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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: "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
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
PBCH	Physical broadcast channel
PCell	Primary cell
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PRACH	Physical random access channel
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
RB	Resource block
RE	Resource element
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 by which a UE acquires time and frequency synchronization with a cell and detects the physical layer Cell ID of that 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 shall assume 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 shall assume 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 in a corresponding cell is either 0 dB or 3 dB.

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.

- Case A - 15 kHz subcarrier spacing: the first symbols of the candidate SS/PBCH blocks have indexes of {2, 8} + 14*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*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*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 D - 120 kHz subcarrier spacing: the first symbols of the candidate SS/PBCH blocks have indexes {4, 8, 16, 20} + 28*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*n. For carrier frequencies larger than 6 GHz, n=0, 1, 2, 3, 5, 6, 7, 8.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $L-1$. A UE shall determine 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 shall determine the 3 MSB bits of the SS/PBCH block index per half frame by 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].

A UE can be configured by higher layer parameter *SSB-transmitted-SIB1*, indexes of SS/PBCH blocks for which the UE shall not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. A UE can also be configured per serving cell, by higher layer parameter *SSB-transmitted*, indexes of SS/PBCH blocks for which the UE shall not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. A configuration by *SSB-transmitted* overrides a configuration by *SSB-transmitted-SIB1*. A UE can be configured per serving cell by higher layer parameter *SSB-periodicityServingCell* a periodicity of the half frames for reception of SS/PBCH blocks per serving cell. If the UE is not configured a periodicity of the half frames for receptions of SS/PBCH blocks, the UE shall assume a periodicity of a half frame. A UE shall assume 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 is present if $k_{SSB} \le 23$ [4, TS 38.211] for FR1 and if $k_{SSB} \le 11$ for FR2. The UE determines that a control resource set for Type0-PDCCH common search space is not present if $k_{SSB} > 23$ for FR1 and if $k_{SSB} > 11$ 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

If a UE is configured with two UL carriers in a serving cell, a same value of $N_{\text{TA\_offset}}$ applies to both carriers. The value of $N_{\text{TA\_offset}}$ is determined from the non-supplementary UL carrier. $N_{\text{TA\_offset}}$ is described in [10, TS 38.133].

Upon reception of a timing advance command for a TAG containing the primary cell or PSCell, the UE shall adjust uplink transmission timing for PUCCH/PUSCH/SRS of the primary cell or PSCell based on the received timing advance command.

The UL transmission timing for PUSCH/SRS of a secondary cell is the same as the primary cell if the secondary cell and the primary cell belong to the same TAG. If the primary cell in a TAG operates with paired DL/UL spectrum and a secondary cell in the same TAG operates with unpaired DL/UL spectrum, a UE may assume that $N_{\text{TA}} \geq 25560$ for FR1 and $N_{\text{TA}} \geq 13763$ for FR2 [10, TS 38.133].

If the UE is configured with a SCG, the UL transmission timing for PUSCH/SRS of a secondary cell other than the PSCell is the same as the PSCell if the secondary cell and the PSCell belong to the same TAG.

Upon reception of a timing advance command or a timing adjustment indication for a TAG not containing the primary cell or PSCell, if all the serving cells in the TAG have the same duplex mode type, the UE shall adjust uplink transmission timing for PUSCH/SRS of all the secondary cells in the TAG based on the received timing advance command or a timing adjustment indication where the UL transmission timing for PUSCH /SRS is the same for all the secondary cells in the TAG.

Upon reception of a timing advance command or a timing adjustment indication for a TAG not containing the primary cell or PSCell, if a serving cell in the TAG has a different duplex mode type compared to the duplex mode type of another serving cell in the same TAG, the UE shall adjust uplink transmission timing for PUSCH/SRS of all the secondary cells in the TAG by using $N_{\text{TA\_offset}} = 25560$ for FR1 and $N_{\text{TA\_offset}} = 13763$ for FR2 regardless of the duplex mode type of the serving cells and based on the received timing advance command or a timing adjustment indication where the UL transmission timing for PUSCH /SRS is the same for all the secondary cells in the TAG.

The timing adjustment indication specified in [12, TS 38.331] indicates the initial 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 as multiples of $16 \cdot 64 \cdot T_c / 2^{\mu}$. The start timing of the random access preamble is specified 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 for subcarrier spacing of $2^{\mu} \cdot 15$ kHz is given by $N_{\text{TA}} = T_{\text{A}} \cdot 16 \cdot 64 / 2^{\mu}$. 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 the current N_{TA} value, $N_{\text{TA\_old}}$, to the new N_{TA} value, $N_{\text{TA\_new}}$, by index values of T_{A} = 0, 1, 2,..., 63, where for a subcarrier spacing of $2^{\mu} \cdot 15$ kHz, $N_{\text{TA\_new}} = N_{\text{TA\_old}} + (T_{\text{A}} - 31) \cdot 16 \cdot 64 / 2^{\mu}$. If a UE has multiple active UL BWPs in a same TAG, including UL BWPs in two UL carriers of a serving cell, the timing advance command value is relative to the larger subcarrier spacing of the multiple active UL BWPs. The applicable $N_{\text{TA\_new}}$ 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..

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

For a timing advance command received on slot n, the corresponding adjustment of the uplink transmission timing applies from the beginning of slot $n+6$. 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 specified 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 corresponding actions in [11, TS 38.321] shall be applied no later than the minimum requirement defined in [12, TS 38.331] and no earlier than slot *n+k*, except for the following:

- the actions related to CSI reporting on a serving cell which is active in slot *n+k*
- the actions related to the *sCellDeactivationTimer* associated with the secondary cell [11, TS 38.321]

which shall be applied in slot *n+k*

- the actions related to CSI reporting on a serving cell which is not active in slot *n+k*

which shall be applied in the earliest slot after *n+k* in which the serving cell is active.

When 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 corresponding actions in [11, TS 38.321] shall apply 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 shall be applied in slot *n+k*.

5 Radio link monitoring

The downlink radio link quality of the primary cell shall be 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 on the primary cell.

If the UE is configured with a SCG, as described in [12, TS 38.331], and the parameter *rlf-TimersAndConstantsSCG* is provided by the higher layers and is not set to release, the downlink radio link quality of the PSCell of the SCG shall be 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, as described in Subclause 12, on the PSCell.

A UE can be configured for each SpCell [11, TS 38.321] with a set of resource indexes for radio link monitoring by higher layer parameter *RLM-RS-List*. The UE is provided by higher layer parameter *RLM-RS* an association between a resource index, from the set of resource indexes, with either a CSI-RS resource configuration or a SS/PBCH block. For a CSI-RS resource configuration, the UE is provided a corresponding index by higher layer parameter *RLM-CSIRS*. The higher layer parameters *CSI-IM-RE-pattern*, *CSI-IM-Resource*, *CSI-IM-ResourceId*, *CSI-IM-timeConfig*, *CSI-IM-FreqBand*, *CSI-IM-ResourceMapping*, and *Pc_SS* in the CSI-RS configuration are not applicable. In CSI-RS resource configuration, 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]. For a SS/PBCH block, the UE is provided a corresponding index by higher layer parameter *RLM-SSB*.

In non-DRX mode operation, the physical layer in the UE shall assess 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 *RLM-IS-OOS-thresholdConfig*. 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 shall assess 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}). 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 shall in frames where the radio link quality is assessed indicate 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 shall in frames where the radio link quality is assessed indicate in-sync to higher layers.

