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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"

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].

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].

BWP	Bandwidth part
CB	Code block
CBG	Code block group
CCE	Control channel element
CP	Cyclic prefix
CRC	Cyclic redundancy check
CSI	Channel state information
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
FR	Frequency range
GSCN	Global synchronization channel number
HARQ-ACK	Hybrid automatic repeat request acknowledgement
MCG	Master cell group
MCS	Modulation and coding scheme
NN-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-collocation
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
SFN	System frame number
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
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel

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 the 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 subcarrier spacing 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 subcarrier spacing: 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 larger than 3 GHz and smaller than or equal to 6 GHz, $n = 0, 1, 2, 3$.

- Case B - 30 kHz subcarrier spacing: 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 larger than 3 GHz and smaller than or equal to 6 GHz, $n = 0, 1$.

- Case C - 30 kHz subcarrier spacing: 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 larger than 3 GHz and smaller than or equal to 6 GHz, $n = 0, 1, 2, 3$.

  - For unpaired spectrum operation

    - For carrier frequencies smaller than or equal to 2.4 GHz, $n = 0, 1$. For carrier frequencies larger than 2.4 GHz and smaller than or equal to 6 GHz, $n = 0, 1, 2, 3$.

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

- Case E - 240 kHz subcarrier spacing: 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 larger than 6 GHz, $n = 0, 1, 2, 3, 5, 6, 7, 8$.

From the above cases, if the subcarrier spacing of SS/PBCH blocks is not provided by higher layer parameter *subcarrierSpacing*, 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 subcarrier spacing is indicated by higher layer parameter *subcarrierSpacing*, Case B applies for frequency bands with only 15 kHz SS/PBCH block subcarrier spacing as specified in [8-1, TS 38.101-1], and the case specified for 30kHz SS/PBCH block subcarrier spacing in [8-1, TS 38.101-1] applies for frequency bands with 30 kHz SS/PBCH block subcarrier spacing or both 15 kHz and 30 kHz SS/PBCH block subcarrier spacing 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 frequency range 2, if the UE is provided values of subcarrier spacings by higher layer parameter *subcarrierSpacing* for receptions of SS/PBCH blocks on any cells from the set of cells, the UE expects the values to be same.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $L-1$. A UE determines the 2 LSB bits, for $L=4$, or the 3 LSB bits, for $L>4$, 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 $L=64$, 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 [4, TS 38.212].

For SS/PBCH blocks providing higher layer parameter *MasterInformationBlock* to a UE, the UE can be configured by higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1*, indexes of the SS/PBCH blocks for which the UE does not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. The UE can also be configured per serving cell, by higher layer parameter *ssb-PositionsInBurst* in *ServingCellConfigCommon*, indexes of the SS/PBCH blocks for which the UE does not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. A UE expects a configuration provided by *ssb-PositionsInBurst* in *ServingCellConfigCommon* to be same as a configuration provided by *ssb-PositionsInBurst* in *SystemInformationBlockType1*. A UE can be provided per serving cell by higher layer parameter *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 that a control resource set for Type0-PDCCH common search space, as described in Subclause 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 that a control resource set for Type0-PDCCH common search space is not present if $k_{\text{SSB}} > 23$ for FR1 or if $k_{\text{SSB}} > 11$ for FR2.

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 higher layer parameter *n-TimingAdvanceOffset* for the serving cell. If the UE is not provided higher layer parameter *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 or of a timing adjustment indication 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 and based on the received timing advance command or the timing adjustment indication where the uplink timing for PUSCH/SRS/PUCCH transmissions is the same for all the serving cells in the TAG.

The timing adjustment indication [11, TS 38.321] indicates an initial time alignment value N_{TA} used for a TAG. For a subcarrier spacing 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 subcarrier spacing 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 subcarrier spacing 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 subcarrier spacing 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 Subclause 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 subcarrier spacing of the multiple active UL BWPs. The applicable N_{TA_new} value for an UL BWP with lower subcarrier spacing may be rounded to align with the timing advance granularity for the UL BWP with the lower subcarrier spacing 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, 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 of N_1 symbols corresponding to a PDSCH reception time for UE processing capability 1 when additional PDSCH DM-RS is configured, $N_{T,2}$ is a time duration of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214], $N_{TA,max}$ is the maximum timing advance value that can be provided by a TA command field of 12 bits, $N_{slot}^{subframe,\mu}$ is a 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 subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in a TAG and of their corresponding configured DL BWPs as described in Subclause 12. Slot n and $N_{slot}^{subframe,\mu}$ are determined with respect to the minimum subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in the TAG. $N_{TA,max}$ is determined with respect to the minimum subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in the TAG and for the initial UL BWP provided by higher layer parameter *initialuplinkBWP*.

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 subcarrier spacing 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

When a UE receives an activation command [11, TS 38.321] for a secondary cell 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.

If a UE receives a deactivation command [11, TS 38.321] for a secondary cell or 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 a serving cell which is active which the UE applies in slot *n+k*.

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 Subclause 12, on the primary cell. If the active DL BWP is the initial DL BWP and for SS/PBCH block and control resource set multiplexing pattern 2 or 3, as described in Subclause 13, the UE is expected to perform RLM using the associated SS/PBCH block.

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 higher layer parameters *RadioLinkMonitoringRS*, for radio link monitoring by higher layer parameter *failureDetectionResources*. The UE is provided either a CSI-RS resource configuration index, by higher layer parameter *csi-RS-Index*, or a SS/PBCH block index, by higher layer parameter *ssb-Index*. The UE can be configured with up to $N_{\mathrm{LR-RLM}}$ *RadioLinkMonitoringRS* for link recovery procedures, as decribed in Subclause 6, and for radio link monitoring. From the $N_{\mathrm{LR-RLM}}$ *RadioLinkMonitoringRS*, up to N_{RLM} *RadioLinkMonitoringRS* can be used for radio link monitoring depending on a maximum number L of candidate SS/PBCH blocks per half frame as described in Subclause 4.1, and up to two *RadioLinkMonitoringRS* can be used for link recovery procedures.

If the UE is not provided higher layer parameter *RadioLinkMonitoringRS* and the UE is provided by higher layer parameter *TCI-states* for PDCCH receptions one or more RSs that include one or more of a CSI-RS and/or a SS/PBCH block

- 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

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

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

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

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

For a CSI-RS resource configuration, the higher layer parameter *powerControlOffsetSS* is not applicable and a UE expects to be provided only 'No CDM' from higher layer parameter *cdm-Type*, only '1' and '3' from higher layer parameter *density*, and only '1 port' from higher layer parameter *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 higher layer parameter *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 control resource sets 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

higher layer parameter *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 higher layer parameter *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 a serving cell, with a set $\overline{q}_0$ of periodic CSI-RS resource configuration indexes by higher layer parameter *failureDetectionResources* and with a set $\overline{q}_1$ of periodic CSI-RS resource configuration indexes and/or SS/PBCH block indexes by higher layer parameter *candidateBeamRSList* for radio link quality measurements on the serving cell. If the UE is not provided with higher layer parameter *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 higher layer parameter *TCI-states* for respective control resource sets that the UE uses for monitoring PDCCH. The UE expects the set $\overline{q}_0$ to include up to two RS indexes 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 single port RS in the set $\overline{q}_0$.

The thresholds $Q_{out,LR}$ and $Q_{in,LR}$ correspond to the default value of higher layer parameter *rlmInSyncOutOfSyncThreshold*, as described in [10, TS38.133] for Q_{out}, and to the value provided by higher layer parameter *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 higher layer parameter *powerControlOffsetSS*.

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.

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 with a control resource set through a link to a search space set provided by higher layer parameter *recoverySearchSpaceId*, as described in Subclause 10.1, for monitoring PDCCH in the control resource set. If the UE is provided higher layer parameter *recoverySearchSpaceId*, the UE does not expect to be provided another search space set for monitoring PDCCH in the control resource set associated with the search space set provided by *recoverySearchSpaceId*.

The UE may receive by higher layer parameter *PRACH-ResourceDedicatedBFR*, a configuration for PRACH transmission as described in Subclause 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

higher layer parameter *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 higher layer parameter *BeamFailureRecoveryConfig*. For the PDCCH monitoring and for the 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 higher layer parameters *TCI-StatesPDCCH-ToAddlist* and/or *TCI-StatesPDCCH-ToReleaseList.*

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 Subcaluses 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 Subclause 12, of carrier f of serving cell c , a UE first scales 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 Subclause 7.1.1, by the ratio of the number of antenna ports with a non-zero PUSCH transmission power to the number of configured antenna ports for the PUSCH transmission scheme. The UE splits the resulting scaled 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

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

where,

- $P_{\text{CMAX},f,c}(i)$ is the configured UE transmit power defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2] 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 higher layer parameter *P0-PUSCH-AlphaSet* or for a Msg3 PUSCH transmission as described in Subclause 8.3, $j=0$, $P_{\text{O\_UE\_PUSCH},f,c}(0)=0$, 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 for carrier f of serving cell c
  - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*, $j=1$, $P_{\text{O\_NOMINAL\_PUSCH},f,c}(1)$ is provided by higher layer parameter *p0-NominalWithoutGrant*, and

$P_{\text{O\_UE\_PUSCH},b,f,c}(1)$ is provided by higher layer parameter *p0* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* that provides an index *P0-PUSCH-AlphaSetId* to a set of higher layer parameters *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 higher layer parameter *p0-NominalWithGrant* 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 higher layer parameters *p0* in *P0-PUSCH-AlphaSet* indicated by a respective set of higher layer parameters *p0-PUSCH-AlphaSetId* for active UL BWP b of carrier f of serving cell c

  - If the UE is provided by higher layer parameter *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 higher layer parameter *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 higher layer parameter *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 a higher layer parameter *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 higher layer parameter *p0-Pusch-AlphaSet* in *p0-AlphaSets*

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

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

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

    - If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl* and more than one values of *p0-PUSCH-AlphaSetId*, DCI format 0_1 includes a SRI field and the UE obtains a mapping from higher layer parameter *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 higher layer parameter *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 a higher layer parameter *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* higher layer parameter 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 subcarrier spacing 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 Subclause 12, of serving cell c

- If the UE is not provided higher layer parameter *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 higher layer parameter *MasterInformationBlock*

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

- If the PUSCH is an Msg3 PUSCH, the UE uses the same RS resource index q_d as for a corresponding PRACH transmission

- If the UE is provided higher layer parameter *SRI-PUSCH-PowerControl* and more than one values of *PUSCH-PathlossReferenceRS-Id*, the UE obtains a mapping from higher layer parameter *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, DCI format 0_1 includes a SRI field and the UE determines the RS resource index q_d from the value of higher layer parameter *PUSCH-PathlossReference-Id* that is mapped to the SRI field value

- If the PUSCH transmission is scheduled by a DCI format 0_0, and if the UE is provided a spatial setting by higher layer parameter *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 Subclause 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 a higher layer parameter *SRI-PUSCH-PowerControl* is not provided to the UE, the UE determines a RS resource index q_d with a respective higher layer parameter *PUSCH-PathlossReference-Id* value being equal to zero

- For a PUSCH transmission configured by higher layer parameter *ConfiguredGrantConfig*, if higher layer parameter *rrc-ConfiguredUplinkGrant* is included in *ConfiguredGrantConfig* , a RS resource index q_d is provided by a value of higher layer parameter *pathlossReferenceIndex* included in *rrc-ConfiguredUplinkGrant*

- For a PUSCH transmission configured by higher layer parameter *ConfiguredGrantConfig* that does not include higher layer parameter *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 higher layer parameter *PUSCH-PathlossReferenceRS-Id* value being equal to zero

$PL_{f,c}(q_d)$ = *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 higher layer parameter *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 higher layer parameter *ss-PBCH-BlockPower*. If the UE is configured periodic CSI-RS reception, *referenceSignalPower* is provided either by higher layer parameter *ss-PBCH-BlockPower* or by higher layer parameter *powerControlOffsetSS* providing an offset of the CSI-RS transmission power relative to the SS/PBCH block transmission power [6, TS 38.214]. If higher layer parameter *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 higher layer parameter *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 $\mathrm{BPRE} = O_{\mathrm{CSI}} / N_{\mathrm{RE}}$ for CSI transmission in a PUSCH without UL-SCH data, where
    - C is a number of code blocks, K_r is a size for code block r, O_{CSI} is a number of CSI part 1 bits including CRC bits, 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 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 Subclause 9.3, when the PUSCH 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
  - $\delta_{\mathrm{PUSCH},b,f,c}(i,l)$ 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 Subclause 11.3
    - $l \in \{0,1\}$ if the UE is configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates* and $l = 0$ if the UE is not configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates* or if the PUSCH is a Msg3 PUSCH
      - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*, the value of $l \in \{0,1\}$ is provided to the UE by higher layer parameter *powerControlLoopToUse*
      - If the UE is provided a higher layer parameter *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 higher layer parameter *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 higher layer parameter *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
  - $f_{b,f,c}(i,l) = f_{b,f,c}(i-i_0,l) + \sum_{m=0}^{\mathcal{C}(D_i)-1} \delta_{\mathrm{PUSCH},b,f,c}(m,l)$ 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 provided higher layer parameter *tpc-Accumulation*, where
    - The $\delta_{\mathrm{PUSCH},b,f,c}$ 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 higher layer parameter *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 higher layer parameter *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

- If the UE has reached maximum power $P_{\text{CMAX},f,c}(i)$ 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, $P_{\text{CMIN},f,c}(i)$, 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 $f_{b,f,c}(0,l)=0$

  - 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

- If $j>1$ and the PUSCH transmission is scheduled by a DCI format 0_1 that includes a SRI field, and the UE is provided higher layer parameter *SRI-PUSCH-PowerControl*, the UE determines the value of l from the value of j based on an indication by the SRI field for a *sri-PUSCH-PowerControlId* value associated with the *sri-P0-PUSCH-AlphaSetId* value corresponding to j and with the *sri-PUSCH-ClosedLoopIndex* value corresponding to l

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

- If $j=1$, l is provided by the value of higher layer parameter *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 not provided higher layer parameter *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 desctibed in subcaluse 8

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

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

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 subclause for both MCG and SCG.

