If the value of *timeFrequencySet* is 'set1', 7 pairs of bits from MSB of a field in the DCI format 2_1 have a one-to-one mapping with 7 groups of consecutive symbols where each of the first $N_{\text{INT}} - \lfloor N_{\text{INT}} / 7 \rfloor \cdot 7$ symbol groups includes $\lceil N_{\text{INT}} / 7 \rceil$ symbols, each of the last $7 - N_{\text{INT}} + \lfloor N_{\text{INT}} / 7 \rfloor \cdot 7$ symbol groups includes $\lfloor N_{\text{INT}} / 7 \rfloor$ symbols, a first bit in a pair of bits for a symbol group is applicable to the subset of first $\lceil B_{\text{INT}} / 2 \rceil$ PRBs from the set of B_{INT} PRBs, a second bit in the pair of bits for the symbol group is applicable to the subset of last $\lfloor B_{\text{INT}} / 2 \rfloor$ PRBs from the set of B_{INT} PRBs, a bit value of 0 indicates transmission to the UE in the corresponding symbol group and subset of PRBs, and a bit value of 1 indicates no transmission to the UE in the corresponding symbol group and subset of PRBs.

11.3 Group TPC commands for PUCCH/PUSCH

For PUCCH transmission on a serving cell, a UE can be provided

- a TPC-PUCCH-RNTI for a DCI format 2_2 by *tpc-PUCCH-RNTI*
  - a field in DCI format 2_2 is a TPC command of 2 bits mapping to $\delta_{\text{PUCCH},b,f,c}$ values as described in Clause 7.2.1
- an index for a location in DCI format 2_2 of a first bit for a TPC command field for the PCell, or the SpCell for EN-DC operation, or for a carrier of the PCell by *tpc-IndexPCell*
- an index for a location in DCI format 2_2 of a first bit for a TPC command field for the PUCCH-SCell or for a carrier for the PUCCH-SCell by *tpc-IndexPUCCH-Scell*
- a mapping for the PUCCH power control adjustment state $l \in \{0,1\}$, by a corresponding {0, 1} value of a closed loop index field that is appended to the TPC command field in DCI format 2_2 if the UE indicates a capability to support two PUCCH power control adjustment states by *twoDifferentTPC-Loop-PUCCH*, and if the UE is configured for two PUCCH power control adjustment states by *twoPUCCH-PC-AdjustmentStates*

The UE is also provided on a serving cell with a configuration for a search space set s and a corresponding CORESET p for monitoring PDCCH candidates for DCI format 2_2 with CRC scrambled by a TPC-PUCCH-RNTI as described in Clause 10.1.

For PUSCH transmission on a serving cell, a UE can be provided

- a TPC-PUSCH-RNTI for a DCI format 2_2 by *tpc-PUSCH-RNTI*
  - a field in DCI format 2_2 is a TPC command of 2 bits mapping to $\delta_{\text{PUSCH},b,f,c}$ values as described in Clause 7.1.1
- an index for a location in DCI format 2_2 of a first bit for a TPC command field for an uplink carrier of the serving cell by *tpc-Index*
- an index for a location in DCI format 2_2 of a first bit for a TPC command field for a supplementary uplink carrier of the serving cell by *tpc-IndexSUL*
- an index of the serving cell by *targetCell*. If *targetCell* is not provided, the serving cell is the cell of the PDCCH reception for DCI format 2_2

- a mapping for the PUSCH power control adjustment state $l \in \{0,1\}$, by a corresponding {0, 1} value of a closed loop index field that is appended to the TPC command field for the uplink carrier or for the supplementary uplink carrier of the serving cell in DCI format 2_2 if the UE indicates a capability to support two PUSCH power control adjustment states, by *twoDifferentTPC-Loop-PUSCH*, and if the UE is configured for two PUSCH power control adjustment states by *twoPUSCH-PC-AdjustmentStates*

The UE is also provided for the serving cell of the PDCCH reception for DCI format 2_2 with a configuration for a search space set s and a corresponding CORESET p for monitoring PDCCH candidates for DCI format 2_2 with CRC scrambled by a TPC-PUSCH-RNTI as described in Clause 10.1.

11.4 SRS switching

DCI format 2_3 is applicable for uplink carrier(s) of serving cells where a UE is not configured for PUSCH/PUCCH transmission or for uplink carrier(s) of a serving cell where *srs-PowerControlAdjustmentStates* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions.

A UE configured by higher layers with parameter *carrierSwitching* is provided

- a TPC-SRS-RNTI for a DCI format 2_3 by *tpc-SRS-RNTI*
- an index of a serving cell where the UE interrupts transmission in order to transmit SRS on one or more other serving cells by *srs-SwitchFromServCellIndex*
- an indication of an uplink carrier where the UE interrupts transmission in order to transmit SRS on one or more other serving cells by *srs-SwitchFromCarrier*
- a DCI format 2_3 field configuration type by *typeA* or *typeB*
  - for *typeA*, an index for a set of serving cells is provided by *cc-SetIndex*, indexes of serving cells in the set of serving cells are provided by *cc-IndexInOneCC-Set*, and a DCI format 2_3 field includes a TPC command for each serving cell from the set of serving cells and can also include a SRS request for SRS transmission on the set of serving cells
  - for *typeB*, DCI format 2_3 field includes a TPC command for a serving cell index and can also include a SRS request for SRS transmission on the serving cell
- an indication for a serving cell for whether or not a field in DCI format 2_3 includes a SRS request by *fieldTypeFormat2-3* where a value of 0/1 indicates absence/presence of the SRS request – a mapping for a 2 bit SRS request to SRS resource sets is as provided in [6, TS 38.214]
- an index for a location in DCI format 2_3 of a first bit for a field for a non-supplementary uplink carrier of the serving cell by *startingBitOfFormat2-3*
- an index for a location in DCI format 2_3 of a first bit for a field for a supplementary uplink carrier of the serving cell by *startingBitOfFormat2-3SUL-v1530*