6 Link reconfiguration procedures

A UE can be configured, for a serving cell, with a set $\bar{q}_0$ of periodic CSI-RS resource configuration indexes by higher layer parameter *Beam-Failure-Detection-RS-ResourceConfig* and with a set $\bar{q}_1$ of CSI-RS resource configuration indexes and/or SS/PBCH block indexes by higher layer parameter *Candidate-Beam-RS-List* for radio link quality measurements on the serving cell. If the UE is not provided with higher layer parameter *Beam-Failure-Detection-RS-ResourceConfig*, the UE determines the set $\bar{q}_0$ to include SS/PBCH block indexes and periodic CSI-RS resource configuration indexes with same values as the RS indexes in the RS sets indicated by the TCI states for respective control resource sets that the UE is configured for monitoring PDCCH. The UE expects single port RS in the set $\bar{q}_0$.

The thresholds $Q_{out,LR}$ and $Q_{in,LR}$ correspond to the default value of higher layer parameter *RLM-IS-OOS-thresholdConfig* and *Beam-failure-candidate-beam-threshold*, respectively..

The physical layer in the UE shall assess the radio link quality according to the set $\bar{q}_0$ of resource configurations against the threshold $Q_{out,LR}$ [10, TS 38.133]. For the set $\bar{q}_0$, the UE shall assess 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 DM-RS monitored by the UE. The UE applies the $Q_{in,LR}$ threshold to the L1-RSRP SS/PBCH blocks. The UE applies the $Q_{in,LR}$ threshold to the L1-RSRP for the CSI-RS resource after scaling a respective CSI-RS reception power with a value provided by higher layer parameter *Pc_SS*.

The physical layer in the UE shall, in slots where the radio link quality according to the set $\bar{q}_0$ is assessed, provide an indication to higher layers when the radio link quality for all corresponding resource configurations in the set $\bar{q}_0$ 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 of periodic CSI-RS configurations or SS/PBCH blocks in the set $\bar{q}_0$ and X.

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

A UE is configured with one control resource set by higher layer parameter *Beam-failure-Recovery-Response-CORESET* and with an associated search space provided by higher layer parameter *search-space-config*, as described in subcaluse 10.1, for monitoring PDCCH in the control resource set. The UE may receive from higher layers, by parameter *Beam-failure-recovery-request-RACH-Resource*, a configuration for a 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 configuration or SS/PBCH block with index q_{new}, the UE monitors PDCCH for detection of a DCI format with CRC scrambled by C-RNTI starting from slot $n+4$ within a window configured by higher layer parameter *Beam-failure-recovery-request-window*, and . For PDSCH reception, the UE assumes the same antenna port quasi-collocation parameters as for monitoring PDCCH until the UE receives by higher layers an activation for a TCI state or a parameter *TCI-StatesPDCCH*. The UE determines the index q_{new} based on TBD.

7 Uplink Power control

Uplink power control determines the transmit power of the different uplink physical channels or signals.

7.1 Physical uplink shared channel

For PUSCH, a UE first scales a linear value $\hat{P}_{\text{PUSCH},f,c}(i,j,q_d,l)$ of the transmit power $P_{\text{PUSCH},f,c}(i,j,q_d,l)$ on UL BWP b, as described in Subclause 12, of carrier f of serving cell c, with parameters as defined in Subclause 7.1.1, by the ratio of the number of antenna ports with a non-zero PUSCH transmission to the number of configured antenna ports for the transmission scheme. The resulting scaled power is then split equally across the antenna ports on which the non-zero PUSCH is transmitted.

7.1.1 UE behaviour

If a UE transmits a PUSCH on 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 shall determine the PUSCH transmission power $P_{\text{PUSCH},f,c}(i,j,q_d,l)$ in PUSCH transmission period i as

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

where,

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

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

  - If a UE is not provided with higher layer parameter *p0-pusch-alpha-setconfig*, $j=0$, $P_{\text{O\_UE\_PUSCH},f,c}(0)=0$, and $P_{\text{O\_NOMINAL\_PUSCH},f,c}(0) = P_{\text{O\_PRE}} + \Delta_{PREAMBLE\_Msg3}$, where the parameter *preambleInitialReceivedTargetPower* [11, TS 38.321] (for $P_{\text{O\_PRE}}$) and *Delta-preamble-msg3* (for $\Delta_{PREAMBLE\_Msg3}$) are provided by higher layers for carrier f of serving cell c.

  - For a PUSCH (re)transmission corresponding to a *UL-TWG-type1* configuration or a *UL-TWG-type2* configuration, $j=1$, $P_{\text{O\_NOMINAL\_PUSCH},f,c}(1)$ is provided by higher layer parameter *p0-nominal-pusch-withoutgrant*, and $P_{\text{O\_UE\_PUSCH},f,c}(1)$ is provided by higher layer parameter *p0alphasetindex*, in *UL-TWG-Type1* or *UL-TWG-Type2* respectively, providing an index to a set of higher layer parameters *p0-pusch-alpha-set* provided by higher layer parameter *p0-pusch-alpha-setconfig* for 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-nominal-pusch-withgrant* for each carrier f of serving cell c and a set of $P_{\text{O\_UE\_PUSCH},f,c}(j)$ values are provided by a set of higher layer parameters *p0-pusch-alpha-set* in *p0-push-alpha-setconfig* and a respective set of indexes provided by higher layer parameter *p0alphasetindex* for UL BWP b of carrier f of serving cell c.

    - If the UE is provided a higher layer parameter *SRI-P0AlphaSetIndex-Mapping*, the UE obtains a mapping 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 *p0alphasetindex* that map to a set of *p0-pusch-alpha-set* values provided by higher layer parameter *p0-push-alpha-setconfig*. If the PUSCH transmission is scheduled by a DCI format 0_1 and if the DCI format 0_1 includes a SRI field, the UE determines the values of $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ from the *p0alphasetindex* 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-P0AlphaSetIndex-Mapping* is not provided to the UE, the UE determines $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ from the first *p0-pusch-alpha-set* in *p0-pusch-alpha-setconfig* for all $j \in S_J$.

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

  - For $j=0$, $\alpha_{b,f,c}(0)=1$.

- For $j=1$, $\alpha_{b,f,c}(1)$ is provided by higher layer parameter *p0alphasetindex* in *UL-TWG-Type1* or *UL-TWG-Type2*, providing an index to a set of higher layer parameters *p0-pusch-alpha-set* provided by higher layer parameter *p0-pusch-alpha-setconfig* for 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 *p0-pusch-alpha-set* in *p0-push-alpha-setconfig* and a respective set of indexes by higher layer parameter *p0alphasetindex* for UL BWP b of carrier f of serving cell c.

  - If the UE is provided a higher layer parameter *SRI-P0AlphaSetIndex-Mapping*, the UE obtains a mapping 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 *p0alphasetindex* that map to a set of *p0-pusch-alpha-set* values provided by higher layer parameter *p0-push-alpha-setconfig*. If the PUSCH transmission is scheduled by a DCI format 0_1 and if the DCI format 0_1 includes a SRI field, the UE determines the values of $\alpha_{b,f,c}(j)$ from the *p0alphasetindex* 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-P0AlphaSetIndex-Mapping* is not provided to the UE, the UE determines $\alpha_{b,f,c}(j)$ from the first *p0-pusch-alpha-set* in *p0-pusch-alpha-setconfig* for all $j \in S_J$.