- When the procedures are applied for MCG, the term 'serving cell' in this subclause refers to serving cell belonging to the MCG.
- When the procedures are applied for SCG, the term 'serving cell' in this subclause refers to serving cell belonging to the SCG. The term 'primary cell' in this subclause 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 subclause 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 subclause 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 subclause refers to serving cell belonging to the secondary PUCCH group. The term 'primary cell' in this subclause 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

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

where

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

- $P_{\mathrm{O\_PUCCH},b,f,c}(q_u)$ is a parameter composed of the sum of a component $P_{\mathrm{O\_NOMINAL\_PUCCH}}$, provided by higher layer parameter *p0-nominal* for carrier f of primary cell c and, if provided, a component $P_{\mathrm{O\_UE\_PUCCH}}(q_u)$ provided by higher layer parameter *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 $P_{\mathrm{O\_UE\_PUCCH}}$ values provided by higher layer parameter *maxNrofPUCCH-P0-PerSet*. The set of $P_{\mathrm{O\_UE\_PUCCH}}$ values is provided by higher layer parameter *p0-Set*. If higher layer parameter *p0-Set* is not provided to the UE, $P_{\mathrm{O\_UE\_PUCCH}}(q_u) = 0$, $0 \le q_u < Q_u$

  - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by higher layer parameter *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 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command

  - If the UE is not provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains the *p0-PUCCH-Value* value from the *P0-PUCCH* with *p0-PUCCH-Id* value equal to 0 in *p0-Set*

- $M^{\mathrm{PUCCH}}_{\mathrm{RB},b,f,c}(i)$ 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 subcarrier spacing 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 Subclause 7.1.1 for the active DL BWP of carrier f of the primary cell c as described in Subcluase 12

  - If the UE is not provided higher layer parameter *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 higher layer parameter *MasterInformationBlock*

  - 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 higher layer parameter *maxNrofPUCCH-PathlossReferenceRSs*. The set of RS resources is provided by higher layer parameter *pathlossReferenceRSs*. The set of RS resources can include one or both of a set of SS/PBCH block indexes, each provided by higher layer parameter *ssb-Index* in *PUCCH-PathlossReferenceRS* when a value of a corresponding higher layer parameter pucch-*PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by higher layer parameter *csi-RS-Index* when a value of a corresponding higher layer parameter *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 higher layer parameter *pucch-PathlossReferenceRS-Id* in *PUCCH-PathlossReferenceRS*

  - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by indexes provided by corresponding higher layer parameters *pucch-PathlossReferenceRS-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of *referencesignal* values provided by higher layer parameter *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 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command

- If higher layer parameter *PUCCH-SpatialRelationInfo* includes higher layer parameter *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 not provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains the *referencesignal* value in *PUCCH-PathlossReferenceRS* from the *pucch-PathlossReferenceRS-Id* with index 0 in *PUCCH-PathlossReferenceRSs*

- The parameter $\Delta_{\text{F\_PUCCH}}(F)$ is provided by higher layer parameter *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

- $\Delta_{\text{TF},b,f,c}(i)$ 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, $\Delta_{\text{TF},b,f,c}(i) = 10\log_{10}\left(\frac{N_{\text{ref}}^{\text{PUCCH}}}{N_{\text{symb}}^{\text{PUCCH}}(i)}\right) + \Delta_{\text{UCI}}(i)$ $\Delta_{\text{TF},b,f,c}(i) = 10\log_{10}\left(\frac{N_{\text{ref}}^{\text{PUCCH}}}{N_{\text{symb}}^{\text{PUCCH}}}\right)$ where

    - $N_{\text{symb}}^{\text{PUCCH}}(i)$ is a number of PUCCH format 0 symbols or PUCCH format 1 symbols included in a PUCCH resource of a PUCCH resource set indicated by a value of a PUCCH resource indicator field in DCI format 1_0 or DCI format 1_1, or provided by higher layer parameter *nrofSymbols* in *PUCCH-format0* or in *PUCCH-format1* respectively

    - $N_{\text{ref}}^{\text{PUCCH}} = 2$ for PUCCH format 0

    - $N_{\text{ref}}^{\text{PUCCH}} = N_{\text{symb}}^{\text{slot}}$ for PUCCH format 1

    - $\Delta_{\text{UCI}}(i) = 0$ for PUCCH format 0

    - $\Delta_{\text{UCI}}(i) = 10\log_{10}\left(O_{\text{UCI}}(i)\right)$ for PUCCH format 1, where $O_{\text{UCI}}(i)$ 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, $\Delta_{\text{TF},b,f,c}(i) = 10\log_{10}\left(K_1 \cdot \left(n_{\text{HARQ-ACK}}(i) + O_{\text{SR}}(i) + O_{\text{CSI}}(i)\right) / N_{\text{RE}}(i)\right)$, where

    - $K_1 = 6$

    - $n_{\text{HARQ-ACK}}(i)$ is a number of HARQ-ACK information bits that the UE determines as described in Subclause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Subclause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided with higher layer parameter *pdsch-HARQ-ACK-Codebook*, $n_{\text{HARQ-ACK}} = 1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $n_{\text{HARQ-ACK}} = 0$

      - $O_{\text{SR}}(i)$ is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1

      - $O_{\text{CSI}}(i)$ is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2

      - $N_{\text{RE}}(i)$ is a number of resource elements determined as $N_{\text{RE}}(i) = M_{\text{RB},b,f,c}^{\text{PUCCH}}(i) \cdot N_{\text{sc,ctrl}}^{\text{RB}}(i) \cdot N_{\text{symb-UCI},b,f,c}^{\text{PUCCH}}(i)$, where $N_{\text{sc,ctrl}}^{\text{RB}}(i)$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N_{\text{symb-UCI},b,f,c}^{\text{PUCCH}}(i)$ is a number of symbols excluding symbols used for DM-RS

transmission, as defined in Subclause 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, $\Delta_{\text{TF},b,f,c}(i)=10\log_{10}\left(2^{K_2\cdot \text{BPRE}(i)}-1\right)$, where
  - $K_2=2.4$
  - $\text{BPRE}(i)=\left(O_{\text{ACK}}(i)+O_{\text{SR}}(i)+O_{\text{CSI}}(i)+O_{\text{CRC}}(i)\right)/N_{\text{RE}}(i)$
  - $O_{\text{ACK}}(i)$ is a number of HARQ-ACK information bits that the UE determines as described in Subclause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Subclause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided with higher layer parameter *pdsch-HARQ-ACK-Codebook*, $O_{\text{ACK}}=1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $O_{\text{ACK}}=0$
  - $O_{\text{SR}}(i)$ is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1
  - $O_{\text{CSI}}(i)$ is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2
  - $O_{\text{CRC}}(i)$ is a number of CRC bits that the UE determines as described in Subclause 9.2.5
  - $N_{\text{RE}}(i)$ is a number of resource elements that the UE determines as $N_{\text{RE}}(i)=M_{\text{RB},b,f,c}^{\text{PUCCH}}(i)\cdot N_{\text{sc,ctrl}}^{\text{RB}}(i)\cdot N_{\text{symb-UCI},b,f,c}^{\text{PUCCH}}(i)$, where $N_{\text{sc,ctrl}}^{\text{RB}}(i)$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N_{\text{symb-UCI},b,f,c}^{\text{PUCCH}}(i)$ is a number of symbols excluding symbols used for DM-RS transmission, as defined in Subclause 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 Subclause 11.3
    - $l\in\{0,1\}$ if the UE is provided higher layer parameters *twoPUCCH-PC-AdjustmentStates* and *PUCCH-SpatialRelationInfo* and $l=0$ if the UE is not provided higher layer parameter *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 higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by higher layer parameter *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of values for higher layer parameter *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
  - $g_{b,f,c}(i,l)=g_{b,f,c}(i-i_0,l)+\sum_{m=0}^{\mathcal{C}(\mathcal{C}_i)-1}\delta_{\text{PUCCH},b,f,c}(m,l)$ 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, $N_{\text{symb}}^{\text{slot}}$, and the minimum of the values provided by higher layer parameter *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

- If the UE has reached maximum power $P_{\text{CMAX},f,c}(i)$ 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, $P_{\text{CMIN},f,c}(i)$, for active UL BWP b of carrier f of primary cell c at PUCCH transmission occasion $i-i_0$ and $\sum_{m=0}^{\mathcal{C}(C_i)-1}\delta_{\text{PUCCH},b,f,c}(m,l)\leq 0$, 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 PUSCH power control adjustment state l for active UL BWP b of carrier f of serving cell c is provided by higher layers,

  - $g_{b,f,c}(0,l)=0$

    If the UE is provided higher layer parameter *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,

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

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

    if the UE transmits PUCCH,

$$\Delta P_{rampup,b,f,c}=\min\left[\begin{array}{l}\max\left(0,\\ P_{\text{CMAX},f,c}-\left(P_{\text{O\_PUCCH},b,f,c}+PL_{b,f,c}(q_d)+\Delta_{\text{F\_PUCCH}}(F)+\Delta_{\text{TF},b,f,c}+\delta_{msg2,b,f,c}\right)\right),\\ \Delta P_{rampuprequested,b,f,c}\end{array}\right],$$

    ;

    otherwise,

$\Delta P_{rampup,b,f,c} = \min\left[\begin{matrix}\max\left(\begin{matrix}0,\\ P_{\text{CMAX},f,c} - \left(P_{\text{O\_PUCCH},b,f,c} + PL_{b,f,c}(q_d)\right)\end{matrix}\right),\\ \Delta P_{rampuprequested,b,f,c}\end{matrix}\right]$ 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 configured UE transmit power defined in [8, TS 38.101-1] and [8-2, TS38.101-2] for carrier f of serving cell c in SRS transmission occasion i
- $P_{\text{O\_SRS},b,f,c}(q_s)$ is provided by higher layer parameter *p0* for active UL BWP b of carrier f of serving cell c and SRS resource set q_s provided by higher layer parameters *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 subcarrier spacing configuration defined in [4, TS 38.211]
- $\alpha_{\text{SRS},b,f,c}(q_s)$ is provided by higher layer parameter *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 Subclause 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 higher layer parameter *pathlossReferenceRS* associated with the SRS resource set q_s and is either a higher layer parameter *ssb-Index* providing a SS/PBCH block index or a higher layer parameter *csi-RS-Index* providing a CSI-RS resource index

- If the UE is not provided higher layer parameter *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 higher layer parameter *MasterInformationBlock*

- 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 Subclause 7.1.1, if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions; or

  - $h_{b,f,c}(i) = h_{b,f,c}(i-1) + \sum_{m=0}^{\mathcal{C}(S_i)-1} \delta_{\text{SRS},b,f,c}(m)$ if the UE is not configured for PUSCH transmissions on active UL BWP b of carrier f of serving cell c, or if higher layer parameter *srs-PowerControlAdjustmentStates* indicates separate power control adjustment states between SRS transmissions and PUSCH transmissions, and if higher layer parameter *tpc-Accumulation* is 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 Subclause 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_{SRS} 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_{SRS} 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 higher layer parameter *k2* in *PUSCH-ConfigCommon* for active UL BWP b of carrier f of serving cell c

    - If the UE has reached $P_{\text{CMAX},f,c}(i)$ 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

      - $h_{b,f,c}(0) = 0$

      - Else

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

  where

  $\delta_{msg\,2,b,f,c}$ 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

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

  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 serving cell c

- $h_{b,f,c}(i) = \delta_{\mathrm{SRS},b,f,c}(i)$ if the UE is not configured for PUSCH transmissions on active UL BWP b of carrier f of serving cell c, or if higher layer parameter *srs-PowerControlAdjustmentStates* indicates separate power control adjustment states between SRS transmissions and PUSCH transmissions, and higher layer parameter *tpc-Accumulation* is not provided, and the UE detects a DCI format 2_3 $K_{\mathrm{SRS,min}}$ symbols before a first symbol of SRS transmission occasion i, where absolute values of $\delta_{\mathrm{SRS},b,f,c}$ are provided in Table 7.1.1-1

- if higher layer parameter *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), $P_{\mathrm{PRACH},b,f,c}(i)$, 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

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

where $P_{\mathrm{CMAX},f,c}(i)$ is the configured UE transmission power defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2] for carrier f of serving cell c within transmission occasion i, $P_{\mathrm{PRACH,target},f,c}$ 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, where RSRP is defined in [7, TS 38.215] and the higher layer filter configuration is defined in [12, TS 38.331].

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 Subclause 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 non-contention based random access procedure and depending on the DL RS that the DM-RS of the PDCCH order is quasi-collocated with as described in Subclause 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 Subclause 6, *referenceSignalPower* is obtained by higher layer parameters *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 within a random access response window, as described in Subclause 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].

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 a PUSCH or PUCCH or PRACH or SRS transmission 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] and [8-2, TS38.101-2], 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 is smaller than or equal to $\hat{P}_{\text{CMAX}}(i)$ in every symbol of transmission occasion i. When determining a total transmit power 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 and prioritizes power allocation for transmissions on the PCell over transmissions on the PSCell. 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 higher layer parameter *p-MaxEUTRA* and a maximum power P_{NR} for transmissions in frequency range 1 on the SCG by higher layer parameter *p-NR*. 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 frequency range 1 as described Subclauses 7.1 through 7.5 using P_{NR} as the maximum transmission power for $P_{\text{CMAX}} \leq P_{\text{NR}}$. The UE determines transmission power for the SCG in frequency range 2 as described Subclauses 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 frequency range 1, the UE determines a transmission power on the SCG as follows.

- If the UE is configured with reference TDD configuration for E-UTRA (by higher layer parameter *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, the UE does not expect to transmit in a slot on the SCG in frequency range 1 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 and
  - if the 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 frequency range 1, 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 frequency range 1, respectively.
- If the UE does not indicate a capability for dynamic power sharing between E-UTRA and NR, the UE expects to be configured with reference TDD configuration for E-UTRA (by higher layer parameter *tdm-PatternConfig-r15* in [13, TS 36.213]).

7.6.2 NN-DC

If a UE is configured with a MCG using NR radio access in frequency range 1 or in frequency range 2 and with a SCG using NR radio access in frequency range 2 or in frequency range 1, respectively, the UE performs transmission power control independently per cell group as described in Subclauses 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, TS38.321] is based on an actual transmission or a reference format based on the 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 UE is configured with a SCG,

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

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

$$PH_{\text{type1},b,f,c}(i,j,q_d,l) = P_{\text{CMAX},f,c}(i) - \left\{ P_{\text{O\_PUSCH},b,f,c}(j) + 10\log_{10}(2^{\mu} \cdot M^{\text{PUSCH}}_{\text{RB},b,f,c}(i)) + \alpha_{b,f,c}(j) \cdot PL_{b,f,c}(q_d) + \Delta_{\text{TF},b,f,c}(i) + f_{b,f,c}(i,l) \right\}$$ [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 Subclause 7.1.1.

If a UE is configured with multiple cells for PUSCH transmissions, where a subcarrier spacing configuration μ_1 on active UL BWP b_1 of carrier f_1 of serving cell c_1 is smaller than a subcarrier spacing 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 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, 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

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

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

where $\tilde{P}_{\text{CMAX},f,c}(i)$ is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB. ΔT_C =0dB. MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2]. The remaining parameters are defined in Subclause 7.1.1 where $P_{\text{O\_PUSCH},b,f,c}(j)$ and $\alpha_{b,f,c}(j)$ are provided from *p0-PUSCH-AlphaSetId = 0* for the UL BWP b of carrier f of serving cell c, $PL_{b,f,c}(q_d)$ is obtained using *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 higher layer parameter *pusch-Config*. If the UE is provided higher layer parameter *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 higher layer parameter *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 subclause 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

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

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 Subclause 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

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

where q_s is a SRS resource set corresponding to *SRS-ResourceSetId = 0* 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 Subclause 7.3.1 with corresponding values obtained from *SRS-ResourceSetId = 0*. $\tilde{P}_{\text{CMAX},f,c}(i)$ is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and ΔT_C =0dB. MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2].