12 Bandwidth part operation

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG

- When the procedures are applied for MCG, the terms 'secondary cell', 'secondary cells' , 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms 'secondary cell', 'secondary cells', 'serving cell', 'serving cells' in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term 'primary cell' in this clause refers to the PSCell of the SCG.

A UE configured for operation in bandwidth parts (BWPs) of a serving cell, is configured by higher layers for the serving cell a set of at most four bandwidth parts (BWPs) for receptions by the UE (DL BWP set) in a DL bandwidth by parameter *BWP-Downlink* or by parameter *initialDownlinkBWP* with a set of parameters configured by *BWP-*

DownlinkCommon and *BWP-DownlinkDedicated*, and a set of at most four BWPs for transmissions by the UE (UL BWP set) in an UL bandwidth by parameter *BWP-Uplink* or by parameter *initialUplinkBWP* with a set of parameters configured by *BWP-UplinkCommon* and *BWP-UplinkDedicated*.

If a UE is not provided *initialDownlinkBWP*, an initial DL BWP is defined by a location and number of contiguous PRBs, starting from a PRB with the lowest index and ending at a PRB with the highest index among PRBs of a CORESET for Type0-PDCCH CSS set, and a SCS and a cyclic prefix for PDCCH reception in the CORESET for Type0-PDCCH CSS set; otherwise, the initial DL BWP is provided by *initialDownlinkBWP*. For operation on the primary cell or on a secondary cell, a UE is provided an initial UL BWP by *initialUplinkBWP*. If the UE is configured with a supplementary UL carrier, the UE can be provided an initial UL BWP on the supplementary UL carrier by *initialUplinkBWP*.

If a UE has dedicated BWP configuration, the UE can be provided by *firstActiveDownlinkBWP-Id* a first active DL BWP for receptions and by *firstActiveUplinkBWP-Id* a first active UL BWP for transmissions on a carrier of the primary cell.

For each DL BWP or UL BWP in a set of DL BWPs or UL BWPs, respectively, the UE is provided the following parameters for the serving cell as defined in [4, TS 38.211] or [6, TS 38.214]:

- a SCS by *subcarrierSpacing*
- a cyclic prefix by *cyclicPrefix*
- a common RB $N_{\text{BWP}}^{\text{start}} = O_{\text{carrier}} + RB_{\text{start}}$ and a number of contiguous RBs $N_{\text{BWP}}^{\text{size}} = L_{\text{RB}}$ provided by *locationAndBandwidth* that indicates an offset RB_{start} and a length L_{RB} as RIV according to [6, TS 38.214], setting $N_{\text{BWP}}^{\text{size}} = 275$, and a value O_{carrier} provided by *offsetToCarrier* for the *subcarrierSpacing*
- an index in the set of DL BWPs or UL BWPs by respective *BWP-Id*
- a set of BWP-common and a set of BWP-dedicated parameters by *BWP-DownlinkCommon* and *BWP-DownlinkDedicated* for the DL BWP, or *BWP-UplinkCommon* and *BWP-UplinkDedicated* for the UL BWP [12, TS 38.331]

For unpaired spectrum operation, a DL BWP from the set of configured DL BWPs with index provided by *BWP-Id* is linked with an UL BWP from the set of configured UL BWPs with index provided by *BWP-Id* when the DL BWP index and the UL BWP index are same. For unpaired spectrum operation, a UE does not expect to receive a configuration where the center frequency for a DL BWP is different than the center frequency for an UL BWP when the *BWP-Id* of the DL BWP is same as the *BWP-Id* of the UL BWP.

For each DL BWP in a set of DL BWPs of the PCell, or of the PUCCH-SCell, a UE can be configured CORESETs for every type of CSS sets and for USS as described in Clause 10.1. The UE does not expect to be configured without a CSS set on the PCell, or on the PUCCH-SCell, of the MCG in the active DL BWP.

If a UE is provided *controlResourceSetZero* and *searchSpaceZero* in *PDCCH-ConfigSIB1* or *PDCCH-ConfigCommon*, the UE determines a CORESET for a search space set from *controlResourcesetZero* as described in Clause 13 and for Tables 13-1 through 13-10, and determines corresponding PDCCH monitoring occasions as described in Clause 13 and for Tables 13-11 through 13-15. If the active DL BWP is not the initial DL BWP, the UE determines PDCCH monitoring occasions for the search space set only if the CORESET bandwidth is within the active DL BWP and the active DL BWP has same SCS configuration and same cyclic prefix as the initial DL BWP.

For each UL BWP in a set of UL BWPs of the PCell or of the PUCCH-SCell, the UE is configured resource sets for PUCCH transmissions as described in Clause 9.2.1.