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

- $PL_{b,f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) resource q_d for UL BWP b of carrier f of serving cell c. If the UE is not provided with higher layer parameter *pusch-pathloss-Reference-rs* and before the UE is provided with dedicated higher layer parameters, the UE identifies a RS resource from the SS/PBCH block that the UE obtains from higher layer parameter *MasterInformationBlock*. Otherwise, the UE is configured with a number of RS resources by higher layer parameter *num-pusch-pathlossReference-rs* and a respective set of RS configurations for the number of RS resources is provided by higher layer parameter *pusch-pathloss-Reference-rs* that includes one or both of a set of SS/PBCH block indexes provided by higher layer parameter *pusch-pathlossReference-SSB* and a set of CSI-RS configuration indexes provided by higher layer parameter *pusch-pathlossReference-CSIRS*. The UE identifies a RS resource in the set of RS resources to correspond to a SS/PBCH block or to a CSI-RS configuration as provided by higher layer parameter *pusch-pathlossreference-index* in *pusch-pathlossReference-rs-config*.

  - If the UE is provided a higher layer parameter *SRI-PathlossReferenceIndex-Mapping*, the UE obtains a mapping between a set of values for the SRI field in DCI format 0_1 and a set of *pusch-pathlossreference-index* values provided by higher layer parameter *pusch-pathlossReference-rs-config*. If the PUSCH transmission is scheduled by a DCI format 0_1 and if the DCI format 0_1 includes a SRI field, the UE determines the RS resource q_d from the value of *pusch-pathlossreference-index* 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-PathlossReferenceIndex-Mapping* is not provided to the UE, the UE determines a RS resource with a respective higher layer parameter *pusch-pathlossreference-index* value being equal to zero.

  - For a PUSCH (re)transmission corresponding to a *UL-TWG-type1* configuration, a RS resource q_d is provided by higher layer parameter *UL-TWG-pathlossreference-index*.

  - For a PUSCH (re)transmission corresponding to a *UL-TWG-type2* configuration, the UE determines the RS resource q_d from the value of *pusch-pathlossreference-index* that is mapped to the SRI field value in the 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 with a respective higher layer parameter *pusch-pathlossreference-index* 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 is defined in [12, TS 38.331] for the reference serving cell.

For $j = 0$, *referenceSignalPower* is configured by higher layer parameter *SS-PBCHBlockPower*. For $j > 0$, *referenceSignalPower* is configured by either higher layer parameter *SS-PBCHBlockPower* or, when periodic CSI-RS transmission is configured, by higher layer parameter *Pc-SS* providing an offset of the CSI-RS transmission power relative to the SS/PBCH block transmission power [6, TS 38.214].

- $\Delta_{\mathrm{TF},f,c}(i) = 10\log_{10}\left(\left(2^{\mathrm{BPRE}\cdot K_s} - 1\right)\cdot \beta_{\mathrm{offset}}^{\mathrm{PUSCH}}\right)$ for $K_S = 1.25$ and $\Delta_{\mathrm{TF},f,c}(i) = 0$ for $K_S = 0$ where K_S is provided by higher layer parameter *deltaMCS-Enabled* provided 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], $\Delta_{\mathrm{TF},f,c}(i) = 0$. BPRE and $\beta_{\mathrm{offset}}^{\mathrm{PUSCH}}$, for each 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 the number of code blocks, K_r is the size for code block r, O_{CSI} is the number of CSI part 1 bits including CRC bits, and N_{RE} is the number of resource elements determined as $N_{\mathrm{RE}} = M_{\mathrm{RB},f,c}^{\mathrm{PUSCH}}(i) \cdot N_{\mathrm{symb},f,c}^{\mathrm{PUSCH}}(i)$ excluding REs used for DM-RS transmission, where $N_{\mathrm{symb},f,c}^{\mathrm{PUSCH}}(i)$ is the number of symbols for PUSCH transmission period i on UL BWP b of carrier f of serving cell c 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 for UL BWP b of carrier f of serving cell c in PUSCH transmission period i

  - $\delta_{\mathrm{PUSCH},f,c}(i - K_{\mathrm{PUSCH}}, l)$ is a correction value, also referred to as a TPC command, and is included in a PDCCH with DCI format 0_0 or DCI format 0_1 that schedules the PUSCH transmission period i on UL BWP b of carrier f of serving cell c or jointly coded with other TPC commands in a PDCCH with DCI format 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI that is last received by the UE prior to the PUSCH transmission;

    - $l \in \{0, 1\}$ if the UE is configured with higher layer parameter *num-pusch-pcadjustment-states*; otherwise, $l = 0$.

      - For a PUSCH (re)transmission corresponding to a *UL-TWG-type1* configuration or a *UL-TWG-type2* configuration, the value of $l \in \{0, 1\}$ is provided to the UE by higher layer parameter *PUSCH-closed-loop-index*;

      - If the UE is provided a higher layer parameter *SRI-PUSCHClosedLoopIndex-Mapping*, the UE obtains a mapping between a set of values for the SRI field in DCI format 0_1 and the l value(s). 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-PUSCHClosedLoopIndex-Mapping* is not provided to the UE, $l = 0$.

  - $f_{f,c}(i,l) = f_{f,c}(i-1,l) + \delta_{\mathrm{PUSCH},f,c}(i - K_{\mathrm{PUSCH}}, l)$ is the PUSCH power control adjustment state for UL BWP b of carrier f of serving cell c and PUSCH transmission period i if accumulation is enabled based on the parameter *Accumulation-enabled* provided by higher layers, where

- $\delta_{\text{PUSCH},f,c}(i-K_{\text{PUSCH}},l)=0$ dB if the UE does not detect a TPC command for UL BWP b of carrier f of serving cell c.
- If the PUSCH transmission is in response to a PDCCH decoding with DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective $\delta_{\text{PUSCH},f,c}$ accumulated values are given in Table 7.1.1-1.
- If the UE has reached $P_{\text{CMAX},f,c}(i)$ for UL BWP b of carrier f of serving cell c, positive TPC commands for UL BWP b of carrier f of serving cell c shall not be accumulated.
- If UE has reached minimum power for UL BWP b of carrier f of serving cell c, negative TPC commands for UL BWP b of carrier f of serving cell c shall not be accumulated.
- A UE shall reset accumulation for UL BWP b of carrier f of serving cell c
  - When $P_{\text{O\_UE\_PUSCH},f,c}(j)$ value is changed by higher layers;
  - When $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$ value is received by higher layers and serving cell c is a secondary cell;
  - When $\alpha_{f,c}(j)$ value is changed by higher layers;
- If the higher layer parameters *SRI-PUSCHClosedLoopIndex-Mapping* and *SRI-P0AlphaSetIndex-Mapping* are provided, the UE determines the value of l from the value of j based on the respective mappings to a same SRI value as provided by the higher layer parameters.
- $f_{b,f,c}(0,l)=0$ is the first value after reset of accumulation.