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 higher layer parameter *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 Msg3 PUSCH, 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 subcarrier spacing 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 subcarrier spacing, $P_{\text{PRACH,target}}$, 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 Subclause 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 higher layer parameter *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 SS/PBCH block n, $0\le n\le N-1$, per valid PRACH occasion start from preamble index 0. If $N\ge 1$, R contention based preambles with consecutive indexes associated with SS/PBCH block n, $0\le n\le N-1$, 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 higher layer parameter *totalNumberOfRA-Preambles* and is an integer multiple of N. SS/PBCH block indexes 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 higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* and/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 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. 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. 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

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 higher layer parameter *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 reception symbol, where N_{gap} is provided in Table 8.1-2.

If a UE is provided higher layer parameter *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 transmission 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 subcarrier spacing configurations μ

Preamble subcarrier spacing	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 first available PRACH occasion 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], $\Delta_{\text{BWPSwitching}} = 0$ 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 subcarrier spacing, the UE determines N_2 assuming subcarrier spacing 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 subcarrier spacing 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 control resource set the UE is configured to receive PDCCH for Type1-PDCCH common search space, as defined in Subclause 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 subcarrier spacing for Type1-PDCCH common search space as defined in Subclause 10.1. The length of the window in number of slots, based on the

subcarrier spacing for Type1-PDCCH common search space, is provided by higher layer parameter *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 reception time for UE processing capability 1 when additional PDSCH DM-RS is configured.

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, 38.214], as for a SS/PBCH block or a CSI-RS resource the UE used for PRACH association, as described in Subclause 8.1, regardless of whether or not the UE is provided higher layer parameter *TCI-States* for the control resource set 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 non-contention based random access procedure, 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.

A RAR UL grant schedules a PUSCH transmission from the UE (Msg3 PUSCH). 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 Msg3 PUSCH without frequency hopping; otherwise, the UE transmits Msg3 PUSCH with frequency hopping.

The Msg3 PUSCH frequency resource allocation is for uplink resource allocation type 1 [6, 38.214]. In case of Msg3 PUSCH transmission with frequency hopping, the first one or two bits, $N_{UL,hop}$ bits, of the Msg3 PUSCH frequency resource allocation field are used as hopping information bits as described in Table 8.3-1. A UE processes the frequency resource allocation field in an active UL BWP of N_{BWP}^{size} RBs as follows

- if $N_{BWP}^{size}<180$
  - truncate the frequency resource allocation field to its $\left\lceil \log_2\left(N_{BWP}^{size}\cdot\left(N_{BWP}^{size}+1\right)/2\right)\right\rceil$ least significant bits and interpret the truncated frequency resource allocation field as for the frequency resource allocation field in DCI format 0_0 as described in [6, 38.214]
- else
  - insert $\left\lceil \log_2\left(N_{BWP}^{size}\cdot\left(N_{BWP}^{size}+1\right)/2\right)\right\rceil-14$ most significant bits with value set to '0' after the $N_{UL,hop}$ bits, where $N_{UL,hop}=0$ if the frequency hopping flag is set to '0', and $N_{UL,hop}$ is provided in Table 8.3-1 if the hopping flag bit is set to '1', and interpret the expanded frequency resource allocation field as for the frequency resource allocation field in DCI format 0_0 as described in [6, 38.214]
- end if

The Msg3 PUSCH MCS is determined from the first sixteen indexes of the applicable MCS index table for PUSCH as described in [6, 38.214].

The TPC command value $\delta_{msg2,b,f,c}$ is used for setting the power of the Msg3 PUSCH, as described in Subclause 7.1.1, and is interpreted according to Table 8.2-2.

In a non-contention based random access procedure, the CSI request field in the RAR UL grant indicates whether or not the UE includes an aperiodic CSI report in the corresponding PUSCH transmission according to [6, TS 38.214]. In a contention based random access procedure, 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
Msg3 PUSCH frequency resource allocation	14
Msg3 PUSCH time resource allocation	4
MCS	4
TPC command for Msg3 PUSCH	3
CSI request	1

Table 8.2-2: TPC Command $\delta_{msg2,b,f,c}$ for Msg3 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 subcarrier spacing, the UE receives subsequent PDSCH using same subcarrier spacing 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 Msg3 PUSCH

Higher layer parameter *msg3-transformPrecoding* indicates to a UE whether or not the UE shall apply transform precoding, as described in [4, TS 38.211], for an Msg3 PUSCH transmission.

If the UE applies transform precoding to an Msg3 PUSCH transmission with frequency hopping, the frequency offset for the second hop [6, TS38.214] is given in Table 8.3-1.

Table 8.3-1: Frequency offset for second hop for Msg3 PUSCH transmission with frequency hopping

Number of PRBs in active 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 subcarrier spacing for an Msg3 PUSCH transmission is provided by higher layer parameter *SubcarrierSpacing* in *BWP-UplinkCommon*. A UE transmits PRACH and Msg3 PUSCH on a same uplink carrier of a same serving cell.

An active UL BWP, as described in Subclause 12 and in [4, TS 38.211], for an Msg3 PUSCH transmission is indicated by higher layers. For determining the frequency domain resource allocation for the Msg3 PUSCH transmission within the active UL BWP

- if the active UL BWP and the initial UL BWP have same subcarrier spacing 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

A UE transmits a transport block in an Msg3 PUSCH scheduled by a RAR UL grant in a corresponding RAR message using redundancy version number 0. Retransmissions, if any, of the transport block in an Msg3 PUSCH 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 an Msg3 PUSCH without repetitions.

With reference to slots for Msg3 PUSCH transmissions, if in slot n a UE receives a PDSCH with a RAR message for a corresponding PRACH transmission from the UE, the UE transmits an Msg3 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 and the first symbol of a corresponding Msg3 PUSCH transmission scheduled by the RAR message in the PDSCH is equal to $N_{T,1}+N_{T,2}+0.5$ msec. $N_{T,1}$ is a time duration of N_1 symbols corresponding to a PDSCH reception time for UE processing capability 1 when additional PDSCH DM-RS is configured and, $N_{T,2}$ is a time duration of N_2 symbols corresponding to a PUSCH preparation time for UE processing capability 1 [6, TS 38.214].

8.4 PDSCH with UE contention resolution identity

In response to an Msg3 PUSCH transmission when a UE has not been provided with 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 initial active UL BWP as the Msg3 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 $N_{T,1}+0.5$ msec. $N_{T,1}$ is a time duration of N_1 symbols corresponding to a PDSCH reception time for UE processing capability 1 when additional PDSCH DM-RS is configured.

9 UE procedure for reporting control information

If a UE is configured with a SCG, the UE shall apply the procedures described in this subclause 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 would multiplex UCI in a PUCCH transmission that overlaps with a PUSCH transmission, and the PUSCH and PUCCH transmissions fulfill the conditions in Subclause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in the PUSCH transmission and does not transmit the PUCCH.

If a UE multiplexes aperiodic CSI or semi-persistent 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 Subclause 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 higher layer parameters *ConfiguredGrantConfig*, and the UE would multiplex UCI in one of the multiple PUSCHs, and the multiple PUSCHs fulfil the conditions in Subclause 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 Subclause 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 Subclause 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 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 Subclause 9.2.5 for multiplexing the HARQ-ACK information, the UE multiplexes the HARQ-ACK information in the PUSCH transmission in the one or more slots. The UE does not multiplex HARQ-ACK information in the PUSCH transmission in a slot from the multiple slots if, in case the PUSCH transmission was absent, the UE would not transmit a single-slot PUCCH with HARQ-ACK information in the slot.

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 higher layer parameter *PDSCH-CodeBlockGroupTransmission*, the UE generates one HARQ-ACK information bit per transport block.

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

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

9.1.1 CBG-based HARQ-ACK codebook determination

If a UE is provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* for a serving cell, the UE receives PDSCHs that include code block groups (CBGs) of a transport block and the UE is provided higher layer parameter *maxCodeBlockGroupsPerTransportBlock* indicating a maximum number $N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,max}}$ 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 as $N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB}} = \min\left(N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,max}}, C\right)$. Each of the first $N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}} = \text{mod}\left(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}}\right)$ CBGs includes $\left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil$ CBs, where CBG $n_{\text{CBG}}, 0 \le n_{\text{CBG}} < N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}}$, includes CBs $n_{\text{CBG}} \cdot \left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil + n_{\text{CB}}, 0 \le n_{\text{CB}} < \left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil$, and each of the last $N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,2}} = N_{\text{HARQ-ACK}}^{\text{CBG/TB}} - \text{mod}\left(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}}\right)$ CBGs includes $\left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor$ CBs, where CBG $n_{\text{CBG}}, N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}} \le n_{\text{CBG}} < N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}} + N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,2}}$, includes CBs $N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}} \cdot \left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil + \left(n_{\text{CBG}} - N_{\text{HARQ}-\text{ACK}}^{\text{CBG/TB,1}}\right) \cdot \left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor + n_{\text{CB}}, 0 \le n_{\text{CB}} < \left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor$. The UE generates

$N_{\text{HARQ-ACK}}^{\text{CBG/TB},1} + N_{\text{HARQ-ACK}}^{\text{CBG/TB},2}$ HARQ-ACK information bits through a one-to-one mapping with the $N_{\text{HARQ-ACK}}^{\text{CBG/TB},1} + N_{\text{HARQ-ACK}}^{\text{CBG/TB},2}$ CBGs. If the UE receives two transport blocks, the UE concatenates the HARQ-ACK information bits for the second transport block after the HARQ-ACK information bits for the first transport block. 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.

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.

If a UE receives a PDSCH that is scheduled by a DCI format 1_0, or a SPS PDSCH, or the UE detects a SPS PDSCH release, the UE generates HARQ-ACK information only for the transport block in the PDSCH or only for the SPS PDSCH release, respectively.

9.1.2 Type-1 HARQ-ACK codebook determination

This subclause 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 higher layer parameter *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 higher layer parameter *dl-DataToUL-ACK* if the PDSCH-to-HARQ feedback timing 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 or only for a PDSCH reception within the $M_{A,c}$ occasions for candidate PDSCH receptions, as determined in Subclause 9.1.2.1, that is scheduled by DCI format 1_0 with a counter downlink assignment indicator (DAI) field value of 1 on the PCell, the UE determines a HARQ-ACK codebook only for the SPS PDSCH release or only for the PDSCH reception; otherwise, the procedures in Subclause 9.1.2.1 and Subclause 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 Subclause 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. 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 higher layer parameter *firstActiveDownlinkBWP*. 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 higher layer parameter *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-TimeDomainResourceAllocationList* in *PDSCH-ConfigCommon* or by Default PDSCH time domain resource allocation A [6, 38.214], or by the union of the first set of row indexes and a second set of row indexes, if provided by higher layer parameter *PDSCH-TimeDomainResourceAllocationList* 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]; and

c) if provided, on higher layer parameter *TDD-UL-DL-ConfigurationCommon* and higher layer parameter *TDD-UL-DL-ConfigDedicated* as described in Subclause 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.

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

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 is same 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 $n - K_{1,k}$ is before the slot for the active DL BWP change on serving cell c or the active UL BWP change on the PCell

$k = k + 1$;

else

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

if the UE is provided higher layer parameter *TDD-UL-DL-ConfigurationCommon*, or higher layer parameter *TDD-UL-DL-ConfigDedicated* and, for each slot from slot $n - K_{1,k} - N_{\text{PDSCH}}^{\text{repeat}} + 1$ to slot $n - K_{1,k}$, 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,

$R = R \setminus r$;

end if

$r = r + 1$;

end while

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

$M_{A,c} = M_{A,c} \bigcup k$;

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

else

Set $\ell(R)$ 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 $r < \ell(R)$

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

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

$R = R \setminus r$;

$B = B \bigcup b_{r,k}$;

end if

$r = r + 1$;

end while

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

$j = j + 1$;

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

end while

end if

$k = k + 1$;

end if

end while

For occasions of candidate PDSCH receptions corresponding to rows of R associated with a same value of $b_{r,k}$, where $b_{r,k} \in B$, the UE does not expect to receive more than one PDSCH in a same 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
- $M_{A,c} = 1$, and
- higher layer parameter *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

- $M_{A,c} > 1$, and

- higher layer parameter *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.

If a UE is provided higher layer parameter *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 higher layer parameter *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 higher layer parameter *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 higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is not provided and generates HARQ-ACK information with value of ACK for the second transport block if higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is provided.

A UE determines $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, ..., \tilde{o}_{O^{ACK}-1}^{ACK}$ 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_{cells}^{DL} to the number of serving cells configured by higher layers for the UE

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

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

while $m < M_c$

if higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is not provided, higher layer parameter *PDSCH-CodeBlockGroupTransmission* is not provided, and the UE is configured by higher layer parameter *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 higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is provided, and the UE is configured by higher layer parameter *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 higher layer parameter *PDSCH-CodeBlockGroupTransmission* is provided, and $N_{\text{HARQ-ACK},c}^{\text{CBG/TBmax}}$ CBGs are indicated by higher layer parameter *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 higher layer parameter *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks for the active DL BWP of serving cell c

$\tilde{o}_{j+n_{\text{CBG}}+N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}}^{ACK}$ = 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

$j = j + N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{NARQ-ACK},c}^{\text{CBG/TBmax}}$, where $N_{\text{TB},c}^{\text{DL}}$ is the value of higher layer parameter *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 Subclause 7.2.1, as $n_{\text{HARQ-ACK}} = \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}} \sum_{m=0}^{M_c - 1} N_{m,c}^{\text{received}} + \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}} \sum_{m=0}^{M_c - 1} N_{m,c}^{\text{received,CBG}}$

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 higher layer parameters *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 higher layer parameter *PDSCH-CodeBlockGroupTransmission* is provided and the PDSCH reception is scheduled by a DCI format 1_0, or the number of PDSCH receptions if higher layer parameter *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 higher layer parameter *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 field in a DCI format scheduling the PDSCH reception or the SPS PDSCH release or on the value of the higher layer parameter *dl-DataToUL-ACK* if the PDSCH-to-HARQ feedback timing 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 Subclause 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 Subclause 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 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 Subclause 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.

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 Subclause 9.1.2.1 when a value of the DAI field in DCI format 0_1 is $V_{\text{T-DAI},m}^{\text{UL}} = 1$ 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 $V_{\text{T-DAI},m}^{\text{UL}} = 0$ unless the UE receives only a SPS PDSCH release 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 Subclause 9.1.2.

9.1.3 Type-2 HARQ-ACK codebook determination

This subclause 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 Subclause 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 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 higher layer parameter *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(s) 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 increasing order of serving cell index and then in increasing 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(s) 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 $V_{\text{C-DAI},c,\text{m}}^{\text{DL}}$ 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 $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, ..., \tilde{o}_{O^{ACK}-1}^{ACK}$, for a total number of O_{ACK} HARQ-ACK information bits, according to the following pseudo-code:

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

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_{cells}^{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 $m < M$

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

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

$j = j + 1$

end if

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

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

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

else

$V_{temp2} = V_{T-DAI,m}^{DL}$

end if

if the higher layer parameter *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 higher layer parameter *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

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

elseif the higher layer parameter *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 higher layer parameter *maxNrofCodeWordsScheduledByDCI* with reception of two transport blocks in at least one configured DL BWP of a serving cell,

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

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

else

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

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

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 the higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is not provided to the UE and the UE is configured by higher layer parameter *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

$O^{ACK} = 4 \cdot j + V_{temp2}$

end if

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

Set $c = 0$

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

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

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

$o_{O^{ACK}-1}^{ACK}$ = 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 higher layer parameter *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 higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is not provided and generates HARQ-ACK information with value of ACK for the second transport block if higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is provided.