A UE receives PDCCH and PDSCH in a DL BWP according to a configured SCS and CP length for the DL BWP. A UE transmits PUCCH and PUSCH in an UL BWP according to a configured SCS and CP length for the UL BWP.

If a bandwidth part indicator field is configured in DCI format 1_1, the bandwidth part indicator field value indicates the active DL BWP, from the configured DL BWP set, for DL receptions as described in [5, TS 38.212]. If a bandwidth part indicator field is configured in DCI format 0_1, the bandwidth part indicator field value indicates the active UL BWP, from the configured UL BWP set, for UL transmissions as described in [5, TS 38.212]. If a bandwidth part indicator field is configured in DCI format 0_1 or DCI format 1_1 and indicates an UL BWP or a DL BWP different from the active UL BWP or DL BWP, respectively, the UE shall

- for each information field in the received DCI format 0_1 or DCI format 1_1
  - if the size of the information field is smaller than the one required for the DCI format 0_1 or DCI format 1_1 interpretation for the UL BWP or DL BWP that is indicated by the bandwidth part indicator, respectively, the UE prepends zeros to the information field until its size is the one required for the interpretation of the information field for the UL BWP or DL BWP prior to interpreting the DCI format 0_1 or DCI format 1_1 information fields, respectively
  - if the size of the information field is larger than the one required for the DCI format 0_1 or DCI format 1_1 interpretation for the UL BWP or DL BWP that is indicated by the bandwidth part indicator, respectively, the UE uses a number of least significant bits of DCI format 0_1 or DCI format 1_1 equal to the one required for the UL BWP or DL BWP indicated by bandwidth part indicator prior to interpreting the DCI format 0_1 or DCI format 1_1 information fields, respectively
- set the active UL BWP or DL BWP to the UL BWP or DL BWP indicated by the bandwidth part indicator in the DCI format 0_1 or DCI format 1_1, respectively

A UE does not expect to detect a DCI format 1_1 or a DCI format 0_1 indicating respectively an active DL BWP or an active UL BWP change with the corresponding time domain resource assignment field providing a slot offset value for a PDSCH reception or PUSCH transmission that is smaller than a delay required by the UE for an active DL BWP change or UL BWP change [10, TS 38.133].

If a UE detects a DCI format 1_1 indicating an active DL BWP change for a cell, the UE is not required to receive or transmit in the cell during a time duration from the end of the third symbol of a slot where the UE receives the PDCCH that includes the DCI format 1_1 in a scheduling cell until the beginning of a slot indicated by the slot offset value of the time domain resource assignment field in the DCI format 1_1.

If a UE detects a DCI format 0_1 indicating an active UL BWP change for a cell, the UE is not required to receive or transmit in the cell during a time duration from the end of the third symbol of a slot where the UE receives the PDCCH that includes the DCI format 0_1 in the scheduling cell until the beginning of a slot indicated by the slot offset value of the time domain resource assignment field in the DCI format 0_1.

A UE does not expect to detect a DCI format 1_1 indicating an active DL BWP change or a DCI format 0_1 indicating an active UL BWP change for a scheduled cell within FR1 (or FR2) in a slot other than the first slot of a set of slots for the DL SCS of the scheduling cell that overlaps with a time duration where the UE is not required to receive or transmit for an active BWP change in a different cell from the scheduled cell within FR1 (or FR2).

A UE expects to detect a DCI format 0_1 indicating active UL BWP change, or a DCI format 1_1 indicating active DL BWP change, only if a corresponding PDCCH is received within the first 3 symbols of a slot.

For a serving cell, a UE can be provided by *defaultDownlinkBWP-Id* a default DL BWP among the configured DL BWPs. If a UE is not provided a default DL BWP by *defaultDownlinkBWP-Id*, the default DL BWP is the initial DL BWP.

If a UE is provided by *bwp-InactivityTimer* a timer value for the serving cell [11, TS 38.321] and the timer is running, the UE decrements the timer at the end of a subframe for FR1 or at the end of a half subframe for FR2 if the restarting conditions in [11, TS 38.321] are not met during the interval of the subframe for FR1 or of the half subframe for FR2.

For a cell where a UE changes an active DL BWP due to a BWP inactivity timer expiration and for accommodating a delay in the active DL BWP change or the active UL BWP change required by the UE [10, TS 38.133], the UE is not required to receive or transmit in the cell during a time duration from the beginning of a subframe for FR1, or of half of a subframe for FR2, that is immediately after the BWP inactivity timer expires until the beginning of a slot where the UE can receive or transmit.

When a UE's BWP inactivity timer for a cell within FR1 (or FR2) expires within a time duration where the UE is not required to receive or transmit for an active UL/DL BWP change in the cell or in a different cell within FR1 (or FR2), the UE delays the active UL/DL BWP change triggered by the BWP inactivity timer expiration until a subframe for FR1 or half a subframe for FR2 that is immediately after the UE completes the active UL/DL BWP change in the cell or in the different cell within FR1 (or FR2).

If a UE is provided by *firstActiveDownlinkBWP-Id* a first active DL BWP and by *firstActiveUplinkBWP-Id* a first active UL BWP on a carrier of a secondary cell, the UE uses the indicated DL BWP and the indicated UL BWP as the respective first active DL BWP on the secondary cell and first active UL BWP on the carrier of the secondary cell.