- $f_{f,c}(i,l)=\delta_{\text{PUSCH},f,c}(i-K_{\text{PUSCH}},l)$ is the PUSCH power control adjustment state for UL BWP b of carrier f of serving cell c and PUSCH transmission period i if accumulation is not enabled based on the parameter *Accumulation-enabled* provided by higher layers, where
  - If the PUSCH transmission is in response to a PDCCH decoding with DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective $\delta_{\text{PUSCH},f,c}$ absolute values are given in Table 7.1.1-1.
  - $f_{f,c}(i,l)=f_{f,c}(i-1,l)$ for a PUSCH transmission period where the UE does not detect a DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI UL BWP b of for carrier f of serving cell c.

- If the UE receives the random access response message for UL BWP b of carrier f of serving cell c
  - $f_{f,c}(0,l)=\Delta P_{rampup,f,c}+\delta_{msg2,f,c}$, where
    - $\delta_{msg2,f,c}$ is the TPC command indicated in the random access response grant of the random access response message corresponding to the random access preamble transmitted for carrier f in the serving cell c, and
    - $\Delta P_{rampup,f,c}=\min\left[\left\{\max\left(0,P_{\text{CMAX},f,c}-\left(\begin{array}{c}10\log_{10}(2^{\mu}\cdot M^{\text{PUSCH}}_{\text{RB},f,c}(0))\\+P_{\text{O\_PUSCH},f,c}(0)+\alpha_{f,c}(0)\cdot PL_c\\+\Delta_{\text{TF},f,c}(0)+\delta_{msg2,f,c}\end{array}\right)\right)\right\},\ \Delta P_{rampuprequested,c}\right]$ and

      $\Delta P_{rampuprequested,f,c}$ 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, $M^{\text{PUSCH}}_{\text{RB},f,c}(0)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for the first PUSCH transmission on UL BWP b of carrier f of serving cell c, and

$\Delta_{TF,f,c}(0)$ is the power adjustment of first PUSCH transmission on 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, having CRC parity bits scrambled by TPC-PUSCH-RNTI, or DCI format 2_3 , to absolute and accumulated $\delta_{\text{PUSCH}c}$ values

TPC Command Field	Accumulated $\delta_{\text{PUSCH}c}$ or $\delta_{\text{SRS}b,f,c}$ [dB]	Absolute $\delta_{\text{PUSCH}c}$ 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 UL BWP b of carrier f in the primary cell c using PUCCH power control adjustment state with index l, the UE shall determine the PUCCH transmission power $P_{\text{PUCCH},f,c}(i,q_u,q_d,l)$ in PUCCH transmission period i as

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

where

- $P_{\text{CMAX},f,c}(i)$ is the 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 period i.

- $P_{\text{O\_PUCCH}f,c}(q_u)$ is a parameter composed of the sum of a component $P_{\text{O\_NOMINAL\_PUCCH}}$, provided by higher layer parameter *P0-nominal-PUCCH* for carrier f of primary cell c, and a component $P_{\text{O\_UE\_PUCCH}}(q_u)$ provided by higher layer parameter *P0-PUCCH* for UL BWP b of carrier f of primary cell c, where $0 \le q_u < Q_u$. Q_u is a size for a set of $P_{\text{O\_UE\_PUCCH}}$ values provided by higher layer parameter *num-p0-pucch*. The set of $P_{\text{O\_UE\_PUCCH}}$ values is provided by higher layer parameter *p0-pucch-set*.

- If the UE is provided higher layer parameters *P0PUCCHIndex-Mapping* and *PUCCH-Spatial-relation-info*, the UE obtains a mapping between a set of *PUCCH-Spatial-relation-info* values and a set of *P0-PUCCH* values provided by higher layer parameter *p0-pucch-set* from higher layer parameters *P0PUCCHIndex-Mapping*. If the UE receives an activation command [11, TS 38.321] indicating a value of *PUCCH-Spatial-relation-info*, the UE determines the value of *P0-PUCCH* that is mapped to the *PUCCH-Spatial-relation-info* value.

- If the UE is not provided higher layer parameter *P0PUCCHIndex-Mapping* or *PUCCH-Spatial-relation-info*, the UE obtains the *P0-PUCCH* value from the first value in *p0-pucch-set*.

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

- $PL_{f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE for UL BWP b of carrier f of the primary cell c. If the UE is not provided with higher layer parameter *pucch-pathloss-Reference-rs* and before the UE is provided with 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 obtains higher layer parameter *MasterInformationBlock*. Otherwise, the UE calculates $PL_{b,f,c}(q_d)$ using RS resource 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 *num-pucch-pathlossReference-rs*. The set of RS resources is provided by higher layer parameter *pucch-pathlossReference-rs*. The set of RS resources can include one or both of a set of SS/PBCH block indexes provided by higher layer parameter *pucch-pathlossReference-SSB* and a set of CSI-RS configuration indexes provided by higher layer parameter *pucch-pathlossReference-CSIRS*. The UE identifies a RS resource in the set of RS resources to correspond to a SS/PBCH block or to a CSI-RS configuration as provided by higher layer parameter *pucch-pathlossreference-index*.

  - If the UE is provided higher layer parameters *PathlossReferenceIndex-Mapping* and *PUCCH-Spatial-relation-info*, the UE obtains a mapping between a set of *PUCCH-Spatial-relation-info* values and a set of *pucch-pathlossreference-index* values provided by higher layer parameter *pucch-pathlossReference-rs-config*. If the UE receives an activation command [11, TS 38.321] indicating a value of *PUCCH-Spatial-relation-info*, the UE determines the value of *pucch-pathlossreference-index* that is mapped to the *PUCCH-Spatial-relation-info* value.

  - If the UE is not provided higher layer parameter *PathlossReferenceIndex-Mapping* or *PUCCH-Spatial-relation-info*, the UE obtains the *pucch-pathlossreference-index* value from the first value in *pucch-pathlossReference-rs-config*.

- The parameter $\Delta_{\mathrm{F\_PUCCH}}(F)$ 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.

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

  - For a PUCCH transmission using PUCCH format 0 or PUCCH format 1, $\Delta_{\mathrm{TF},f,c}(i) = 10\log_{10}\left(\frac{N_{\mathrm{ref}}^{\mathrm{PUCCH}}}{N_{\mathrm{symb}}^{\mathrm{PUCCH}}}\right)$

    where

    - $N_{\mathrm{symb}}^{\mathrm{PUCCH}}$ is the number of PUCCH format 0 symbols or PUCCH format 1 symbols, provided by higher layer parameters *PUCCH-F0-F2-number-of-symbols* or *PUCCH-F1-F3-F4-number-of-symbols*, respectively

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

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

  - For a PUCCH transmission using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and for a number of UCI bits smaller than or equal to 11, $\Delta_{\mathrm{TF},b,f,c}(i) = 10\log_{10}\left(K_1 \cdot \left(n_{\mathrm{HARQ\text{-}ACK}} + O_{\mathrm{SR}} + O_{\mathrm{CSI}}\right) / N_{\mathrm{RE}}\right)$.