If a UE is not provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* for each of the $N_{\text{cells}}^{\text{DL}}$ serving cells, or for PDSCH receptions scheduled by DCI format 1_0, or for SPS PDSCH receptions, or for SPS PDSCH release, and 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 Subclause 7.2.1, as

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

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_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 $N_{\text{cells}}^{\text{DL}} > 1$
  - 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, $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$ 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, $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$ is the value of the total DAI in the at least one DCI format 1_1

- $V_{\mathrm{DAI},m_{\mathrm{last}}}^{\mathrm{DL}} = 0$ 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.

- $N_{\mathrm{TB,max}}^{\mathrm{DL}} = 2$ if the value of higher layer parameter *maxNrofCodeWordsScheduledByDCI* is 2 for any serving cell c and higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is not provided; otherwise, $N_{\mathrm{TB,max}}^{\mathrm{DL}} = 1$.

- $N_{m,c}^{\mathrm{received}}$ 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 higher layer parameter *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 higher layer parameter *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.

- $N_{\mathrm{SPS},c}$ 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 or SPS PDSCH release scheduled by DCI format 1_0 within the M PDCCH monitoring occasions.

If a UE

- is provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* for $N_{cells}^{DL,CBG}$ serving cells; and

- is not provided higher layer parameter *PDSCH-CodeBlockGroupTransmission*, for $N_{cells}^{DL,TB}$ serving cells where $N_{cells}^{DL,TB} + N_{cells}^{DL,CBG} = N_{cells}^{DL}$

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_{cells}^{DL} is used for the determination of a first HARQ-ACK sub-codebook for SPS PDSCH releases, SPS PDSCH receptions, and for TB-based PDSCH receptions scheduled by DCI formats 1_0 on the $N_{\mathrm{cells}}^{\mathrm{DL,CBG}}$ serving cells and by DCI formats 1_0 and DCI formats 1_1 on the $N_{\mathrm{cells}}^{\mathrm{DL,TB}}$ serving cells

- N_{cells}^{DL} is replaced by $N_{cells}^{DL,CBG}$ for the determination of a second HARQ-ACK sub-codebook corresponding to the $N_{cells}^{DL,CBG}$ 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 $N_{cells}^{DL,CBG}$ serving cells, the UE generates $N_{\mathrm{HARQ-ACK,max}}^{\mathrm{CBG/TB,max}}$ HARQ-ACK information bits, where $N_{\mathrm{HARQ-ACK,max}}^{\mathrm{CBG/TB,max}}$ is the maximum value of $N_{\mathrm{TB},c}^{\mathrm{DL}} \cdot N_{\mathrm{HARQ-ACK},c}^{\mathrm{CBG/TB,max}}$ across all $N_{cells}^{DL,CBG}$ serving cells and $N_{\mathrm{TB},c}^{\mathrm{DL}}$ is the value of higher layer parameter *maxNrofCodeWordsScheduledByDCI* for serving cell c. If for a serving cell c it is $N_{\mathrm{TB},c}^{\mathrm{DL}} \cdot N_{\mathrm{HARQ-ACK},c}^{\mathrm{CBG/TB,max}} < N_{\mathrm{HARQ-ACK,max}}^{\mathrm{CBG/TB,max}}$, the UE generates NACK for the last $N_{\mathrm{HARQ-ACK,max}}^{\mathrm{CBG/TB,max}} - N_{\mathrm{TB},c}^{\mathrm{DL}} \cdot N_{\mathrm{HARQ-ACK},c}^{\mathrm{CBG/TB,max}}$ HARQ-ACK information bits for serving cell c

  - The pseudo-code operation when higher layer parameter *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 Subclause 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 $N_{\text{cells}}^{\text{DL}} > 1$, $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$ $V_{\text{C-DAI},m_{\text{last}}}^{\text{DL}}$ 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_{C-DAI}^{DL} or V_{T-DAI}^{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 SPS PDSCH reception(s) to multiplex in the PUSCH, as described in Subclause 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 Subclause 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 Subclause 9.1.3.1, with the following modifications:

- For $0 \le m < M-1$, $V_{T-DAI,m}^{DL} = \varnothing$ and for $m = M-1$, $V_{T-DAI,m}^{DL}$ is replaced by $V_{T-DAI,m}^{UL}$ where $V_{T-DAI,m}^{UL}$ 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*.

A UE does not multiplex in a PUSCH transmission HARQ-ACK information that is in response to PDSCH reception or SPS PDSCH release scheduled by DCI format 1_0 or DCI format 1_1 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.

If a UE is not provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* and the UE is scheduled for a PUSCH transmission by DCI format 0_1 with DAI field value $V_{\mathrm{T-DAI}}^{\mathrm{UL}} = 4$ 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 SPS PDSCH reception(s) to multiplex in the PUSCH, as described in Subclause 9.1.3.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission.

If a UE is provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* and the UE is scheduled for a PUSCH transmission by DCI format 0_1 with first DAI field value $V_{\mathrm{T-DAI}}^{\mathrm{UL}} = 4$ or with second DAI field value $V_{\mathrm{T-DAI}}^{\mathrm{UL}} = 4$ 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 SPS PDSCH reception(s) to multiplex in the PUSCH, as described in Subclause 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_{T-DAI}^{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 $X \ge 1$
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 Subclause 9.1.

A UE may transmit one or two PUCCHs on a serving cell in different symbols within a slot of $N_{\mathrm{symb}}^{\mathrm{slot}}$ 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.

9.2.1 PUCCH Resource Sets

If a UE does not have dedicated PUCCH resource configuration, provided by higher layer parameter *PUCCH-ResourceSet* in *PUCCH-Config*, a PUCCH resource set is provided by higher layer parameter *pucch-ResourceCommon* in *SystemInformationBlockType1* through an index to a row of Table 9.2.1-1 for transmission of HARQ-ACK information on PUCCH in an initial active UL BWP of $N_{\mathrm{BWP}}^{\mathrm{size}}$ PRBs provided by *SystemInformationBlockType1*. The PUCCH resource set includes sixteen resources, each corresponding to a PUCCH format, a first symbol, a duration, a PRB offset $RB_{\mathrm{BWP}}^{\mathrm{offset}}$, 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 the Msg3 PUSCH transmission.

The UE does not expect to generate more than one HARQ-ACK information bit prior to establishing RRC connection as described in [12, TS38.331].

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}, $0 \le r_{\text{PUCCH}} \le 15$, 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 control resource set of a PDCCH reception with DCI format 1_0 or DCI format 1_1, as described in Subclause 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 higher layer parameter *pucch-ResourceId*
- an index of the first PRB prior to frequency hopping or for no frequency hopping by higher layer parameter *startingPRB*
- an index of the first PRB after frequency hopping by higher layer parameter *secondHopPRB*;
- an indication for intra-slot frequency hopping by higher layer parameter *intraSlotFrequencyHopping*
- a configuration for a PUCCH format, from PUCCH format 0 through PUCCH format 4, provided by higher layer parameter *format*

If the higher layer parameter *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 higher layer parameter *initialCyclicShift*, a number of symbols for a PUCCH transmission provided by higher layer parameter *nrofSymbols*, a first symbol for the PUCCH transmission provided by higher layer parameter *startingSymbolIndex*.

If the higher layer parameter *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 higher layer parameter *initialCyclicShift*, a number of symbols for a PUCCH transmission provided by higher layer parameter *nrofSymbols*, a first symbol for the PUCCH transmission provided by higher layer parameter *startingSymbolIndex*, and an index for an orthogonal cover code by higher layer parameter *timeDomainOCC*.

If the higher layer parameter *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 higher layer parameter *nrofPRBs*, a number of symbols for a PUCCH transmission provided by higher layer parameter *nrofSymbols*, and a first symbol for the PUCCH transmission provided by higher layer parameter *startingSymbolIndex*.

If the higher layer parameter *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 higher layer parameter *nrofSymbols*, a length for an orthogonal cover code by higher layer parameter *occ-Length*, an index for an orthogonal cover code by higher layer parameter *occ-Index*, and a first symbol for the PUCCH transmission provided by higher layer parameter *startingSymbolIndex*.

A UE can be configured up to four sets of PUCCH resources. A PUCCH resource set is provided by higher layer parameter *PUCCH-ResourceSet* and is associated with a PUCCH resource set index provided by higher layer parameter *pucch-ResourceSetId*, with a set of PUCCH resource indexes provided by higher layer parameter *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 higher layer parameter *maxPayloadMinus1*. 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 higher layer parameter *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 N_{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 $N_{\text{UCI}} \leq 2$ 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 $2 < N_{\text{UCI}} \leq N_2$ where N_2 is provided by higher layer parameter *maxPayloadMinus1* for the PUCCH resource set with *pucch-ResourceSetId = 1*, or
- a third set of PUCCH resources with *pucch-ResourceSetId = 2*, if provided by higher layers, if $N_2 < N_{\text{UCI}} \leq N_3$ where N_3 is provided by higher layer parameter *maxPayloadMinus1* for the PUCCH resource set with *pucch-ResourceSetId = 2*, or

- a fourth set of PUCCH resources with *pucch-ResourceSetId = 3*, if provided by higher layers, if $N_3 < N_{\text{UCI}} \leq 1706$.

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 higher layer parameter *PUCCH-SpatialRelationInfo* if the UE is configured with a single value for higher layer parameter *pucch-SpatialRelationInfoId*; otherwise, if the UE is provided multiple values for higher layer parameter *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 3 msec after the slot where the UE transmits HARQ-ACK information with ACK value corresponding to a PDSCH reception providing the *PUCCH-SpatialRelationInfo*

- If *PUCCH-SpatialRelationInfo* provides higher layer parameter *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 higher layer parameter *servingCellId* is provided, for a serving cell indicated by *servingCellId*
- else if *PUCCH-SpatialRelationInfo* provides higher layer parameter *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 higher layer parameter *servingCellId* is provided, for a serving cell indicated by *servingCellId*
- else *PUCCH-SpatialRelationInfo* provides higher layer parameter *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 higher layer parameters *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 higher layer parameter *additionalDMRS*.

Use of π/2-PBSK, instead of QPSK, for a PUCCH transmission using PUCCH format 3 or 4 is indicated by higher layer parameter *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-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-timing-indicator field values map to values for a set of number of slots provided by higher layer parameter *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-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-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 higher layer parameter *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-timing-indicator field in the DCI format, if present, or provided by higher layer parameter *dl-DataToUL-ACK*. If the PDSCH subcarrier spacing is equal to or larger than the PUCCH subcarrier spacing or, in case of SPS PDSCH release if the PDCCH subcarrier spacing is equal to or larger than the PUCCH subcarrier spacing, $k=0$ corresponds to the slot of the PUCCH transmission that overlaps with the slot of the PDSCH reception or of the PDCCH reception in case of SPS PDSCH release. If the PDSCH subcarrier spacing is smaller than the PUCCH subcarrier spacing or, in case of SPS PDSCH release if the PDCCH subcarrier spacing is smaller than the PUCCH subcarrier spacing, $k=0$ corresponds to the slot of the PUCCH transmission that ends at a same time as the slot of the PDSCH reception or of 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 Subclause 11.1 and Subclause 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 N_{UCI} HARQ-ACK information bits, as described in Subclause 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 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 higher layer parameter *ResourceList* for PUCCH resources from a set of PUCCH resources provided by higher layer parameter *PUCCH-ResourceSet* with a maximum of eight PUCCH resources.

For the first set of PUCCH resources and when the size R_{PUCCH} of higher layer parameter *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

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

where $N_{\text{CCE},p}$ is a number of CCEs in control resource set p of the PDCCH reception for the DCI format 1_0 or DCI format 1_1 as described in Subclause 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 symbols from a first symbol of the first resource for PUCCH transmission in the slot where, for UE processing capability 1 and subcarrier spacing configuration μ, $N_3 = 8$ 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 higher layer parameter *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 higher layer parameter

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 9.2.3-3 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	$m_{\text{CS}} = 0$	$m_{\text{CS}} = 6$

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	$m_{\text{CS}} = 0$	$m_{\text{CS}} = 3$	$m_{\text{CS}} = 6$	$m_{\text{CS}} = 9$

If a UE transmits a PUCCH with HARQ-ACK information using PUCCH format 1, the UE is provided a value for m_0 by higher layer parameter *initialCyclicShift* of *PUCCH-format1*.

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 higher layer parameter *nrofPRBs* of *PUCCH-format2* or *nrofPRBs* of *PUCCH-format3* and starts 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 Subclause 9.2.5.2. 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 higher layer parameter *SchedulingRequestResourceId* providing a PUCCH format 0 resource or a PUCCH format 1 resource as described in Subclause 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 higher layer parameter *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 $(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - SR_{\text{OFFSET}}) \bmod SR_{\text{PERIODICITY}} = 0$.

If $SR_{\text{PERIODICITY}}$ is one slot, the UE expects that SR_{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 higher layer parameter *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 higher layer parameter *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 Subclause 11.1 and Subclause 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 Subclause 9.2.3 and by setting $m_{cs} = 0$. 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 Subclause is applicable to the case that a PUCCH transmission is over a single slot. The case that a PUCCH transmission is with repetitions over multiple slots is described in Subclause 9.2.6.