A UE does not expect to monitor PDCCH when the UE performs RRM measurements [10, TS 38.133] over a bandwidth that is not within the active DL BWP for the UE.

13 UE procedure for monitoring Type0-PDCCH CSS sets

If during cell search a UE determines from *MIB* that a CORESET for Type0-PDCCH CSS set is present, as described in Clause 4.1, the UE determines a number of consecutive resource blocks and a number of consecutive symbols for the CORESET of the Type0-PDCCH CSS set from *controlResourceSetZero* in *pdcch-ConfigSIB1*, as described in Tables 13-1 through 13-10, and determines PDCCH monitoring occasions from *searchSpaceZero* in *pdcch-ConfigSIB1*, included in *MIB*, as described in Tables 13-11 through 13-15. SFN_C and n_C are the SFN and slot index within a frame of the CORESET based on SCS of the CORESET and $\text{SFN}_{\text{SSB},i}$ and $n_{\text{SSB},i}$ are the SFN and slot index based on SCS of the CORESET, respectively, where the SS/PBCH block with index i overlaps in time with system frame $\text{SFN}_{\text{SSB},i}$ and slot $n_{\text{SSB},i}$. The symbols of the CORESET associated with *pdcch-ConfigSIB1* in *MIB* or with *searchSpaceSIB1* in *PDCCH-ConfigCommon* have normal cyclic prefix.

The offset in Tables 13-1 through 13-10 is defined with respect to the SCS of the CORESET for Type0-PDCCH CSS set, provided by *subCarrierSpacingCommon*, from the smallest RB index of the CORESET for Type0-PDCCH CSS set to the smallest RB index of the common RB overlapping with the first RB of the corresponding SS/PBCH block. In Tables 13-7, 13-8, and 13-10 k_{SSB} is defined in [4, TS 38.211].

For the SS/PBCH block and CORESET multiplexing pattern 1, a UE monitors PDCCH in the Type0-PDCCH CSS set over two consecutive slots starting from slot n_0. For SS/PBCH block with index i, the UE determines an index of slot n_0 as $n_0 = \left(O \cdot 2^\mu + \lfloor i \cdot M \rfloor\right) \text{mod} N_{\text{slot}}^{\text{frame},\mu}$ located in a frame with system frame number (SFN) SFN_C satisfying $\text{SFN}_\text{C} \bmod 2 = 0$ if $\lfloor \left(O \cdot 2^\mu + \lfloor i \cdot M \rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \rfloor \bmod 2 = 0$ or in a frame with SFN satisfying $\text{SFN}_\text{C} \bmod 2 = 1$ if $\lfloor \left(O \cdot 2^\mu + \lfloor i \cdot M \rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \rfloor \bmod 2 = 1$. M and O are provided by Tables 13-11 and 13-12, and $\mu \in \{0,1,2,3\}$ based on the SCS for PDCCH receptions in the CORESET [4, TS 38.211]. The index for the first symbol of the CORESET in slots n_0 and $n_0 + 1$ is the first symbol index provided by Tables 13-11 and 13-12.

For the SS/PBCH block and CORESET multiplexing patterns 2 and 3, a UE monitors PDCCH in the Type0-PDCCH CSS set over one slot with Type0-PDCCH CSS set periodicity equal to the periodicity of SS/PBCH block. For the SS/PBCH block and CORESET multiplexing patterns 2 and 3, if the active DL BWP is the initial DL BWP, the UE is expected to be able to perform radio link monitoring, as described in Clause 5, and measurements for radio resource management [10, TS 38.133] using a SS/PBCH block that provides a CORESET for Type0-PDCCH CSS set. For a SS/PBCH block with index i, the UE determines the slot index n_C and SFN_C based on parameters provided by Tables 13-13 through 13-15.

Table 13-1: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {15, 15} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	2
2	1	24	2	4
3	1	24	3	0
4	1	24	3	2
5	1	24	3	4
6	1	48	1	12
7	1	48	1	16
8	1	48	2	12
9	1	48	2	16
10	1	48	3	12
11	1	48	3	16
12	1	96	1	38
13	1	96	2	38
14	1	96	3	38
15	Reserved			

Table 13-2: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {15, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	24	2	5
1	1	24	2	6
2	1	24	2	7
3	1	24	2	8
4	1	24	3	5
5	1	24	3	6
6	1	24	3	7
7	1	24	3	8
8	1	48	1	18
9	1	48	1	20
10	1	48	2	18
11	1	48	2	20
12	1	48	3	18
13	1	48	3	20
14	Reserved			
15	Reserved			

Table 13-3: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {30, 15} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	Offset (RBs)
0	1	48	1	2
1	1	48	1	6
2	1	48	2	2
3	1	48	2	6
4	1	48	3	2
5	1	48	3	6
6	1	96	1	28
7	1	96	2	28
8	1	96	3	28
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-4: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {30, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	1
2	1	24	2	2
3	1	24	2	3
4	1	24	2	4
5	1	24	3	0
6	1	24	3	1
7	1	24	3	2
8	1	24	3	3
9	1	24	3	4
10	1	48	1	12
11	1	48	1	14
12	1	48	1	16
13	1	48	2	12
14	1	48	2	14
15	1	48	2	16