- $n_{\text{HARQ-ACK}}$ 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 *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_{SR} is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1.
- O_{CSI} is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2.
- N_{RE} is a number of resource elements determined as $N_{\text{RE}}=M_{\text{RB}b,f,c}^{\text{PUSCH}}(i)\cdot N_{\text{symb}b,f,c}^{\text{PUSCH}}(i)$ excluding REs used for DM-RS transmission, where $N_{\text{symb}b,f,c}^{\text{PUSCH}}(i)$ is the number of symbols for PUCCH transmission period i on 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, $\Delta_{\text{TF},b,f,c}(i)=10\log_{10}\left(\left(2^{\text{K}_2\cdot\text{BPRE}}-1\right)\right)$.
  - $\text{BPRE}=\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)/N_{\text{RE}}$.
  - O_{ACK} 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 *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_{SR} is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1.
  - O_{CSI} is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2.
- N_{RE} is a number of resource elements that the UE determines as $N_{\text{RE}}=M_{\text{RB}b,f,c}^{\text{PUSCH}}(i)\cdot N_{\text{symb}b,f,c}^{\text{PUSCH}}(i)$ excluding REs used for DM-RS transmission, where $N_{\text{symb}b,f,c}^{\text{PUSCH}}(i)$ is the number of symbols for PUCCH transmission period i on UL BWP b of carrier f of serving cell c.

- For the PUCCH power control adjustment state for UL BWP b of carrier f of primary cell c and PUCCH transmission period i
  - $\delta_{\text{PUCCH},f,c}(i-K_{\text{PUCCH}},l)$ is a correction value, also referred to as a TPC command, and is included in a PDCCH with DCI format 1_0 or DCI format 1_1 for UL BWP b of carrier f of the primary cell c that the UE detects in PUCCH transmission period $i-K_{\text{PUCCH}}$, or jointly coded with other TPC commands in a PDCCH with DCI format 2_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI [5, TS 36.212], and $l\in\{0,1\}$ if the UE is provided by higher layer parameter *num-pucch-pcadjustment-states* and $l=0$ otherwise;
    - A higher layer parameter *PUCCHClosedLoopIndex-Mapping*, when provided, provides a mapping between a set of *PUCCH-Spatial-relation-info* values and the l value(s). If the UE receives an activation command [11, TS 38.321] indicating a value of *PUCCH-Spatial-relation-info*, the UE determines the value of l that is mapped to the *PUCCH-Spatial-relation-info* value.
    - The $\delta_{\text{PUCCH},f,c}$ dB values signaled on PDCCH with DCI format 1_0 or DCI format 1_1 or DCI format 2_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI are given in Table 7.2.1-1.
    - $\delta_{\text{PUCCH},f,c}(i-K_{\text{PUCCH}},l)=0$ dB if the UE does not detect a TPC command for UL BWP b of carrier f of the primary cell c.
  - $g_{f,c}(i,l)=g_{f,c}(i-1,l)+\delta_{\text{PUCCH},f,c}(i-K_{\text{PUCCH}},l)$ is the current PUCCH power control adjustment state and $g_{f,c}(0,l)=0$ is the first value after reset

- If $P_{\text{O\_PUCCH}b,f,c}(q_u)$ value is changed by higher layers,
  - $g_{f,c}(0,l) = 0$

    If the higher layer parameters *P0PUCCHIndex-Mapping* and *PUCCHClosedLoopIndex-Mapping* are provided, the UE determines the value of l from the value of q_u based on the respective mappings to a same *PUCCH-Spatial-relation-info* value as provided by the higher layer parameters.
- Else,
  - $g_{f,c}(0,l) = \Delta P_{rampup f,c} + \delta_{msg2,f,c}$, where

    $\delta_{msg2,f,c}$ is the TPC command indicated in the random access response grant corresponding to the random access preamble transmitted for carrier f in the serving cell c, and,

    if the UE transmits PUCCH,

    $\Delta P_{rampup f,c} = \min\left[\left\{\max\left(0,\ P_{\text{CMAX},f,c} - \left(P_{\text{O\_PUCCH}f,c} + PL_c + \Delta_{\text{F\_PUCCH}}(F) + \Delta_{\text{TF},f,c} + \delta_{msg2,f,c}\right)\right)\right\},\quad \Delta P_{rampuprequested,f,c}\right]$;

    otherwise, $\Delta P_{rampup f,c} = \min\left[\left\{\max\left(0,\ P_{\text{CMAX},f,c} - \left(P_{\text{O\_PUCCH}f,c} + PL_c\right)\right)\right\},\quad \Delta P_{rampuprequested,f,c}\right]$ and $\Delta P_{rampuprequested,f,c}$ 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 UL BWP b of carrier f in primary cell c, and $\Delta_{\text{F\_PUCCH}}(F)$ corresponds to PUCCH format 0 or PUCCH format 1.
- If the UE has reached $P_{\text{CMAX},c}(i)$ for UL BWP b of carrier f in primary cell c, the UE does not accumulate positive TPC commands for UL BWP b of carrier f in primary cell c.
- If the UE has reached minimum power for UL BWP b of carrier f in primary cell c, the UE does not accumulate negative TPC commands for UL BWP b of carrier f in primary cell c.

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 having CRC parity bits scrambled by TPC-PUCCH-RNTI to accumulated $\delta_{\text{PUCCH},c}$ values

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

7.3 Sounding reference signals

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

7.3.1 UE behaviour

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

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

where,

- $P_{\mathrm{CMAX},f,c}(i)$ 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 period i.

- $P_{\mathrm{O\_SRS}b,f,c}(q_s)$ is a parameter composed of the sum of a component $P_{\mathrm{O\_NOMINAL\_SRS},f,c}$, provided by higher layer parameter *p0-nominal-srs-set* for carrier f of primary cell c, and a component $P_{\mathrm{O\_UE\_SRS}}(q_s)$ provided by higher layer parameter *p0-srs-set* for 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*.

- $M_{\mathrm{SRS}b,f,c}(i)$ is the SRS bandwidth expressed in number of resource blocks for SRS transmission period i on UL BWP b of carrier f of serving cell c and μ is defined in [4, TS 38.211].

- $\alpha_{\mathrm{SRS}b,f,c}(q_s)$ is provided by higher layer parameter *alpha-srs* for UL BWP b of carrier f of serving cell c and SRS resource set q_s.

- $PL_{b,f,c}(q_s)$ is a downlink path-loss estimate in dB calculated by the UE for UL BWP b of carrier f of serving cell c and SRS resource set q_s [6, TS 38.214] using a RS resource provided by higher layer parameter *srs-pathlossReference-rs*. The RS resource is from a set of RS resources that include a set of SS/PBCH block indexes provided by higher layer parameter *srs-pathlossReference-SSB* and a set of CSI-RS configuration indexes provided by higher layer parameter *srs-pathlossReference-CSIRS*.

- For the SRS power control adjustment state for UL BWP b of carrier f of serving cell c and SRS transmission period 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-pcadjustment-state-config* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions; or

  - $h_{b,f,c}(i) = h_{b,f,c}(i-1) + \delta_{\mathrm{SRS}b,f,c}(i-K_{\mathrm{SRS}})$ if the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c, or if higher layer parameter *srs-pcadjustment-state-config* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions, and if accumulation is enabled based on the parameter *Accumulation-enabled-srs* provided by higher layers, where $\delta_{\mathrm{SRS},f,c}(i-K_{\mathrm{SRS}})$ is jointly coded with other TPC commands in a PDCCH with DCI format 2_3 having CRC parity bits scrambled by TPC-SRS-RNTI that is last received by the UE prior to the SRS transmission and accumulative values of $\delta_{\mathrm{SRS},f,c}(i-K_{\mathrm{SRS}})$ are provided in Table 7.1.1-1, where

    - $\delta_{\mathrm{SRS}b,f,c}(i-K_{\mathrm{SRS}}) = 0$ dB if the UE does not detect a TPC command for serving cell c.