If a UE is configured with multiple PUCCH resources in a slot to transmit only semi-persistent or periodic CSI reports

- if the UE is not provided higher layer parameter *multi-CSI-PUCCH-ResourceList*, the UE determines a first resource corresponding to a CSI report with the highest priority [6, TS38.214]
  - 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 higher layer parameter *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 Subclause 9.2.5.2

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 Subclauses 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 PUCCHs or PUSCHs 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 $T_{\text{proc},1}^{\text{mux}} = (N_1 + d_{1,1} + 1) \cdot (2048+144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$ after a last symbol of any corresponding PDSCH, where μ corresponds to the smallest subcarrier spacing configuration among the subcarrier spacing configuration of the PDCCH scheduling the PDSCH, the subcarrier spacing configuration of the PDSCH, and the smallest subcarrier spacing configuration for the group of overlapping PUCCHs and PUSCHs where the UE transmits HARQ-ACK information in response to the reception of the PDSCH
- S_0 is not before a symbol with CP starting after $T_{\text{proc,release}}^{\text{mux}} = (N + d_{1,1} + 1) \cdot (2048+144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C$ after a last symbol of any corresponding SPS PDSCH release, where N is described in Subclause 10.2 and μ corresponds to the smallest subcarrier spacing configuration among the subcarrier spacing configuration of the PDCCH providing the SPS PDSCH release and the smallest subcarrier spacing configuration for the group of overlapping PUCCHs or overlapping PUCCHs and PUSCHs where the UE transmits HARQ-ACK information in response to the detection of the SPS PDSCH release
- 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 $T_{\text{proc},2}^{\text{mux}} = \max\left((N_2 + d_{2,1} + 1) \cdot (2048+144) \cdot \kappa \cdot 2^{-\mu} \cdot T_C, d_{2,2}\right)$ after a last symbol of a PDCCH scheduling the PUSCH or after a last symbol of 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 subcarrier spacing configuration among the subcarrier spacing configuration of the PDCCHs and the smallest subcarrier spacing of the overlapping PUCCHs and PUSCHs

- 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 $T_{\text{proc,CSI}}^{\text{mux}} = \max\left((Z+d)\cdot(2048+144)\cdot\kappa\cdot 2^{-\mu}\cdot T_C, d_{2,2}\right)$ after a last symbol of a PDCCH with the DCI format scheduling the PUSCH or after a last symbol of 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 subcarrier spacing configuration among the subcarrier spacing configuration of the PDCCHs, the smallest subcarrier spacing configuration for the group of the overlapping PUCCHs and PUSCHs, and the smallest subcarrier spacing configuration of aperiodic CSI-RS associated with the DCI format scheduling the PUSCH, 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] for PDSCH receptions, 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 subcarrier spacing 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 $Z'^{\text{mux}}_{\text{proc,CSI}} = (Z'+d)\cdot(2048+144)\cdot\kappa\cdot 2^{-\mu}\cdot T_C$ 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 subcarrier spacing configuration among the subcarrier spacing configurations of the PDCCHs scheduling the PUSCHs, the smallest subcarrier spacing configuration of aperiodic CSI-RSs associated with DCI formats provided by the PDCCHs triggering the aperiodic CSI reports, and the smallest subcarrier spacing 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 higher layer parameter *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 periodic/semi-persistent 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 HARQ-ACK information and/or the SR being multiplexed on two one PUCCH transmissions with periodic/semi-persistent CSI reports

the UE

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

Set Q to the set of resources for transmission of corresponding PUCCHs in a slot 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 $\text{order}(Q)$
- if the UE is not provided higher layer parameter *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 higher layer parameter *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 $j \le \mathcal{O}(Q)-1$

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

$o = o+1$

$j = j+1$

else

if $o > 0$

multiplex UCI for resources $\{Q(j-o), Q(j-o+1), ..., Q(j)\}$ in a single resource as described in Subclauses 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

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
- 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 Subclause 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 Subclause 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.

Subclauses 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 time-overlapping PUSCH in a same frequency band in the slot

For the determination of the number of PRBs in Subclauses 9.2.5.1 and 9.2.5.2, $O_{\text{CRC}} = 11$ if the number of respective UCI bits is larger than or equal to 360; otherwise, O_{CRC} is the number of CRC bits calculated based on the number of respective UCI bits as described in [5, TS 38.212].

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 higher layer parameters *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 periodic/semi persistent CSI transmission 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 Subclause 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 higher layer parameter *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 Subclause 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 Subclause 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 Subclause 9.2.3.

If a UE would transmit a PUCCH with 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 Subclause 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 UCI bits in a PUCCH using a resource with PUCCH format 2 or PUCCH format 3 or PUCCH format 4 for transmission of HARQ-ACK information bits. 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 periodic/semi-persistent CSI 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 periodic/semi-persistent CSI information bits as described in Subclause 9.2.5.2 and the UE transmits a PUCCH with the combined 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 higher layer parameter *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 Subclause 9.2.5.2. 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

A UE multiplexes HARQ-ACK, with or without SR, and periodic/semi-persistent CSI in a same PUCCH if the UE is provided higher layer parameter *simultaneousHARQ-ACK-CSI*; otherwise, the UE drops the periodic/semi-persistent CSI report(s) and includes only HARQ-ACK, with or without SR, in the PUCCH.

For a transmission occasion of a single periodic/semi-persistent CSI report, a PUCCH resource is provided by higher layer parameter *pucch-CSI-ResourceList*. For a transmission occasion of multiple periodic/semi-persistent CSI reports, corresponding PUCCH resources are provided by higher layer parameter *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 higher layer parameter *simultaneousHARQ-ACK-CSI*.

A UE is configured by higher layer parameter *maxCodeRate* a code rate for multiplexing HARQ-ACK, SR, and periodic/semi-persistent CSI report(s) in a PUCCH transmission using PUCCH format 2, PUCCH format 3, or PUCCH format 4. If the PUCCH transmission uses PUCCH format 4 and if the total number of UCI bits is more than 115, the UE drops CSI reports as described in [6, TS38.214] until the total number of UCI bits is smaller than or equal to 115.

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 of a CSI report with wideband CSI and sub-band CSI.

If a UE transmits periodic/semi-persistent CSI reports that include Part 2 CSI reports, the UE determines a PUCCH resource and a number of PRBs in the PUCCH resource assuming that each of the periodic/semi-persistent CSI reports indicates rank 1. 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 Subclause 9.2.5.1
- $O_{\text{CSI}} = \sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} (O_{\text{CSI-part1},n} + O_{\text{CSI-part2},n})$, where $O_{\text{CSI-part1},n}$ is a number of Part 1 CSI report bits for CSI report with priority level n, $O_{\text{CSI-part2},n}$ is a number of Part 2 CSI report bits, if any, for CSI report with priority level n [6, TS 38.214], and $N_{\text{CSI}}^{\text{total}}$ is a number of periodic/semi-persistent 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 higher layer parameter *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 higher layer parameter *nrofPRBs* in *PUCCH-format2* for PUCCH format 2 or by higher layer parameter *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 higher layer parameter *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 higher layer parameter *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 higher layer parameter *pi2BPSK* for PUCCH format 3 or PUCCH format 4. For PUCCH format 2, $Q_m=2$

If a UE has 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 the UE is provided by higher layer parameter *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 Subclause 9.2.1, where the resources are indexed according to an ascending order for the product of a number of corresponding REs, where for PUCCH format 4 the number of REs is $N_{\text{sc}}^{\text{RB}}/N_{\text{SF}}^{\text{PUCCH,4}}$, modulation order Q_m, and configured code rate r;

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

  - else if $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right) > M_{\text{RB},j}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI},j}^{\text{PUCCH}} \cdot Q_m \cdot r$ and $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right) \le M_{\text{RB},j+1}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI},j+1}^{\text{PUCCH}} \cdot Q_m \cdot r$, $0 \le j < J-1$, the UE transmits a PUCCH conveying HARQ-ACK information, SR and periodic/semi-persistent 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 order as described in [6, TS 38.214]

- else, the UE transmits the HARQ-ACK information, SR, and a CSI report as described in Subclause 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, TS38.214] 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 Subclause 9.2.1 and Subclause 9.2.3 for N_{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 periodic/semi-persistent 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 Subclauses 9.2.3 and 9.2.5.1;
- else, the UE selects $N_{\text{CSI}}^{\text{reported}}$ CSI report(s) for transmission together with HARQ-ACK and SR in ascending priority order, where the value of $N_{\text{CSI}}^{\text{reported}}$ satisfies

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

$$\left(O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}+1}O_{\text{CSI-part1},n}+O_{\text{CRC,CSI-part1},N+1}\right)>M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb-UCI}}^{\text{PUCCH}}\cdot Q_m\cdot r$$, 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 Subclause 9.2.1 and Subclause 9.2.3 for N_{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 $N_{\text{CSI}}^{\text{total}}$ periodic/semi-persistent 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 Subclauses 9.2.3 and 9.2.5.1
- else,
  - if for $N_{\text{CSI-part2}}^{\text{reported}}>0$ CSI part 2 report priority level(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 $N_{\text{CSI-part2}}^{\text{reported}}$ CSI part 2 report priority level(s), according to [6, TS 38.214], for transmission together with the HARQ-ACK, SR and $N_{\text{CSI}}^{\text{total}}$ CSI part 1 reports , where $O_{\text{CSI-part1},n}$ is the number of CSI part

1 report bits for the n_{th} CSI report and $O_{\text{CSI-part2},n}$ is the number of CSI part 2 report bits for the n_{th} CSI report priority level, $O_{\text{CRC, CSI-part2},N}$ 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 CSI part 2 reports and selects $N_{\text{CSI,part1}}^{\text{reported}}$ CSI part 1 report(s), in ascending priority order, 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 higher layer parameter *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 a PUCCH transmission by respective higher layer parameters *nrofSlots*.

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

- the UE repeats the PUCCH transmission with the UCI over $N_{\text{PUCCH}}^{\text{repeat}}$ slots
- a PUCCH transmission in each of the $N_{\text{PUCCH}}^{\text{repeat}}$ slots has a same number of consecutive symbols, as provided by higher layer parameter *nrofSymbols* in *PUCCH-format1*, *nrofSymbols* in *PUCCH-format3*, or *nrofSymbols* in *PUCCH-format4*
- a PUCCH transmission in each of the $N_{\text{PUCCH}}^{\text{repeat}}$ slots has a same first symbol, as provided by higher layer parameter *startingSymbolIndex* in *PUCCH-format1*, *startingSymbolIndex* in *PUCCH-format3*, or *startingSymbolIndex* in *PUCCH-format4*
- the UE is configured by higher layer parameter *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 higher layer parameter *startingPRB*, in slots with even number and starting from the second PRB, provided by higher layer parameter *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 $N_{\text{PUCCH}}^{\text{repeat}}$ 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 higher layer parameter *nrofSymbols* for the corresponding PUCCH format, the UE does not transmit the PUCCH in the slot.

If a UE is provided higher layer parameter *TDD-UL-DL-ConfigurationCommon*, or is additionally provided higher layer parameter *TDD-UL-DL-ConfigDedicated*, as described in Subclause 11.1, the UE determines the $N_{\text{PUCCH}}^{\text{repeat}}$ slots for a PUCCH transmission starting from a slot indicated to the UE as described in Subclause 9.2.3 and having

- an UL symbol or flexible symbol provided by higher layer parameter *startingSymbolIndex* in *PUCCH-format1*, or in *PUCCH-format3*, or in *PUCCH-format4* as a first symbol, and
- consecutive UL symbols or flexible symbols, starting from the first symbol, equal to or larger than a number of symbols provided by higher layer parameter *nrofsymbols* in *PUCCH-format1*, or in *PUCCH-format3*, or in *PUCCH-format4*

If a UE is not provided higher layer parameter *TDD-UL-DL-ConfigurationCommon*, the UE determines the $N_{\text{PUCCH}}^{\text{repeat}}$ slots for a PUCCH transmission as the $N_{\text{PUCCH}}^{\text{repeat}}$ consecutive slots starting from a slot indicated to the UE as described in Subclause 9.2.3.

If a UE would transmit a PUCCH over a first number $N_{\text{PUCCH}}^{\text{repeat}}>1$ 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 Subclause 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 $N_{\text{PUCCH}}^{\text{repeat,1}}>1$ slots.

If a UE would transmit a first PUCCH over a first number $N_{\text{PUCCH}}^{\text{repeat,1}}>1$ of slots and a second PUCCH over a second number of $N_{\text{PUCCH}}^{\text{repeat,2}}>1$ slots and the transmissions of the first PUCCH and the second PUCCH would overlap in a third number of slots then, for the third 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 the second PUCCH to start at a same slot and include a UCI type with same priority
- if the first PUCCH and the second PUCCH 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 the second PUCCH 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 includes the UCI type with lower priority

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

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

If a UE has a PUSCH transmission that overlaps with a PUCCH transmission that includes HARQ-ACK information and/or semi-persistent/periodic CSI reports and the conditions in Subclause 9.2.5 for multiplexing the UCI in the PUSCH are satisfied, the UE multiplexes the HARQ-ACK information and/or the semi-persistent/periodic CSI reports in the PUSCH.

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, 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 configured by higher layers for the corresponding HARQ-ACK information, CSI part 1 reports and CSI part 2 reports.

HARQ-ACK information offsets $\beta_{\text{offset}}^{\text{HARQ-ACK}}$ are configured to values according to Table 9.3-1. The higher layer parameters *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.

CSI part 1 report and CSI part 2 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. Higher layer parameters *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 CSI part 1 reports or CSI part 2 reports in the PUSCH. Higher layer parameters *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 CSI part 1 reports or CSI part 2 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 higher layer parameter *uci-OnPUSCH*, the UE is provided by each of higher layer parameters {*betaOffsetACK-Index1*, *betaOffsetACK-Index2*, *betaOffsetACK-Index3*} a set of four $I_{\text{offset}}^{\text{HARQ-ACK}}$ indexes, by each of higher layer parameters {*betaOffsetCSI-Part1-Index1*, *betaOffsetCSI-Part1-Index2*} a set of four $I_{\text{offset}}^{\text{CSI-1}}$ indexes and by each of higher layer parameters { *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, CSI part 1 reports, and CSI part 2 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

$I_{\text{offset},0}^{\text{HARQ-ACK}}$ or $I_{\text{offset},1}^{\text{HARQ-ACK}}$ or $I_{\text{offset},2}^{\text{HARQ-ACK}}$	$\beta_{\text{offset}}^{\text{HARQ-ACK}}$
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

$I_{\text{offset},0}^{\text{CSI-1}}$ or $I_{\text{offset},1}^{\text{CSI-2}}$	$I_{\text{offset},0}^{\text{CSI-2}}$ or $I_{\text{offset},1}^{\text{CSI-2}}$	$\beta_{\text{offset}}^{\text{CSI-1}}$ $\beta_{\text{offset}}^{\text{CSI-2}}$
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	($I_{offset,0}^{HARQ-ACK}$ or $I_{offset,1}^{HARQ-ACK}$ or $I_{offset,2}^{HARQ-ACK}$), ($I_{offset,0}^{CSI-1}$ or $I_{offset,0}^{CSI-2}$), ($I_{offset,1}^{CSI-1}$ or $I_{offset,1}^{CSI-2}$)
'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 common search spaces 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 control resource sets 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 *SystemInformationBlockType1* 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 common search space 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 *SystemInformationBlockType1*, 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 common search space 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 common search space on the serving cell according to the procedure described in Subclause 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 the UE is configured for carrier aggregation operation over more than 4 cells, the UE does not expect to monitor per slot a number of PDCCH candidates that is larger than the maximum number.

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 common search space set or a UE-specific search space set. A UE monitors PDCCH candidates in one or more of the following search spaces sets

- a Type0-PDCCH common search space set configured by *pdcch-ConfigSIB1* in *MasterInformationBlock* 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;

- a Type0A-PDCCH common search space set configured by *searchSpaceOtherSystemInformation* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on the primary cell;

- a Type1-PDCCH common search space 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 common search space set configured by *pagingSearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a P-RNTI on the primary cell;

- a Type3-PDCCH common search space 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 UE-specific search space set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = ue-Specific* for DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI(s).

If a UE is not provided higher layer parameter *searchSpace-SIB1* for Type0-PDCCH common search space set, the UE determines a control resource set and PDCCH monitoring occasions for Type0-PDCCH common search space set as described in Subclause 13. The Type0-PDCCH common search space set is defined by the CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level given in Table 10.1-1. The control resource set configured for Type0-PDCCH common search space set has control resource set index 0. The Type0-PDCCH common search space set has search space set index 0.