Table 13-5: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {30, 15} kHz for frequency bands with minimum channel bandwidth 40MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESE}}$	Offset (RBs)
0	1	48	1	4
1	1	48	2	4
2	1	48	3	4
3	1	96	1	0
4	1	96	1	56
5	1	96	2	0
6	1	96	2	56
7	1	96	3	0
8	1	96	3	56
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-6: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {30, 30} kHz for frequency bands with minimum channel bandwidth 40MHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	4
2	1	24	3	0
3	1	24	3	4
4	1	48	1	0
5	1	48	1	28
6	1	48	2	0
7	1	48	2	28
8	1	48	3	0
9	1	48	3	28
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-7: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {120, 60} kHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	48	1	0
1	1	48	1	8
2	1	48	2	0
3	1	48	2	8
4	1	48	3	0
5	1	48	3	8
6	1	96	1	28
7	1	96	2	28
8	2	48	1	-41 if $k_{\mathrm{SSB}}=0$ -42 if $k_{\mathrm{SSB}}>0$
9	2	48	1	49
10	2	96	1	-41 if $k_{\mathrm{SSB}}=0$ -42 if $k_{\mathrm{SSB}}>0$
11	2	96	1	97
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-8: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {120, 120} kHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	4
2	1	48	1	14
3	1	48	2	14
4	3	24	2	-20 if $k_{\mathrm{SSB}}=0$ -21 if $k_{\mathrm{SSB}}>0$
5	3	24	2	24
6	3	48	2	-20 if $k_{\mathrm{SSB}}=0$ -21 if $k_{\mathrm{SSB}}>0$
7	3	48	2	48
8	Reserved			
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-9: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {240, 60} kHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	96	1	0
1	1	96	1	16
2	1	96	2	0
3	1	96	2	16
4	Reserved			
5	Reserved			
6	Reserved			
7	Reserved			
8	Reserved			
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-10: Set of resource blocks and slot symbols of CORESET for Type0-PDCCH search space set when {SS/PBCH block, PDCCH} SCS is {240, 120} kHz

Index	SS/PBCH block and CORESET multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Offset (RBs)
0	1	48	1	0
1	1	48	1	8
2	1	48	2	0
3	1	48	2	8
4	2	24	1	-41 if $k_{\mathrm{SSB}}=0$ -42 if $k_{\mathrm{SSB}}>0$
5	2	24	1	25
6	2	48	1	-41 if $k_{\mathrm{SSB}}=0$ -42 if $k_{\mathrm{SSB}}>0$
7	2	48	1	49
8	Reserved			
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

Table 13-11: Parameters for PDCCH monitoring occasions for Type0-PDCCH CSS set - SS/PBCH block and CORESET multiplexing pattern 1 and FR1

Index	O	Number of search space sets per slot	M	First symbol index
0	0	1	1	0
1	0	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
2	2	1	1	0
3	2	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
4	5	1	1	0
5	5	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
6	7	1	1	0
7	7	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
8	0	1	2	0
9	5	1	2	0
10	0	1	1	1
11	0	1	1	2
12	2	1	1	1
13	2	1	1	2
14	5	1	1	1
15	5	1	1	2

Table 13-12: Parameters for PDCCH monitoring occasions for Type0-PDCCH CSS set - SS/PBCH block and CORESET multiplexing pattern 1 and FR2

Index	O	Number of search space sets per slot	M	First symbol index
0	0	1	1	0
1	0	2	1/2	{0, if i is even}, {7, if i is odd}
2	2.5	1	1	0
3	2.5	2	1/2	{0, if i is even}, {7, if i is odd}
4	5	1	1	0
5	5	2	1/2	{0, if i is even}, {7, if i is odd}
6	0	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
7	2.5	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
8	5	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
9	7.5	1	1	0
10	7.5	2	1/2	{0, if i is even}, {7, if i is odd}
11	7.5	2	1/2	{0, if i is even}, { $N_{\text{symb}}^{\text{CORESET}}$, if i is odd}
12	0	1	2	0
13	5	1	2	0
14	Reserved			
15	Reserved			

Table 13-13: PDCCH monitoring occasions for Type0-PDCCH CSS set - SS/PBCH block and CORESET multiplexing pattern 2 and {SS/PBCH block, PDCCH} SCS {120, 60} kHz

Index	PDCCH monitoring occasions (SFN and slot number)	First symbol index (k = 0, 1, … 15)
0	$\text{SFN}_\text{C} = \text{SFN}_{\text{SSB},i}$ $n_\text{C} = n_{\text{SSB},i}$	0, 1, 6, 7 for $i = 4k$, $i = 4k+1$, $i = 4k+2$, $i = 4k+3$
1	Reserved	
2	Reserved	
3	Reserved	
4	Reserved	
5	Reserved	
6	Reserved	
7	Reserved	
8	Reserved	
9	Reserved	
10	Reserved	
11	Reserved	
12	Reserved	
13	Reserved	
14	Reserved	
15	Reserved	

Table 13-14: PDCCH monitoring occasions for Type0-PDCCH CSS set - SS/PBCH block and CORESET multiplexing pattern 2 and {SS/PBCH block, PDCCH} SCS {240, 120} kHz