    - If the UE has reached $P_{\mathrm{CMAX},f,c}(i)$ for UL BWP b of carrier f of serving cell c, positive TPC commands for serving cell c shall not be accumulated.

    - If UE has reached minimum power for UL BWP b of carrier f of serving cell c, negative TPC commands shall not be accumulated.

    - A UE shall reset accumulation for UL BWP b of carrier f of serving cell c

      - When $P_{\mathrm{O\_SRS}b,f,c}(q_s)$ value is changed by higher layers;

      - When $\alpha_{\mathrm{SRS}b,f,c}(q_s)$ value is changed by higher layers.

    - $h_{b,f,c}(0) = 0$ is the first value after reset of accumulation.

  - $h_{b,f,c}(i) = \delta_{\mathrm{SRS}b,f,c}(i-K_{\mathrm{SRS}})$ if the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c, or if higher layer parameter *srs-pcadjustment-state-config* indicates a separate power

control adjustment state between SRS transmissions and PUSCH transmissions and if accumulation is not enabled based on the parameter *Accumulation-enabled-srs* provided by higher layers, jointly coded with other TPC commands in a PDCCH with DCI format 2_3 having CRC parity bits scrambled by TPC-SRS-RNTI that is last received by the UE prior to the SRS transmission and absolute values of $\delta_{\text{SRS},f,c}(i-K_{\text{SRS}})$ are provided in Table 7.1.1-1, where

- If DCI format 2_3 having CRC scrambled by TPC-SRS-RNTI the $\delta_{\text{PUSCH}f,c}$ absolute values are given in Table 7.1.1-1.
- $h_{b,f,c}(i)=h_{b,f,c}(i-1)$ for a SRS transmission period i where the UE does not detect a DCI format 2_3 having CRC scrambled by TPC-SRS-RNTI for UL BWP b of carrier f of serving cell c.

- if higher layer parameter *srs-pcadjustment-state-config* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions, the update of the power control adjustment state for SRS transmission period 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 period i occurs at the beginning of the first SRS resource in the SRS resource set q_s.

7.4 Physical random access channel

A UE determines a transmission power for a physical random access channel (PRACH), $P_{\text{PRACH}b,f,c}(i)$, on an UL BWP b of carrier f based on a current SS/PBCH block determination for serving cell c in transmission period i as

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

where $P_{\text{CMAX},f,c}(i)$ is the 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 period i, $P_{\text{PRACH,target},f,c}$ is the PRACH preamble target reception power *PREAMBLE_RECEIVED_TARGET_POWER* provided by higher layers [11, TS 38.321]for the UL BWP b on carrier f of serving cell c, and $PL_{b,f,c}$ is a pathloss for the UL BWP b on carrier f for the current SS/PBCH block of serving cell c 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 the PRACH transmission from the UE is not in response to a detection of a PDCCH order by the UE, *referenceSignalPower* is provided by *SS-PBCHBlockPower*, where *SS-PBCHBlockPower* is provided by *SystemInformationBlockType1*.

If the PRACH transmission from the UE is in response to a detection of a PDCCH order by the UE, *referenceSignalPower* is *SS-PBCHBlockPower* or, when the UE is configured a periodic CSI-RS transmission, is obtained by higher layer parameter *Pc-SS* that provides an offset of CSI-RS transmission power relative to SS/PBCH block transmission power [6, TS 38.214], depending on the DL RS that the DMRS of the PDCCH order is quasi-collocated with as described in Subclause 10.1.

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 shall determine 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 shall notify 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 UL 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 period 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 period 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 period i. When determining a total transmit power in a symbol of transmission period i, the UE does not include power for transmissions starting after the symbol of transmission period i. The total UE transmit power is defined as the sum of the linear values of UE transmit powers for PUSCH, PUCCH, PRACH, and SRS. In case of same priority order and for operation with carrier aggregation, transmission on the primary cell of the MCG or the SCG is prioritized over transmission on a secondary cell and transmission on the PCell is prioritized over transmission on the PSCell.

- PRACH transmission on the PCell;
- PUCCH transmission with HARQ-ACK/SR or PUSCH transmission with HARQ-ACK;
- PUCCH transmission with CSI or PUSCH transmission with CSI;
- PUSCH transmission without HARQ-ACK 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.

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-LTE* and a maximum power P_{NR} for transmissions 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 as described Subclauses 7.1 through 7.5 using P_{NR} as the maximum transmission power for $P_{\text{CMAX}} \le P_{\text{NR}}$.

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 EUTRA (by higher layer parameter *SUO-case1* in [13, TS 36.213])
  - If the UE does not indicate a capability for dynamic power sharing between EUTRA and NR, the UE is not expected to transmit in a slot on the SCG 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 EUTRA and NR and
  - if the UE is not configured for operation with shortened TTI and processing time on the MCG [13, TS 36.213], 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, and
  - if $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) > \hat{P}_{\text{Total}}^{\text{EN-DC}}$ in a portion of slot i_2 of the SCG,

    the UE reduces transmission power in the 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, respectively.
- If the UE does not indicate a capability for dynamic power sharing between EUTRA and NR, the UE is expected to be configured with reference TDD configuration for EUTRA (by higher layer parameter *SUO-case1* in [13, TS 36.213]).

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 period i on UL BWP b of carrier f of serving cell c. A type 3 UE power headroom PH that is valid for SRS transmission period i on UL BWP b of carrier f of serving cell c.

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 transmits PUSCH in PUSCH transmission period i on UL BWP b of carrier f of serving cell c, the UE computes a power headroom for a Type 1 report as

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

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

If the UE does not transmit PUSCH in PUSCH transmission period i on UL BWP b of carrier f of serving cell c, the UE computes a power headroom for a Type 1 report as

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

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.

7.7.2 Type 2 PH report

This subclause is reserved.

7.7.3 Type 3 PH Report

If a UE transmits SRS in a SRS transmission period i on UL BWP b of carrier f of serving cell c and the UE is not configured for PUSCH transmissions on carrier f of serving cell c, the UE computes a power headroom for a Type 3 report as

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

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

If the UE does not transmit SRS in SRS transmission period i on UL BWP b of carrier f of serving cell c, and the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c, the UE computes power headroom for a Type 3 report as

$$PH_{\text{type3},f,c}(i,q_s,l) = \tilde{P}_{\text{CMAX},f,c}(i) - \left\{ P_{\text{O\_SRS},f,c}(q_{s0}) + \alpha_{\text{SRS},f,c}(q_{s0}) \cdot PL_{f,c}(q_{s0}) + h_{f,c}(i,l) \right\} \text{ [dB]}$$

where q_{s0} is a SRS resource set with a respective higher layer parameter *SRS-ResourceSetId* value being equal to zero and $P_{\text{O\_SRS}b,f,c}(q_{s0})$, $\alpha_{\text{SRS},f,c}(q_{s0})$, $PL_{b,f,c}(q_{s0})$ and $h_{b,f,c}(i,l)$ are defined in Subclause 7.3.1. $\tilde{P}_{\text{CMAX},f,c}(i)$ 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]. The remaining parameters are defined in Subclause 7.3.1. For this case, the physical layer delivers $\tilde{P}_{\text{CMAX},f,c}(i)$ instead of $P_{\text{CMAX},f,c}(i)$ to higher layers.