If a UE is not provided a control resource set for Type0A-PDCCH common search space, the corresponding control resource set is same as the control resource set for Type0-PDCCH common search space. If the UE is not provided higher layer parameter *searchSpaceOtherSystemInformation* for Type0A-PDCCH common search space set, the Type0A-PDCCH common search space set is same as the Type0-PDCCH common search space set. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level for Type0A-PDCCH common search space are given in Table 10.1-1.

For Type1-PDCCH common search space, a UE is provided a configuration for a search space by higher layer parameter *ra-SearchSpace*. If a UE is not provided by higher layers a control resource set for Type1-PDCCH common search space, the control resource set for Type1-PDCCH common search space is same as the control resource set for Type0-PDCCH common search space..

If a UE is not provided a control resource set for Type2-PDCCH common search space, the corresponding control resource set is same as the control resource set for Type0-PDCCH common search space. If a UE is not provided higher layer parameter *pagingSearchSpace* for Type2-PDCCH common search space set, the Type2-PDCCH common search space set is same as the Type0-PDCCH common search space set. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level for Type2-PDCCH common search space are given in Table 10.1-1.

The UE may assume that the DM-RS antenna port associated with PDCCH receptions in the control resource set configured by *pdcch-ConfigSIB1* in *MasterInformationBlock* and for 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]. The value for the DM-RS scrambling sequence initialization is the cell ID. A subcarrier spacing is provided by higher layer parameter *subCarrierSpacingCommon* in *MasterInformationBlock*.

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 common search space if the SS/PBCH block or the CSI-RS the UE selects for PRACH association, as described in Subclause 8.1, does not have same QCL-TypeD [6, TS 38.214] with a DM-RS for monitoring the PDCCH, and if the PDCCH or an associated PDSCH overlaps in at least one symbol with a PDCCH the UE monitors in a Type1-PDCCH common search space or with an associated PDSCH.

If a UE is configured with one or more downlink bandwidth parts (BWPs), as described in Subclause 12, the UE can be configured with *PDCCH-ConfigCommon* and *PDCCH-Config* for each configured DL BWP on the primary cell, other than the initial active DL BWP, as described in Subclause 12.

If a UE is provided one or more search space sets by corresponding one or more higher layer parameters *searchSpaceZero*, *searchSpaceSIB1*, *searchSpaceOtherSystemInformation*, *pagingSearchSpace*, *ra-SearchSpace*, and

the UE is provided with 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 the C-RNTI, the MCS-C-RNTI, or the CS-RNTI in the one or more search space sets.

Table 10.1-1: CCE aggregation levels and maximum number of PDCCH candidates per CCE aggregation level for common search space sets configured by *searchSpace-SIB1*

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 $P \le 3$ control resource sets. For each control resource set, the UE is provided the following by higher layer parameter *ControlResourceSet*:

- a control resource set index p, $0 \le p < 12$, by higher layer parameter *controlResourceSetId*;
- a DM-RS scrambling sequence initialization value by higher layer parameter *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 higher layer parameter *precoderGranularity*;
- a number of consecutive symbols provided by higher layer parameter *duration*;
- a set of resource blocks provided by higher layer parameter *frequencyDomainResources*;
- CCE-to-REG mapping parameters provided by higher layer parameter *cce-REG-MappingType*;
- an antenna port quasi co-location, from a set of antenna port quasi co-locations provided by higher layer parameter *TCI-States*, indicating quasi co-location information of the DM-RS antenna port for PDCCH reception in a respective control resource set;
- an indication for a presence or absence of a transmission configuration indication (TCI) field for DCI format 1_1 transmitted by a PDCCH in control resource set p, by higher layer parameter *TCI-PresentInDCI*.

When *precoderGranularity* = *allContiguousRBs*, a UE does not expect to be configured a set of resource blocks of a control resource set that includes more than four sub-sets of resource blocks that are not contiguous in frequency.

For each control resource set in a DL BWP of a serving cell, a respective higher layer parameter *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 position $N_{\text{BWP}}^{\text{start}}$ where the first common RB of the first group of 6 PRBs has index $6 \cdot \lceil N_{\text{BWP}}^{\text{start}} / 6 \rceil$. A group of 6 PRBs is allocated to a control resource set if a corresponding bit value in the bitmap is 1; else, if a corresponding bit value in the bitmap is 0, the group of 6 PRBs is not allocated to the control resource set.

If a UE has received initial configuration of more than one TCI states for PDCCH receptions by higher layer parameter *TCI-States* but has not received a MAC CE activation command for one of the TCI states, 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 the UE has received a MAC CE activation command for one of the TCI states, the UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.

If a UE has received higher layer parameter *TCI-States* for PDCCH receptions containing a single TCI state, the UE assumes that the DM-RS antenna port associated with PDCCH receptions is quasi co-located with the one or more DL RS configured by the TCI state.

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 higher layer parameter *SearchSpace*:

- a search space set index s, $0 \le s < 40$, by higher layer parameter *searchSpaceId*;
- an association between the search space set s and a control resource set p by higher layer parameter *controlResourceSetId*;
- a PDCCH monitoring periodicity of $k_{p,s}$ slots and a PDCCH monitoring offset of $o_{p,s}$ slots, by higher layer parameter *monitoringSlotPeriodicityAndOffset*;
- a PDCCH monitoring pattern within a slot, indicating first symbol(s) of the control resource set within a slot for PDCCH monitoring, by higher layer parameter *monitoringSymbolsWithinSlot*;
- a number of PDCCH candidates $M_{p,s}^{(L)}$ per CCE aggregation level L by higher layer parameters *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 common search space set or a UE-specific search space set by higher layer parameter *searchSpaceType*;
- if search space set s is a common search space set
  - an indication by higher layer parameter *dci-Format0-0-AndFormat1-0* to monitor PDCCH candidates for DCI format 0_0 and DCI format 1_0 with CRC scrambled by a C-RNTI, an MCS-C-RNTI (if configured), a CS-RNTI (if configured), RA-RNTI, TC-RNTI, P-RNTI, or a SI-RNTI
  - an indication by higher layer parameter *dci-Format2-0* to monitor one or two PDCCH candidates for DCI format 2_0 and a corresponding CCE aggregation level
  - an indication by higher layer parameter *dci-Format2-1* to monitor PDCCH candidates for DCI format 2_1
  - an indication by higher layer parameter *dci-Format2-2* to monitor PDCCH candidates for DCI format 2_2
  - an indication by higher layer parameter *dci-Format2-3* to monitor PDCCH candidates for DCI format 2_3
- if search space set s is a UE-specific search space set, an indication by higher layer parameter *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

The UE can also be provided, by higher layer parameter *duration*, a duration of $T_{p,s} < k_{p,s}$ slots indicating a number of slots that the search space set s exists.

If the higher layer parameter *monitoringSymbolsWithinSlot* indicates to a UE to monitor PDCCHin 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 subcarrier spacing 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 control resource set that results to a PDCCH candidate mapping to symbols of different slots.

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

A UE determines a PDCCH monitoring occasion from the PDCCH monitoring periodicity, the PDCCH monitoring offset, and the PDCCH monitoring pattern within a slot. For search space set s in control resource set p, 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 $\left(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - o_{p,s}\right) \bmod k_{p,s} = 0$. If the UE is provided higher layer parameter *duration*, the UE monitors PDCCH for search space set s in control resource set p for $T_{p,s}$ consecutive slots, starting from slot $n_{s,f}^{\mu}$, and does not monitor PDCCH for search space set s in control resource set p for the next $k_{p,s} - T_{p,s}$ consecutive slots.

A UE-specific search space 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 higher layer parameter *CrossCarrierSchedulingConfig* for a serving cell the carrier indicator field value corresponds to the value indicated by *CrossCarrierSchedulingConfig.*

For a DL BWP of a serving cell on which a UE monitors PDCCH candidates in a UE-specific search space, if the UE is not configured with a carrier indicator field, the UE monitors the PDCCH candidates without carrier indicator field. For a serving cell on which a UE monitors PDCCH candidates in a UE-specific search space, 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 a 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 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 control resource set 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 a serving cell corresponding to carrier indicator field value n_{CI} are given by

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

where

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

for a UE-specific search space, $Y_{p,n_{s,f}^{\mu}} = \left(A_p \cdot Y_{p,n_{s,f}^{\mu}-1}\right) \bmod D$, $Y_{p,-1} = n_{\mathrm{RNTI}} \neq 0$, $A_p = 39827$ for $p \bmod 3 = 0$, $A_p = 39829$ for $p \bmod 3 = 1$, $A_p = 39839$ for $p \bmod 3 = 2$, and $D = 65537$;

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

$N_{\mathrm{CCE},p}$ is the number of CCEs, numbered from 0 to $N_{\mathrm{CCE},p} - 1$, in control resource set p;

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

$m_{s,n_{CI}} = 0, ..., M_{p,s,n_{CI}}^{(L)} - 1$, where $M_{p,s,n_{CI}}^{(L)}$ 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 common search space, $M_{p,s,\max}^{(L)} = M_{p,s,0}^{(L)}$;

for a UE-specific search space, $M_{p,s,\max}^{(L)}$ is the maximum of $M_{p,s,n_{CI}}^{(L)}$ over all configured n_{CI} values for a CCE aggregation level L of search space set s in control resource set p;

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 higher layer parameter *searchSpaceSharingCA-UL*, and has a PDCCH candidate with CCE aggregation level L in control resource set p for a DCI format 0_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 control resource set p for a DCI format 0_1 having a second size and associated with serving cell $n_{CI,1}$ if the first size and the second size are same. A UE that is configured for operation with carrier aggregation, and indicates support of search space sharing through higher layer parameter *searchSpaceSharingCA-DL*, and has a PDCCH candidate with CCE aggregation level L in

control resource set p for 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 control resource set p for a DCI format 1_1 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.

A PDCCH candidate with index $m_{s_j,n_{CI}}$ for a search space set s_j using a set of CCEs in a control resource set p for serving cell n_{CI} is not counted as a monitored PDCCH candidate 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 control resource set p 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 as a monitored PDCCH candidate.

Table 10.1-2 provides the maximum number of monitored PDCCH candidates, $M_{\text{PDCCH}}^{\max,\text{slot},\mu}$, for subcarrier spacing 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 subcarrier spacing 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, $C_{\text{PDCCH}}^{\max,\text{slot},\mu}$, for subcarrier spacing 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 control resource set indexes, or
- different first symbols for the reception of the respective PDCCH candidates.

Table 10.1-3: Maximum number $C_{\text{PDCCH}}^{\max,\text{slot},\mu}$ of non-overlapped CCEs per slot for subcarrier spacing 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 $C_{\text{PDCCH}}^{\max,\text{slot},\mu}$
0	56
1	56
2	48
3	32

If a UE is capable for operation with carrier aggregation with a maximum of 4 downlink cells and the UE is configured with $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells for each corresponding subcarrier spacing configuration μ where $\sum_{\mu=0}^{3} N_{\text{cells}}^{\text{DL},\mu} \le 4$, and for scheduling on a same cell, the UE is expected to be capable to monitor $M_{\text{PDCCH}}^{\max,\text{slot},\mu}$ PDCCH candidates, and $C_{\text{PDCCH}}^{\max,\text{slot},\mu}$ non-overlapped CCEs per slot per cell with subcarrier spacing configuration μ.

If a UE is capable for operation with carrier aggregation with more than 4 downlink cells, and the UE indicates through *pdcch-BlindDetectionCA* a capability to monitor PDCCH candidates for $N_{\text{cells}}^{\text{cap}} \ge 4$ downlink cells, and the UE is

configured with $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with subcarrier spacing configuration μ, and for scheduling on a same cell or for cross-carrier scheduling over the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells, the UE is expected to be able to monitor a total of $M_{\text{PDCCH}}^{\text{total},\mu} = \min\left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} \Big/ \sum_{\mu=0}^{3} N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\}$ PDCCH candidates for DCI formats with different size and/or different corresponding DM-RS scrambling sequences per slot over the $N_{\text{cells}}^{\text{DL},\mu}$ cells with subcarrier spacing configuration μ, and a total of $C_{\text{PDCCH}}^{\text{total},\mu} = \min\left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} \Big/ \sum_{\mu=0}^{3} N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\}$ non-overlapped CCEs per slot over the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with subcarrier spacing configuration μ. The maximum number of PDCCH candidates and the maximum number of non-overlapped CCEs per slot and per cell of the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells are $M_{\text{PDCCH}}^{\text{max,slot},\mu}$ and $C_{\text{PDCCH}}^{\text{max,slot},\mu}$, respectively.

If aUE is configured with a total of $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with same subcarrier spacing configuration μ or if the UE indicates through *pdcch-BlindDetectionCA* a capability to monitor PDCCH candidates for $N_{\text{cells}}^{\text{cap}} \geq 4$ downlink cells then, for cross-carrier scheduling over the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with same subcarrier spacing configuration μ, including the scheduling cell, the UE is expected to monitor $\min\left(N_{\text{cells}}^{\text{DL},\mu}, N_{\text{cells}}^{\text{cap}}\right) \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu}$ PDCCH candidates per slot on the scheduling cell and $\min\left(N_{\text{cells}}^{\text{DL},\mu}, N_{\text{cells}}^{\text{cap}}\right) \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu}$ non-overlapped CCEs per slot on the scheduling cell.

A UE does not expect to be configured common search space sets that result to corresponding total numbers of monitored PDCCH candidates and non-overlapped CCEs per slot that exceed the corresponding maximum numbers per slot.

For same cell scheduling, 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 monitored PDCCH candidates and the number of non-overlapped CCEs per slot are separately counted for each serving cell.

For all search space sets within a slot n, denote by S_{css} a set of common search space sets with cardinality of I_{css} and by S_{uss} a set of UE-specific search space sets with cardinality of J_{uss}. The location of UE-specific search space sets s_j, $0 \leq j < J_{\text{uss}}$, in S_{uss} is according to an ascending order of the search space set index.

Denote by $M_{S_{\text{css}}(i)}^{(L)}$, $0 \leq i < I_{\text{css}}$, the number of configured PDCCH candidates for common search space set $S_{\text{css}}(i)$ and by $M_{S_{\text{uss}}(j)}^{(L)}$, $0 \leq j < J_{\text{uss}}$, the number of PDCCH candidates for UE-specific search space set $S_{\text{uss}}(j)$.

For the common search space sets, a UE monitors $M_{\text{PDCCH}}^{\text{CSS}} = \sum_{i=0}^{I_{\text{css}}-1} \sum_{L} M_{S_{\text{css}}(i)}^{(L)}$ PDCCH candidates requiring a total of $C_{\text{PDCCH}}^{\text{CSS}}$ non-overlapping CCEs in a slot.

The UE allocates monitored PDCCH candidates to UE-specific search space sets for the primary cell with subcarrier spacing configuration μ in slot n according to the following pseudocode. A UE does not expect to monitor PDCCH in a UE-specific search space set without monitored PDCCH candidates.