Index	PDCCH monitoring occasions (SFN and slot number)	First symbol index (k = 0, 1, …, 7)
0	$\text{SFN}_\text{C} = \text{SFN}_{\text{SSB},i}$ $n_\text{C} = n_{\text{SSB},i}$ or $n_\text{C} = n_{\text{SSB},i} - 1$	0, 1, 2, 3, 0, 1 in $i = 8k$, $i = 8k+1$, $i = 8k+2$, $i = 8k+3$, $i = 8k+6$, $i = 8k+7$ ($n_\text{C} = n_{\text{SSB},i}$) 12, 13 in $i = 8k+4$, $i = 8k+5$ ($n_\text{C} = n_{\text{SSB},i} - 1$)
1	Reserved	
2	Reserved	
3	Reserved	
4	Reserved	
5	Reserved	
6	Reserved	
7	Reserved	
8	Reserved	
9	Reserved	
10	Reserved	
11	Reserved	
12	Reserved	
13	Reserved	
14	Reserved	
15	Reserved	

Table 13-15: PDCCH monitoring occasions for Type0-PDCCH CSS set - SS/PBCH block and CORESET multiplexing pattern 3 and {SS/PBCH block, PDCCH} SCS {120, 120} kHz

Index	PDCCH monitoring occasions (SFN and slot number)	First symbol index (k = 0, 1, … 15)
0	$\text{SFN}_\text{C} = \text{SFN}_{\text{SSB},i}$ $n_\text{C} = n_{\text{SSB},i}$	4, 8, 2, 6 in $i = 4k$, $i = 4k+1$, $i = 4k+2$, $i = 4k+3$
1	Reserved	
2	Reserved	
3	Reserved	
4	Reserved	
5	Reserved	
6	Reserved	
7	Reserved	
8	Reserved	
9	Reserved	
10	Reserved	
11	Reserved	
12	Reserved	
13	Reserved	
14	Reserved	
15	Reserved	

If a UE detects a first SS/PBCH block and determines that a CORESET for Type0-PDCCH CSS set is not present, and for $24 \le k_{\text{SSB}} \le 29$ for FR1 or for $12 \le k_{\text{SSB}} \le 13$ for FR2, the UE may determine the nearest (in the corresponding frequency direction) global synchronization channel number (GSCN) of a second SS/PBCH block having a CORESET for an associated Type0-PDCCH CSS set as $N_{\text{GSCN}}^{\text{Reference}} + N_{\text{GSCN}}^{\text{Offset}}$. $N_{\text{GSCN}}^{\text{Reference}}$ is the GSCN of the first SS/PBCH block and $N_{\text{GSCN}}^{\text{Offset}}$ is a GSCN offset provided by Table 13-16 for FR1 and Table 13-17 for FR2. If the UE detects the second SS/PBCH block and the second SS/PBCH block does not provide a CORESET for Type0-PDCCH CSS set, as described in Clause 4.1, the UE may ignore the information related to GSCN of SS/PBCH block locations for performing cell search.

If a UE detects a SS/PBCH block and determines that a CORESET for Type0-PDCCH CSS set is not present, and for $k_{\text{SSB}} = 31$ for FR1 or for $k_{\text{SSB}} = 15$ for FR2, the UE determines that there is no SS/PBCH block having an associated Type0-PDCCH CSS set within a GSCN range $[N_{\text{GSCN}}^{\text{Reference}} - N_{\text{GSCN}}^{\text{Start}}, N_{\text{GSCN}}^{\text{Reference}} + N_{\text{GSCN}}^{\text{End}}]$. $N_{\text{GSCN}}^{\text{Start}}$ and $N_{\text{GSCN}}^{\text{End}}$ are respectively determined by *controlResourceSetZero* and *searchSpaceZero* in *pdcch-ConfigSIB1*. If the GSCN range is $[N_{\text{GSCN}}^{\text{Reference}}, N_{\text{GSCN}}^{\text{Reference}}]$, the UE determines that there is no information for a second SS/PBCH block with a CORESET for an associated Type0-PDCCH CSS set on the detected SS/PBCH block.

If a UE does not detect any SS/PBCH block providing a CORESET for Type0-PDCCH CSS set, as described in Clause 4.1, within a time period determined by the UE, the UE may ignore the information related to GSCN of SS/PBCH locations in performing cell search.

Table 13-16: Mapping between the combination of k_{SSB} and *controlResourceSetZero* and *searchSpaceZero* in *pdcch-ConfigSIB1* to N_{GSCN}^{Offset} for FR1

k_{SSB}	*16×controlResourceSetZero +searchSpaceZero*	N_{GSCN}^{Offset}
24	0, 1, …, 255	1, 2, …, 256
25	0, 1, …, 255	257, 258, …, 512
26	0, 1, …, 255	513, 514, …., 768
27	0, 1, …, 255	-1, -2, …, -256
28	0, 1, …, 255	-257, -258, …, -512
29	0, 1, …, 255	-513, -514, …., -768
30	0, 1, …, 255	Reserved, Reserved, …, Reserved

Table 13-17: Mapping between the combination of k_{SSB} and *controlResourceSetZero* and *searchSpaceZero* in *pdcch-ConfigSIB1* to N_{GSCN}^{Offset} for FR2

k_{SSB}	*16×controlResourceSetZero +searchSpaceZero*	N_{GSCN}^{Offset}
12	0, 1, …, 255	1, 2, …, 256
13	0, 1, …, 255	-1, -2, …, -256
14	0, 1, …, 255	Reserved, Reserved, …, Reserved