8 Random access procedure

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

Prior to initiation of the physical random access procedure, Layer 1 shall receive 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 encompasses 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 random access preamble transmission is with a same subcarrier spacing as a random access preamble 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 random access preamble 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 preamble 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 of SS/PBCH blocks associated with one PRACH occasion by the value of higher layer parameter *SSB-perRACH-Occasion*. If the value of *SSB-perRACH-Occasion* is smaller than one, one SS/PBCH block is mapped to 1/*SSB-per-rach-occasion* consecutive PRACH occasions. The UE is provided a number of preambles per SS/PBCH block by the value of higher layer parameter *cb-preamblePerSSB* and the UE determines a total number of preambles per SSB per PRACH occasion as the multiple of the value of *SSB-perRACH-Occasion* and the value of *cb-preamblePerSSB.*

SS/PBCH block indexes are mapped to 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.

The period, starting from frame 0, for the mapping of SS/PBCH blocks to PRACH occasions is the smallest of {1, 2, 4} PRACH configuration periods that is larger than or equal to $\lceil N_{\text{Tx}}^{\text{SSB}} / N_{\text{PRACHperiod}}^{\text{SSB}} \rceil$, where the UE obtains $N_{\text{Tx}}^{\text{SSB}}$ from higher layer parameter *SSB-transmitted-SIB1* and $N_{\text{PRACHperiod}}^{\text{SSB}}$ is the number of SS/PBCH blocks that can be mapped to one PRACH configuration period.

If a random access procedure is initiated by a PDCCH order, the UE shall, if requested by higher layers, transmit a PRACH in the first available PRACH occasion 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 PUSCH processing capability 1 [6, TS 38.214], $\Delta_{\text{BWPSwitching}}$ is defined in [10, TS 38.133], and $\Delta_{\text{Delay}} > 0$.

8.2 Random access response

In response to a PRACH transmission, a UE attempts to detect a PDCCH with 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 for Type1-PDCCH common search space, as defined in Subclause 10.1, that is at least $\lceil (\Delta \cdot N_{\text{slot}}^{\text{subframe},\mu} \cdot N_{\text{symb}}^{\text{slot}}) / T_{sf} \rceil$ symbols after the last symbol of the preamble sequence transmission, where Δ is defined in [10, TS 38.133]. The length of the window in number of slots, based on the subcarrier spacing for Type0-PDCCH common search space as defined in Subclause 10.1, is provided by higher layer parameter *rar-WindowLength*.

If a UE detects the PDCCH with the corresponding RA-RNTI and a corresponding PDSCH that includes a DL-SCH transport block 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 DL-SCH 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 higher layers do not identify the RAPID associated with the PRACH transmission, the higher layers can indicate to the physical layer to transmit a PRACH. A minimum time between the last symbol of the PDSCH reception and the first symbol of the PRACH transmission is equal to $N_{\text{T,1}} + \Delta_{\text{new}} + 0.5$ msec where $N_{\text{T,1}}$ is a time duration of N_1 symbols corresponding to a PDSCH reception time for PDSCH processing capability 1 when additional PDSCH DM-RS is configured and $\Delta_{\text{new}} \geq 0$.

A UE shall receive the PDCCH with the corresponding RA-RNTI and the corresponding PDSCH that includes the DL-SCH transport block with the same DM-RS antenna port quasi co-location properties, as described in [6, 38.214], as for a detected SS/PBCH block or a received CSI-RS. If the UE attempts to detect the PDCCH with the corresponding RA-RNTI in response to a PRACH transmission initiated by a PDCCH order, the UE assumes that the PDCCH 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.

The Msg3 PUSCH frequency resource allocation is for uplink resource allocation type 1 [6, 38.214]. In case of frequency hopping, based on the indication of the frequency hopping flag field, the first one or two bits, $N_{\text{UL,hop}}$ bits, of the Msg3 PUSCH frequency resource allocation field are used as hopping information bits as described in Table 8.3-1.

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

The TPC command $\delta_{msg2,b,f,c}$ 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 non-contention based random access procedure, the CSI request field is interpreted to determine whether an aperiodic CSI report is included in the corresponding PUSCH transmission according to [6, TS 38.214]. In 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	12
Msg3 PUSCH time resource allocation	4
MCS	4
TPC command for Msg3 PUSCH	3
CSI request	1
Reserved bits	3

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 a 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 a UE does not detect the PDCCH with a corresponding RA-RNTI and a corresponding DL-SCH transport block within the window, the UE procedure is as described in [11, TS 38.321].

8.3 Msg3 PUSCH

Higher layer parameter *msg3-tp* 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 initial active UL BWP	Value of $N_{\mathrm{UL,hop}}$ Hopping Bits	Frequency offset for 2nd hop
$N_{\mathrm{BWP}}^{\mathrm{size}} < 50$	0	$N_{\mathrm{BWP}}^{\mathrm{size}}/2$
	1	$N_{\mathrm{BWP}}^{\mathrm{size}}/4$
$N_{\mathrm{BWP}}^{\mathrm{size}} \geq 50$	00	$N_{\mathrm{BWP}}^{\mathrm{size}}/2$
	01	$N_{\mathrm{BWP}}^{\mathrm{size}}/4$
	10	$-N_{\mathrm{BWP}}^{\mathrm{size}}/4$
	11	Reserved

The subcarrier spacing for Msg3 PUSCH transmission is provided by higher layer parameter *msg3-scs*. A UE shall transmit PRACH and Msg3 PUSCH on a same uplink carrier of the same serving cell.

An UL BWP, as described in Subclause 12 and in [4, TS 38.211], for Msg3 PUSCH transmission is indicated by *SystemInformationBlockType1*.

A minimum time between the last symbol of a PDSCH reception conveying a RAR and the first symbol of a corresponding Msg3 PUSCH transmission scheduled by the RAR in the PDSCH for a UE when the PDSCH and the PUSCH have a same subcarrier spacing is equal to $N_{T,1} + N_{T,2} + N_{TA,max} + 0.5$ msec. $N_{T,1}$ is a time duration of N_1 symbols corresponding to a PDSCH reception time for PDSCH 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 PUSCH processing capability 1 [6, TS 38.214], and $N_{TA,max}$ is the maximum timing adjustment value that can be provided by the TA command field in the RAR.

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 PDCCH with 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. A minimum time between the last symbol of the PDSCH reception and the first symbol of the corresponding HARQ-ACK transmission 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 PDSCH 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 has a same first symbol with a PUSCH transmission, the UE multiplexes the UCI in the PUSCH transmission and does not transmit the PUCCH.

If a UE multiplexes aperiodic CSI in a PUSCH and the UE would multiplex UCI in a PUCCH with a same first symbol as the PUSCH, the UE multiplexes the UCI in the PUSCH.

If a UE transmits multiple PUSCHs that start at a same symbol 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 the PUSCH of the serving cell with the smallest *ServCellIndex*.

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 configured with higher layer parameter *CBG-DL = ON*, the UE generates one HARQ-ACK information bit per transport block.

A UE is not expected 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 or a CS-RNTI and the CRC for DCI format 1_1 is scrambled with a C-RNTI.