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 monitored PDCCH candidates for the common search space sets and the monitored PDCCH candidates for all search space sets $S_{\text{uss}}(k)$, $0 \leq k \leq j$.

Set $M_{\text{PDCCH}}^{\text{uss}} = M_{\text{PDCCH}}^{\text{max,slot},\mu} - M_{\text{PDCCH}}^{\text{css}}$

Set $C_{\text{PDCCH}}^{\text{uss}} = C_{\text{PDCCH}}^{\max,\text{slot},\mu} - C_{\text{PDCCH}}^{\text{css}}$

Set $j = 0$

while $\sum_{L} M_{S_{\text{uss}}(j)}^{(L)} \le M_{\text{PDCCH}}^{\text{uss}}$ AND $\mathcal{C}\left(V_{\text{CCE}}(S_{\text{uss}}(j))\right) \le C_{\text{PDCCH}}^{\text{uss}}$

allocate $\sum_{L} M_{S_{\text{uss}}(j)}^{(L)}$ monitored PDCCH candidates to UE-specific search space set $S_{\text{uss}}(j)$

$M_{\text{PDCCH}}^{\text{uss}} = M_{\text{PDCCH}}^{\text{uss}} - \sum_{L} M_{S_{\text{uss}}(j)}^{(L)}$;

$C_{\text{PDCCH}}^{\text{uss}} = C_{\text{PDCCH}}^{\text{uss}} - \mathcal{C}\left(V_{\text{CCE}}(S_{\text{uss}}(j))\right)$;

$j = j + 1$;

end while

For a serving cell and at any time, a UE expects to have received at most 16 PDCCHs with DCI formats scheduling 16 PDSCH receptions for which the UE has not received any corresponding PDSCH symbol and at most 16 PDCCHs with DCI formats scheduling 16 PUSCH transmissions for which the UE has not transmitted any corresponding PUSCH symbol.

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 Subclause 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 higher layer parameters *resourceblocks* and s*ymbolsInResourceBlock* in *RateMatchPattern*, or if the UE is additionally provided higher layer parameter *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 subcarriers that overlap with subcarriers 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 higher layer parameter *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 considers the DCI format as having been detected with a non-matching CRC.

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
Resource block 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. For UE processing capability 1 [6, TS 36.214] and for the subcarrier spacing of the PDCCH reception, $N=10$ for 15 kHz, $N=12$ for 30 kHz, $N=22$ for 60 kHz, and $N=25$ for 120 kHz. For a UE with capability 2 [6, TS 36.214] in frequency range 1 and for the subcarrier spacing of the PDCCH reception, $N=5$ for 15 kHz, $N=5.5$ for 30 kHz, and $N=11$ for 60 kHz.

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 higher layer parameter *TDD-UL-DL-ConfigurationCommon*, the UE sets the slot format per slot over a number of slots as indicated by higher layer parameter *TDD-UL-DL-ConfigurationCommon*.

The higher layer parameter *TDD-UL-DL-ConfigurationCommon* provides

- a reference subcarrier spacing configuration μ_{ref} by higher layer parameter *referenceSubcarrierSpacing*
- a higher layer parameter *pattern1*.

The higher layer parameter *pattern1* provides

- a slot configuration period of P msec by higher layer parameter *dl-UL-TransmissionPeriodicity*
- a number of slots d_{slots} with only downlink symbols by higher layer parameter *nrofDownlinkSlots*
- a number of downlink symbols d_{sym} by higher layer parameter *nrofDownlinkSymbols*
- a number of slots u_{slots} with only uplink symbols by higher layer parameter *nrofUplinkSlots*
- a number of uplink symbols u_{sym} by higher layer parameter *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 subcarrier spacing 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 higher layer parameter *TDD-UL-DL-ConfigurationCommon* provides both higher layer parameters *pattern1* and *pattern2*, the UE sets the slot format per slot over a first number of slots as indicated by higher layer parameter *pattern1* and the UE sets the slot format per slot over a second number of slots as indicated by *pattern2*.

The higher layer parameter *pattern2* provides

- a slot configuration period of P_2 msec by higher layer parameter *dl-UL-TransmissionPeriodicity*
- a number of slots $d_{\text{slots},2}$ with only downlink symbols by higher layer parameter *nrofDownlinkSlots*
- a number of downlink symbols $d_{\text{sym},2}$ by higher layer parameter *nrofDownlinkSymbols*
- a number of slots $u_{\text{slots},2}$ with only uplink symbols by higher layer parameter *nrofUplinkSlots*
- a number of uplink symbols $u_{\text{sym},2}$ by higher layer parameter *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 $S_2=P_2\cdot 2^{\mu_{\text{ref},2}}$ 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 subcarrier spacing configuration μ_{ref} is smaller than or equal to a subcarrier spacing configuration μ for any configured DL BWP or UL BWP. Each slot provided by higher layer parameter *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 subcarrier spacing configuration μ_{ref} and each downlink or flexible or uplink symbol for the reference subcarrier spacing configuration μ_{ref} corresponds to $2^{(\mu-\mu_{\text{ref}})}$ consecutive downlink or flexible or uplink symbols for the subcarrier spacing configuration μ.

If the UE is additionally provided higher layer parameter *TDD-UL-DL-ConfigDedicated*, the parameter *TDD-UL-DL-ConfigDedicated* overrides only flexible symbols per slot over the number of slots as provided by *TDD-UL-DL-ConfigurationCommon*.

The higher layer parameter *TDD-UL-DL-ConfigDedicated* provides

- a set of slot configurations by higher layer parameter *slotSpecificConfigurationsToAddModList*
- for each slot configuration from the set of slot configurations

- a slot index for a slot provided by higher layer parameter *slotIndex*
- a set of symbols for a slot by higher layer parameter *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* and higher layer parameter *nrofDownlinkSymbols* provides a number of downlink first symbols in the slot and higher layer parameter *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 higher layer parameter *slotIndex*, the UE applies a format provided by the corresponding higher layer parameter *symbols*. The UE does not expect *TDD-UL-DL-ConfigDedicated* 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-ConfigDedicated*, a reference subcarrier spacing configuration is the reference subcarrier spacing 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 higher layer parameters *TDD-UL-DL-ConfigurationCommonTDD* and *TDD-UL-DL-ConfigDedicated* and are common to each configured BWP.

A UE considers symbols in a slot indicated as downlink by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated* to be available for receptions and considers symbols in a slot indicated as uplink by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or by *TDD-UL-DL-ConfigDedicated* 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 higher layer parameters *TDD-UL-DL-ConfigurationCommon* or *TDD-UL-DL-ConfigDedicated*, when provided to a UE, or when *TDD-UL-DL-ConfigurationCommon* and *TDD-UL-DL-ConfigDedicated* 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, or DCI format 2_3

If a UE is configured by higher layers to receive a PDCCH, or a PDSCH, or a CSI-RS in the set of symbols of the 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.

If a UE is configured by higher layers to transmit periodic 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 subset of symbols that occur, relative to a last symbol of a control resource set 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]
- the UE cancels the PUCCH, or PUSCH, or PRACH transmission in remaining symbols from the set of symbols and cancels the periodic SRS transmission in remaining symbols from the subset of symbols

A PUSCH preparation time throughout Subclause 11.1 is as described in [6, TS38.214].

For a set of symbols of a slot that are indicated to a UE as uplink by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to the UE, the UE does not receive PDCCH, PDSCH, or CSI-RS in the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE as downlink by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to the UE, the UE does not 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 to a UE as flexible by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to the UE, 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 a set of symbols of a slot that are indicated to a UE by higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon*, when provided to the UE, 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 higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, 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 for Type1-PDCCH common search space, 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 higher layer parameters *TDD-UL-DL-ConfigurationCommon* or *TDD-UL-DL-ConfigDedicated*.

For a set of symbols of a slot indicated to a UE by higher layer parameters *pdcch-ConfigSIB1* in *MasterInformationBlock* for a control resource set for Type0-PDCCH common search space, the UE does not expect the set of symbols to be indicated as uplink by higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*.

If a UE is scheduled by a DCI format 1_1 to receive PDSCH over multiple slots, and if higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to the UE, 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 higher layer parameter *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to a UE, 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 subclause applies for a serving cell that is included in a set of serving cells configured to a UE by higher layer parameters *slotFormatCombToAddModList* and *slotFormatCombToReleaseList*.

If a UE is configured by higher layers with parameter *SlotFormatIndicator*, the UE is provided with a SFI-RNTI by higher layer parameter *sfi-RNTI* and with a payload size of DCI format 2_0 by higher layer parameter *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 control resource set 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 Subclause 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 control resource set p.

For each serving cell in the set of serving cells, the UE can be provided:

- an identity of the serving cell by higher layer parameter *servingCellId*
- a location of a SFI-index field in DCI format 2_0 by higher layer parameter *positionInDCI*
- a set of slot format combinations by higher layer parameter *slotFormatCombinations*, where each slot format combination in the set of slot format combinations includes

- one or more slot formats indicated by a respective higher layer parameter *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 higher layer parameter *slotFormatCombinationId*

- for unpaired spectrum operation, a reference subcarrier spacing configuration μ_{SFI} by higher layer parameter *subcarrierSpacing* and, when a supplementary UL carrier is configured for the serving cell, a reference subcarrier spacing configuration $\mu_{\text{SFI,SUL}}$ by higher layer parameter *subcarrierSpacing2* for the supplementary UL carrier
- for paired spectrum operation, a reference subcarrier spacing configuration $\mu_{\text{SFI,DL}}$ for a DL BWP by higher layer parameter *subcarrierSpacing* and a reference subcarrier spacing configuration $\mu_{\text{SFI, UL}}$ for an UL BWP by higher layer parameter *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 higher layer parameters *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 higher layer parameter *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 subcarrier spacing 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-ConfigDedicated* and, if any, on detected DCI formats													

For unpaired spectrum operation for a UE on a serving cell, the UE is provided by higher layer parameter *subcarrierSpacing* a reference subcarrier spacing 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 subcarrier spacing configuration μ_{SFI} and for an active DL BWP or an active UL BWP with subcarrier spacing 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 subcarrier spacing configuration μ_{SFI} and each downlink or flexible or uplink symbol for the reference subcarrier spacing configuration μ_{SFI} corresponds to $2^{(\mu-\mu_{\text{SFI}})}$ consecutive downlink or flexible or uplink symbols for the subcarrier spacing 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 higher layer parameter *subcarrierSpacing* a reference subcarrier spacing 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 higher layer parameter *subcarrierSpacing2* a reference subcarrier spacing 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 higher layer parameter *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 higher layer parameter *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 with a reference subcarrier spacing configuration $\mu_{\text{SFI,DL}}$ so that for an active DL BWP with subcarrier spacing configuration μ_{DL}, it is $\mu_{\text{DL}} \geq \mu_{\text{SFI,DL}}$. The UE is provided with a reference subcarrier spacing configuration $\mu_{\text{SFI,UL}}$ so that for an active UL BWP with subcarrier spacing 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 subcarrier spacing configuration $\mu_{\text{SFI,DL}}$ corresponds to $2^{(\mu_{\text{DL}}-\mu_{\text{SFI, DL}})}$ consecutive downlink or flexible symbols for the subcarrier spacing 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 subcarrier spacing configuration $\mu_{\text{SFI,UL}}$ corresponds to $2^{(\mu_{\text{UL}}-\mu_{\text{SFI, UL}})}$ consecutive uplink or flexible symbols for the subcarrier spacing 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 higher layer parameter *subcarrierSpacing* a reference subcarrier spacing 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 higher layer parameter *subcarrierSpacing2* a reference subcarrier spacing 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 higher layer parameter *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 with a reference subcarrier spacing configuration $\mu_{\text{SFI,SUL}}$ so that for an active UL BWP in the second UL carrier with subcarrier spacing 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 $2^{(\mu_{\text{SUL}}-\mu_{\text{SFI,SUL}})}$ 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 $\mu_{\text{SFI}} = 0$, $\mu_{\text{SFI}} = 1$, or $\mu_{\text{SFI}} = 2$. 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 subcarrier spacing configuration μ_{SFI}, or $\mu_{\text{SFI,DL}}$, or $\mu_{\text{SFI, UL}}$, or $\mu_{\text{SFI,SUL}}$ is either 0, or 1, or 2 for frequency range 1 and is either 2 or 3 for frequency range 2.

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 higher layer parameters *TDD-UL-DL-ConfigurationCommon*, or *TDD-UL-DL-ConfigDedicated*, when provided to a UE, 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 higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* 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 indicated to a UE by higher layer parameter *prach-ConfigurationIndex* in *RACH-ConfigCommon* for PRACH transmissions, 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 higher layer parameters *pdcch-ConfigSIB1* in *MasterInformationBlock* for a control resource set for Type0-PDCCH common search space, 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 higher layer parameters *TDD-UL-DL-ConfigurationCommon* and *TDD-UL-DL-ConfigDedicated*, when provided to the UE, or when higher layer parameters *TDD-UL-DL-ConfigurationCommon* and *TDD-UL-DL-ConfigDedicated* 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 control resource set configured to the UE for PDCCH monitoring, the UE receives PDCCH in the control resource set 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_1indicating 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 periodic SRS in the set of symbols of the slot, the UE transmits the periodic 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 if the set of symbols of the slot includes symbols corresponding to a first repetition of a PUSCH transmission activated by an UL Type 2 grant PDCCH as described in Subclause 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 periodic 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 subset of symbols that occur, relative to a last symbol of a control resource set 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]

- the UE cancels the PUCCH, or PUSCH, or PRACH transmission in remaining symbols from the set of symbols and cancels the periodic SRS transmission in remaining symbols from the subset of symbols.

A PUSCH preparation time throughout Subclause 11.1.1 is as described in [6, TS38.214].

A UE assumes that flexible symbols in a control resource set 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 higher layer parameters *TDD-UL-DL-ConfigurationCommon*, and *TDD-UL-DL-ConfigDedicated*, when provided to a UE, or when higher layer parameters

TDD-UL-DL-ConfigurationCommon, and *TDD-UL-DL-ConfigDedicated* 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, or DCI format 2_3
- the UE receives PDCCH as described in Subclause 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 periodic 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 a number of symbols equal to the PUSCH preparation time N_2 for the corresponding PUSCH timing capability after a last symbol of a control resource set where the UE is configured to monitor PDCCH for DCI format 2_0
  - does not expect to cancel the transmission of the periodic 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 a number of symbols equal to the PUSCH preparation time N_2 for the corresponding PUSCH timing capability after a last symbol of a control resource set where the UE is configured to monitor PDCCH for DCI format 2_0

For unpaired spectrum operation for a UE on a cell in a frequency band of frequency range 1, 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 higher layer parameter *DownlinkPreemption*, the UE is configured with an INT-RNTI provided by higher layer parameter *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 higher layer parameter *INT-ConfigurationPerServingCell* that includes a set of serving cell indexes provided by corresponding higher layer parameters *servingCellId* and a corresponding set of locations for fields in DCI format 2_1 by higher layer parameter *positionInDCI*
- an information payload size for DCI format 2_1 by higher layer parameter *dci-PayloadSize*
- an indication granularity for time-frequency resources by higher layer parameter *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 Subclause 12 and includes B_{INT} PRBs.