Annex A:
Change history

Date	TSG #	TSG Doc.	CR	Rev	Cat	Subject/Comment	New version
2017-04	RAN1#89	R1-1707925				Draft skeleton	0.0.0
2017-07	AH_NR2	R1-1712015				Inclusion of agreements until RAN1-adhoc#2	0.0.1
2017-08	RAN1#90	R1-1714553				Inclusion of agreements on CA and first revisions	0.0.2
2017-08	RAN1#90	R1-1714565				Second revisions	0.0.3
2017-08	RAN1#90	R1-1714658				Endorsed by RAN1#90	0.1.0
2017-08	RAN1#90	R1-1715323				Inclusion of agreements from RAN1#90	0.1.1
2017-08	RAN1#90	R1-1715330				Updated editor's version	0.1.2
2017-09	RAN#77	RP-171995				For information to plenary	1.0.0
2017-09	RAN1#90bis	R1-1716929				Inclusion of agreements until RAN1-adhoc#3	1.0.1
2017-10	RAN1#90bis	R1-1719107				Endorsed by RAN1#90bis	1.1.0
2017-11	RAN1#90bis	R1-1719226				Inclusion of agreements from RAN1#90bis	1.1.1
2017-11	RAN1#90bis	R1-1719243				Updated editor's version	1.1.2
2017-11	RAN1#90bis	R1-1721050				Endorsed by RAN1#90bis	1.2.0
2017-12	RAN1#91	R1-1721343				Inclusion of agreements from RAN1#91	1.3.0
2017-12	RAN#78	RP-172703				Endorsed version for approval by plenary	2.0.0
2017-12	RAN#78					Approved by plenary – Rel-15 spec under change control	15.0.0
2018-03	RAN#79	RP-180200	0001	-	F	CR capturing the NR ad-hoc 1801 and RAN1#92 meeting agreements	15.1.0
2018-06	RAN#80	RP-181172	0002	1	F	CR to TS 38.213 capturing the RAN1#92bis and RAN1#93 meeting agreements and aligning higher layer parameters with TS 38.331	15.2.0
2018-09	RAN#81	RP-181789	0005	-	F	CR to 38.213 capturing the RAN1#94 meeting agreements	15.3.0
2018-09	RAN#81	RP-182071	0006	-	C	Support maximum 8 SS/PBCH blocks for unpaired spectrum beyond 2.4GHz	15.3.0
2018-12	RAN#82	RP-182523	0007	2	F	Combined CR of all essential corrections to 38.213 from RAN1#94bis and RAN1#95.	15.4.0
2019-03	RAN#83	RP-190449	0009	-	F	Correction on search space sharing	15.5.0
2019-03	RAN#83	RP-190449	0010	-	F	CR on timing adjustment indicator	15.5.0
2019-03	RAN#83	RP-190449	0011	-	F	CR on SSB-RO association	15.5.0
2019-03	RAN#83	RP-190449	0012	-	F	Removal of CSI request in RAR grant	15.5.0
2019-03	RAN#83	RP-190449	0014	-	F	Correction to dynamic HARQ codebook in NR	15.5.0
2019-03	RAN#83	RP-190449	0015	1	F	Correcttions to TS 38.213	15.5.0
2019-03	RAN#83	RP-190449	0016	-	F	CR on simultaneous active BWP switching across carriers	15.5.0
2019-03	RAN#83	RP-190449	0017	-	F	CR on using CORESET#0 in dedicated DL BWP	15.5.0
2019-03	RAN#83	RP-190449	0018	-	F	PDCCH monitoring for overlapped CORESETs	15.5.0
2019-03	RAN#83	RP-190449	0019	-	F	Correction to last PUCCH resource set configuration	15.5.0
2019-03	RAN#83	RP-190449	0020	-	F	Correction on physical downlink control channel	15.5.0
2019-03	RAN#83	RP-190449	0021	-	F	Correction to align RAN1 and RAN4 specifications for EN-DC power control	15.5.0
2019-03	RAN#83	RP-190449	0022	-	F	(Late Drop) CR on PRACH Power Ramping Counter Suspension	15.5.0
2019-03	RAN#83	RP-190449	0023	-	F	QCL properties of Msg4 in CONNECTED Mode	15.5.0
2019-03	RAN#83	RP-190449	0024	-	F	CR on latency after gNB response for recovery	15.5.0
2019-03	RAN#83	RP-190449	0025	-	F	Clarifying DL reception and UL transmision related restrictions	15.5.0
2019-03	RAN#83	RP-190449	0026	-	F	CR on QCL assumption for receiving PDCCH for RAR	15.5.0
2019-03	RAN#83	RP-190449	0027	-	F	CR on identifying transmission occasion after resetting a PC closed loop	15.5.0
2019-03	RAN#83	RP-190449	0028	-	F	CR on overlapping of CSI and PUSCH with slot aggregation	15.5.0
2019-03	RAN#83	RP-190449	0029	-	F	Correction on PHR timing for configured grant	15.5.0
2019-03	RAN#83	RP-190449	0030	-	F	CR on QCL assumption for a CORESET other than 0	15.5.0
2019-03	RAN#83	RP-190449	0031	-	F	Correction on DCI format 2_3 for SUL cell in TS 38.213	15.5.0
2019-03	RAN#83	RP-190449	0032	-	F	Correction to support FR1 extension to 7.125 GHz	15.5.0
2019-03	RAN#83	RP-190449	0033	-	F	CR on UE procedure for reporting multiple UCI types	15.5.0
2019-03	RAN#83	RP-190449	0034	-	F	Correction to transmission timing adjustments in TS 38.213	15.5.0
2019-06	RAN#84	RP-191283	0035	-	F	CR on missing case for DCI format 1_1 with CS-RNTI	15.6.0
2019-06	RAN#84	RP-191283	0036	1	F	CR on the determination of the minimum number of PRBs for PUCCH transmission	15.6.0