If a UE detects a DCI format 2_1 in a PDCCH transmitted in a control resource set in a slot, the set of symbols is the last $N_{\mathrm{symb}}^{\mathrm{slot}} \cdot T_{\mathrm{INT}} \cdot 2^{\mu - \mu_{INT}}$ symbols prior to the first symbol of the control resource set in the slot where T_{INT} is the PDCCH monitoring periodicity provided by the value of higher layer parameter *monitoringSlotPeriodicityAndOffset*, as described in Subclause 10.1, $N_{\mathrm{symb}}^{\mathrm{slot}}$ is the number of symbols per slot, μ is the subcarrier spacing configuration for a serving cell with mapping to a respective field in the DCI format 2_1, μ_{INT} is the subcarrier spacing configuration of the DL BWP where the UE receives the PDCCH with the DCI format 2_1. If the UE is configured with higher layer parameters *TDD-UL-DL-ConfigurationCommon*, symbols indicated as uplink by *TDD-UL-DL-ConfigurationCommon*

are excluded from the last $N_{\text{symb}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{INT}}$ symbols prior to the first symbol of the control resource set 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 $N_{\text{symb}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{INT}}$ that is not an integer. The UE does not expect to be configured by higher layer parameter *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 higher layer parameter *timeFrequencySet*.

If the value of *timeFrequencySet* is 0, 14 bits 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 1, 7 pairs of bits 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 with

- a TPC-PUCCH-RNTI for a DCI format 2_2 by higher layer parameter *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 Subclause 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 higher layer parameter *tpc-IndexPCell*
- an index for a location in DCI format 2_2 of a first bit for a TPC command field for the PSCell or for a carrier for the PSCell by higher layer parameter *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 higher layer parameter *twoDifferentTPC-Loop-PUCCH*, and if the UE is configured for two PUCCH power control adjustment states by higher layer parameter *twoPUCCH-PC-AdjustmentStates*

The UE is also provided on a serving cell with a configuration for a search space set s and a corresponding control resource set p for monitoring PDCCH candidates for DCI format 2_2 with CRC scrambled by a TPC-PUCCH-RNTI as described in Subclause 10.1.

For PUSCH transmission on a serving cell, a UE can be provided with

- a TPC-PUSCH-RNTI for a DCI format 2_2 by higher layer parameter *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 Subclause 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 higher layer parameter *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 higher layer parameter *tpc-IndexSUL*

- an index of the serving cell by higher layer parameter *targetCell*. If higher layer parameter *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 higher layer parameter *twoDifferentTPC-Loop-PUSCH*, and if the UE is configured for two PUSCH power control adjustment states by higher layer parameter *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 control resource set p for monitoring PDCCH candidates for DCI format 2_2 with CRC scrambled by a TPC-PUSCH-RNTI as described in Subclause 10.1.

11.4 SRS switching

DCI format 2_3 is applicable for serving cells where a UE is not configured for PUSCH/PUCCH transmission or for a serving cell where higher layer parameter *srs-pcadjustment-state-config* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions.

A UE configured by higher layers with parameter *SRS-CarrierSwitching* is provided with

- a TPC-SRS-RNTI for a DCI format 2_3 by higher layer parameter *srs-TPC-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 higher layer parameter *srs-SwitchFromServCellIndex*

- a DCI format 2_3 field configuration type by higher layer parameter *typeA* or higher layer parameter *typeB*

  - for higher layer parameter *typeA*, an index for a set of serving cells is provided by higher layer parameter *cc-SetIndex*, indexes of serving cells in the set of serving cells are provided by higher layer parameter *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 higher layer parameter *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 - a mapping between a serving cell index for SRS transmission and a DCI format 2_3 field is provided by higher layer parameter *srs-CellToSFI*

- an indication for a serving cell for whether or not a field in DCI format 2_3 includes a SRS request by higher layer parameter *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 by higher layer parameter *startingBitOfFormat2-3*

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* and a set of at most four BWPs for transmissions by the UE (UL BWP set) in an UL bandwidth by parameter *BWP-Uplink*.

If a UE is not provided higher layer parameter *initialDownlinkBWP*, an initial active 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 control resource set for Type0-PDCCH common search space, and a subcarrier spacing and a cyclic prefix for PDCCH reception in the control resource set for Type0-PDCCH common search space; otherwise, the initial active DL BWP is provided by higher layer parameter *initialDownlinkBWP*. For operation on the primary cell or on a secondary cell, a UE is provided an initial active UL BWP by higher layer parameter *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 higher layer parameter *initialUplinkBWP* in *supplementaryUplink*.

If a UE has dedicated BWP configuration, the UE can be provided by higher layer parameter *firstActiveDownlinkBWP-Id* a first active DL BWP for receptions and by higher layer parameter *firstActiveUplinkBWP-Id* a first active UL BWP for transmissions on 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 subcarrier spacing by higher layer parameter *subcarrierSpacing*
- a cyclic prefix by higher layer parameter *cyclicPrefix*
- a first PRB and a number of contiguous PRBs by higher layer parameter *locationAndBandwidth* that is interpreted as RIV according to [4, TS 38.214], setting N_{BWP}^{size} =275, and the first PRB is a PRB offset relative to the PRB indicated by higher layer parameters *offsetToCarrier* and *subcarrierSpacing*
- an index in the set of DL BWPs or UL BWPs by respective higher layer parameter *bwp-Id*
- a set of BWP-common and a set of BWP-dedicated parameters by higher layer parameters *bwp-Common* and *bwp-Dedicated* [12, TS 38.331]

For unpaired spectrum operation, a DL BWP from the set of configured DL BWPs with index provided by higher layer parameter *bwp-Id* is linked with an UL BWP from the set of configured UL BWPs with index provided by higher layer parameter *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 on the primary cell, a UE can be configured control resource sets for every type of common search space and for UE-specific search space as described in Subclause 10.1. The UE does not expect to be configured without a common search space on the PCell, or on the PSCell, of the MCG in the active DL BWP.

For each UL BWP in a set of UL BWPs, the UE is configured resource sets for PUCCH transmissions as described in Subclause 9.2.1.

A UE receives PDCCH and PDSCH in a DL BWP according to a configured subcarrier spacing and CP length for the DL BWP. A UE transmits PUCCH and PUSCH in an UL BWP according to a configured subcarrier spacing 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 [4, TS38.212]. 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 [4, TS38.212]. 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 dalye required by the UE for an active DL BWP change or UL BWP change [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 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 the primary cell, a UE can be provided by higher layer parameter *defaultDownlinkBWP-Id* a default DL BWP among the configured DL BWPs. If a UE is not provided a default DL BWP by higher layer parameter *defaultDownlinkBWP-Id*, the default DL BWP is the initial active DL BWP.

If a UE is configured for a secondary cell with higher layer parameter *defaultDownlinkBWP-Id* indicating a default DL BWP among the configured DL BWPs and the UE is configured with higher layer parameter *bwp-InactivityTimer* indicating a timer value, the UE procedures on the secondary cell are same as on the primary cell using the timer value for the secondary cell and the default DL BWP for the secondary cell.

If a UE is configured by higher layer parameter *bwp-InactivityTimer* a timer value for the primary cell [11, TS 38.321] and the timer is running, the UE increments the timer every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the restarting conditions in [11, TS 38.321] are met during the interval.

If a UE is configured by higher layer parameter *bwp-InactivityTimer* a timer value for a secondary cell [11, TS 38.321] and the timer is running, the UE increments the timer every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the restarting conditions in [11, TS 38.321] are not met during the interval.

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 [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 frequency range 1, or of half of a subframe for frequency range 2, that is immediatelly after the BWP inactivity timer expires until the beginning of a slot where the UE can receive or transmit.

If a UE is configured by higher layer parameter *firstActiveDownlinkBWP-Id* a first active DL BWP and by higher layer parameter *firstActiveUplinkBWP-Id* a first active UL BWP on a secondary cell or on a supplementary UL carrier, 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 secondary cell or the supplementary UL carrier.

For paired spectrum operation, a UE does not expect to transmit a PUCCH with HARQ-ACK information on a PUCCH resource indicated by a DCI format 1_0 or a DCI format 1_1 if the UE changes its active UL BWP on the PCell between a time of a detection of the DCI format 1_0 or the DCI format 1_1 and a time of a corresponding PUCCH transmission with HARQ-ACK information.

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 common search space

If during cell search a UE determines that a control resource set for Type0-PDCCH common search space is present, as described in Subclause 4.1, the UE determines a number of consecutive resource blocks and a number of consecutive symbols for the control resource set of the Type0-PDCCH common search space from the four most significant bits of *pdcch-ConfigSIB1* as described in Tables 13-1 through 13-10 and determines PDCCH monitoring occasions from the four least significant bits of *pdcch-ConfigSIB1*, included in *MasterInformationBlock*, 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 control resource set based on subcarrier spacing of the control resource set and $\text{SFN}_{\text{SSB},i}$ and $n_{\text{SSB},i}$ are the SFN and slot index based on subcarrier spacing of the control resource set, 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 offset in Tables 13-1 through 13-10 is defined with respect to the subcarrier spacing of the control resource set for Type0-PDCCH common search space, provided by higher layer parameter *subCarrierSpacingCommon*, from the smallest RB index of the control resource set for Type0-PDCCH common search space 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_{SSE} is defined in [4, TS 38.211].

For the SS/PBCH block and control resource set multiplexing pattern 1, a UE monitors PDCCH in the Type0-PDCCH common search space 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 $n_0 = \left(O \cdot 2^\mu + \left\lfloor i \cdot M \right\rfloor\right) \bmod N_{\text{slot}}^{\text{frame},\mu}$ located in a frame with system frame number (SFN) SFN_C satisfying $\text{SFN}_\text{C} \bmod 2 = 0$ if $\left\lfloor \left(O \cdot 2^\mu + \left\lfloor i \cdot M \right\rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \right\rfloor \bmod 2 = 0$ or in a frame with SFN satisfying $\text{SFN}_\text{C} \bmod 2 = 1$ if $\left\lfloor \left(O \cdot 2^\mu + \left\lfloor i \cdot M \right\rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \right\rfloor \bmod 2 = 1$. M and O are provided by Tables 13-11 and 13-12, and $\mu \in \{0,1,2,3\}$ based on the subcarrier spacing for PDCCH receptions in the control resource set [4, TS 38.211]. The index for the first symbol of the control resource set in slot n_C is the first symbol index provided by Tables 13-11 and 13-12.

For the SS/PBCH block and control resource set multiplexing patterns 2 and 3, a UE monitors PDCCH in the Type0-PDCCH common search space over one slot with Type0-PDCCH common search space periodicity equal to the periodicity of SS/PBCH block. For the SS/PBCH block and control resource set 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 Subclause 5, and measurements for radio resource management [10, TS 38.133] using a SS/PBCH block that provides a control resource set for Type0-PDCCH common search space. 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {15, 15} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {15, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 15} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 15} kHz for frequency bands with minimum channel bandwidth 40MHz

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Number of Symbols $N_{\mathrm{symb}}^{\mathrm{CORESET}}$	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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 30} kHz for frequency bands with minimum channel bandwidth 40MHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {120, 60} kHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {120, 120} kHz

Index	SS/PBCH block and control resource set 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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {240, 60} kHz

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{\text{RB}}^{\text{CORESET}}$	Number of Symbols $N_{\text{symb}}^{\text{CORESET}}$	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 control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {240, 120} kHz

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{\text{RB}}^{\text{CORESET}}$	Number of Symbols $N_{\text{symb}}^{\text{CORESET}}$	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 $k_{\text{SSB}}=0$ -42 if $k_{\text{SSB}}>0$
5	2	24	1	25
6	2	48	1	-41 if $k_{\text{SSB}}=0$ -42 if $k_{\text{SSB}}>0$
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 common search space - SS/PBCH block and control resource set multiplexing pattern 1 and frequency range 1

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 common search space - SS/PBCH block and control resource set multiplexing pattern 1 and frequency range 2

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 common search space - SS/PBCH block and control resource set multiplexing pattern 2 and {SS/PBCH block, PDCCH} subcarrier spacing {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 common search space - SS/PBCH block and control resource set multiplexing pattern 2 and {SS/PBCH block, PDCCH} subcarrier spacing {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 common search space - SS/PBCH block and control resource set multiplexing pattern 3 and {SS/PBCH block, PDCCH} subcarrier spacing {120, 120} kHz

Index	PDCCH monitoring occasions (SFN and slot number)	First symbol index (k = 0, 1, … 15)
0	$\mathrm{SFN}_{\mathrm{C}} = \mathrm{SFN}_{\mathrm{SSB},i}$ $n_{\mathrm{C}} = n_{\mathrm{SSB},i}$	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 control resource set for Type0-PDCCH common search space is not present, and for $24 \le k_{\mathrm{SSB}} \le 29$ for FR1 or for $12 \le k_{\mathrm{SSB}} \le 13$ 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 control resource set for an associated Type0-PDCCH common search space as $N_{\mathrm{GSCN}}^{\mathrm{Reference}} + N_{\mathrm{GSCN}}^{\mathrm{Offset}}$. $N_{\mathrm{GSCN}}^{\mathrm{Reference}}$ is the GSCN of the first SS/PBCH block and $N_{\mathrm{GSCN}}^{\mathrm{Offset}}$ 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 control resource set for Type0-PDCCH common search space, as described in Subclause 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 control resource set for Type0-PDCCH common search space is not present, and for $k_{\mathrm{SSB}} = 31$ for FR1 or for $k_{\mathrm{SSB}} = 15$ for FR2, the UE determines that there is no SS/PBCH block having an associated Type0-PDCCH common search space within a GSCN range $[N_{\mathrm{GSCN}}^{\mathrm{Reference}} - N_{\mathrm{GSCN}}^{\mathrm{Start}}, N_{\mathrm{GSCN}}^{\mathrm{Reference}} + N_{\mathrm{GSCN}}^{\mathrm{End}}]$. $N_{\mathrm{GSCN}}^{\mathrm{Start}}$ and $N_{\mathrm{GSCN}}^{\mathrm{End}}$ are respectively determined by the four most significant bits and the four least significant bits of *pdcch-ConfigSIB1*. If the GSCN range is $[N_{\mathrm{GSCN}}^{\mathrm{Reference}}, N_{\mathrm{GSCN}}^{\mathrm{Reference}}]$, the UE determines that there is no information for a second SS/PBCH block with a control resource set for an associated Type0-PDCCH common search space on the detected SS/PBCH block.

If a UE does not detect any SS/PBCH block providing a control resource set for Type0-PDCCH common search space, as described in Subclause 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 *pdcch-ConfigSIB1* to N_{GSCN}^{Offset} for FR1

k_{SSB}	***pdcch-ConfigSIB1***	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 *pdcch-ConfigSIB1* to N_{GSCN}^{Offset} for FR2

k_{SSB}	***pdcch-ConfigSIB1***	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

History

Document history		
V15.2.0	July 2018	Publication
V15.3.0	October 2018	Publication