2019-06	RAN#84	RP-191283	0037	-	F	CR on PHR determination and transmission	15.6.0
2019-06	RAN#84	RP-191283	0038	4	F	Corrections to 38.213 including alignment of terminology across specifications	15.6.0
2019-06	RAN#84	RP-191283	0039	1	F	Correction on PUSCH power scaling	15.6.0
2019-06	RAN#84	RP-191283	0040	-	F	Correction on PDCCH monitoring	15.6.0
2019-06	RAN#84	RP-191283	0041	-	F	Correction on CRC assumption for multi-CSI resource selection and CSI report(s) selection	15.6.0
2019-06	RAN#84	RP-191283	0042	-	F	Clarification of reference to PDSCH processing capability 1 in TS 38.213	15.6.0
2019-06	RAN#84	RP-191283	0043	-	F	Correction on the timeline condition of multiplexing two HARQ-ACK information in one slot	15.6.0
2019-06	RAN#84	RP-191283	0044	-	F	CR on Type-1 HARQ-ACK codebook determination	15.6.0
2019-06	RAN#84	RP-191283	0045	-	F	Correction on PHR in EN-DC	15.6.0
2019-06	RAN#84	RP-191283	0046	-	F	CR to 38.213 on deactivation timing for ScellDeactivationTimer	15.6.0
2019-06	RAN#84	RP-191283	0047	-	F	CR on single transmission timing for synchronous intra-band EN-DC	15.6.0
2019-06	RAN#84	RP-191283	0048	-	F	CR on PDCCH Monitoring for NR-DC	15.6.0
2019-06	RAN#84	RP-191283	0049	-	F	CR on Timing for MAC CE Applicability	15.6.0
2019-09	RAN#85	RP-191942	0051	-	F	Correction on RA procedure triggered by higher layers	15.7.0
2019-09	RAN#85	RP-191942	0052	1	F	CR on UE procedure for reporting multiple UCI types	15.7.0
2019-09	RAN#85	RP-191942	0053	-	F	CR to 38.213 fix to HARQ-ACK Type-1 codebook pseudo-code	15.7.0
2019-09	RAN#85	RP-191942	0054	-	F	CR to 38.213 on clarification of the RNTI used for scrambling a PUSCH transmission scheduled by RAR UL grant	15.7.0
2019-09	RAN#85	RP-191942	0055	2	F	Corrections to 38.213 including alignment of terminology across specifications in RAN1#98	15.7.0
2019-09	RAN#85	RP-191942	0056	-	F	Correction on intra-band EN-DC with single TAG	15.7.0
2019-09	RAN#85	RP-191942	0057	-	F	Correction on PHR in EN-DC/NE-DC/NR-CA	15.7.0
2019-09	RAN#85	RP-191942	0058	-	F	Correction on the time gap definition	15.7.0
2019-09	RAN#85	RP-191942	0059	-	F	Correction on slot configuration	15.7.0
2019-09	RAN#85	RP-191942	0060	-	F	CR to 38.213 on PUCCH configuration for NR-DC	15.7.0
2019-09	RAN#85	RP-191942	0061	-	F	Correction on PUCCH power control	15.7.0
2019-12	RAN#86	RP-192626	0062	1	F	CR on beta_offset values for UCI reporting in PUSCH	15.8.0
2019-12	RAN#86	RP-192626	0063	-	F	Correction on RACH occasion	15.8.0
2019-12	RAN#86	RP-192626	0064	-	F	Correction on HARQ-ACK transmission with BWP change	15.8.0
2019-12	RAN#86	RP-192626	0065	-	F	CR on slot configuration regarding PUSCH scheduled by RAR	15.8.0
2019-12	RAN#86	RP-192626	0066	-	F	Correction on power control for NE-DC	15.8.0
2019-12	RAN#86	RP-192626	0067	-	F	Correction on time gap definition for HARQ-ACK transmission	15.8.0
2019-12	RAN#86	RP-192626	0068	-	F	Correction on time gap definition for random access procedure	15.8.0
2019-12	RAN#86	RP-192626	0069	3	F	Corrections to 38.213 including alignment of terminology across specifications in RAN1#98bis and RAN1#99	15.8.0
2020-03	RAN#87-e	RP-200181	0096	-	F	Corrections to 38.213 including alignment of terminology across specifications in RAN1#100-e	15.9.0
2020-06	RAN#88-e	RP-200683	0101	-	F	Correction on PDCCH Blind Detection for NR-DC	15.10.0
2020-06	RAN#88-e	RP-201348	0116	1	F	Extending 8 SSB support to the newly introduced 30 kHz Case C SSB pattern on band n40	15.10.0

History

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V15.2.0	July 2018	Publication
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