9.1.1 CBG-based HARQ-ACK codebook determination

If a UE is configured per serving cell with higher layer parameter *CBG-DL = ON*, the UE receives PDSCHs that include code block groups (CBGs) of a transport block. If the UE is configured by higher layer parameter *CBG-DL = ON*, the UE is configured by higher layer parameter *CBGs-per-TB-DL* per serving cell a maximum number $N_{\text{HARQ–ACK}}^{\text{CBG/TB,max}}$ of CBGs for generating respective HARQ-ACK information bits for a transport block reception.

For a number of C code blocks (CBs) in a transport block, the UE determines a number of CBGs as $N_{\text{HARQ–ACK}}^{\text{CBG/TB}} = \min\left(N_{\text{HARQ–ACK}}^{\text{CBG/TB,max}}, C\right)$. Each of the first $N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}} = \text{mod}\left(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}}\right)$ CBGs includes $\left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil$ CBs, where CBG n_{CBG}, $0 \le n_{\text{CBG}} < N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}}$, 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 $N_{\text{HARQ–ACK}}^{\text{CBG/TB,2}} = N_{\text{HARQ-ACK}}^{\text{CBG/TB}} - \text{mod}\left(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}}\right)$ CBGs includes $\left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor$ CBs, where CBG n_{CBG}, $N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}} \le n_{\text{CBG}} < N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}} + N_{\text{HARQ–ACK}}^{\text{CBG/TB,2}}$, includes CBs $N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}} \cdot \left\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rceil + \left(n_{\text{CBG}} - N_{\text{HARQ–ACK}}^{\text{CBG/TB,1}}\right) \cdot \left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor + n_{\text{CB}}$, $0 \le n_{\text{CB}} < \left\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \right\rfloor$. 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.

A retransmission of a transport block to a UE, corresponding to a same HARQ process as a previous transmission of the transport block to the UE, includes the same CBs in a CBG as the initial transmission of the transport block.

If DCI format 1_1 schedules the retransmission of the transport block and includes a CBG transmission information (CBGTI) field of $N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ–ACK}}^{\text{CBG/TB,max}}$ bits, where $N_{\text{TB},c}^{\text{DL}}$ is the value of higher layer parameter *Number-MCS-HARQ-DL-DCI* for serving cell c, the first $N_{\text{HARQ–ACK}}^{\text{CBG/TB}}$ bits of the CBGTI field for the transport block have a one-to-one mapping with the $N_{\text{HARQ–ACK}}^{\text{CBG/TB}}$ CBGs of the transport block. The UE determines whether or not a CBG is retransmitted based on a corresponding value of the CBGTI field where a binary 0 indicates that a corresponding CBG is retransmitted and a binary 1 indicates that a corresponding CBG is not retransmitted.

If a UE is configured with higher layer parameter *HARQ-ACK-codebook=semi-static*, 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 PDCCH with DCI format 1_0, the UE generates HARQ-ACK information only for the transport block in the PDSCH.

If a UE receives a PDSCH that is scheduled by a PDCCH with DCI format 1_0, and if the UE is configured with higher layer parameter *HARQ-ACK-codebook=semi-static*, the UE repeats $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ times the HARQ-ACK information for the transport block in the PDSCH for generating $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$ HARQ-ACK information bits as described in Subclause 9.1.2.

9.1.2 Type-1 HARQ-ACK codebook determination

This subclause applies if the UE is configured with *HARQ-ACK-codebook=semi-static*.

If a UE reports HARQ-ACK information in a PUSCH or 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 the PDSCH reception; otherwise, the following procedures 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 and the active DL BWP and the 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. The determination is based:

a) on a set of slot timing values K_1 associated with the active DL 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 on serving cell c, K_1 is provided by higher layer parameter *DL-data-DL-acknowledgement* for DCI format 1_1;

   c) If the UE is configured to monitor PDCCH for both DCI format 1_0 and DCI format 1_1 on serving cell c, K_1 for DCI format 1_0 is provided by the intersection of (a) the set of slot timing values provided by higher layer parameter *DL-data-DL-acknowledgement* for DCI format 1_1 and (b) the union 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-data-DL-acknowledgement* for DCI format 1_1.

b) when provided, on a set of row indexes of a table provided by higher layer parameter *pdsch-symbolAllocation* 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) when provided, on higher layer parameter *UL-DL-configuration-common*, higher layer parameter *UL-DL-configuration-common-Set2*, and higher layer parameter *UL-DL-configuration-dedicated* as described in Subclause 11.1; and

d) on a PDCCH monitoring periodicity, a PDCCH monitoring offset, and a PDCCH monitoring pattern within a slot for each search space in the set of search spaces configured to the UE for PDCCH candidates corresponding to DCI format 1_0 or DCI format 1_1 for serving cell c as described in Subclause 10.1.

For the set of slot timing values K_1, the UE determines $M_{A,c}$ 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 $K_{1,C}$ to the cardinality of set K_1

Set k =0 – index of slot timing values in set K_1

while $k < K_{1,C}$

Set R to the set of rows provided by *pdsch-symbolAllocation*

Set R_C to the cardinality of R ,

Set $r = 0$ – index of row provided by *pdsch-symbolAllocation*

while $r < R_C$

if the UE is provided higher layer parameter *UL-DL-configuration-common*, or higher layer parameter *UL-DL-configuration-common-Set2*, or higher layer parameter *UL-DL-configuration-dedicated* and at least one OFDM symbol of the PDSCH time resource derived by row r in slot $n - K_{1,k}$ is configured as UL or slot $n - K_{1,k} - K_0$, does not include at least one configured PDCCH monitoring occasion for PDCCH with DCI format 1_0 or DCI format 1_1, where $K_{1,k}$ is the k-th slot timing value in set K_1 and K_0 is derived by row r of *pdsch-symbolAllocation*,

$R = R \setminus r$;

end if

$r = r + 1$;

end while

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

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

else

Set R_C 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 $\mathrm{r} < R_C$

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

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

$j = j + 1$;

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

end while

end if

$k = k + 1$;

end while

For rows of *pdsch-symbolAllocation* associated with a same value of $b_{r,k}$, where $b_{r,k} \in B$, the UE is not expected to receive more than one PDSCH in a same slot.

A UE does not report HARQ-ACK information corresponding to PDSCH receptions or SPS PDSCH releases that occur prior to a change of the active DL BWP of the UE on any serving cell.

A UE does not report HARQ-ACK information corresponding to PDSCH receptions or SPS PDSCH releases if the active UL BWP of the UE on the PCell changes between a time of a corresponding DCI format 1_0 or DCI format 1_1 detection and a time of a PUCCH or PUSCH transmission with the HARQ-ACK information.

If a UE is provided higher layer parameter *DL-data-DL-acknowledgement*, 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-data-DL-acknowledgement* 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 *Number-MCS-HARQ-DL-DCI* indicates reception of two transport blocks, when the UE receives a PDSCH with one transport block, the HARQ-ACK response is associated with the first transport block and the UE generates a NACK for the second transport block if spatial bundling is not applied (*HARQ-ACK-spatial-bundling-PUCCH = FALSE*) and generates HARQ-ACK value of ACK for the second transport block if spatial bundling is applied.

A UE shall determine $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, ..., \tilde{o}_{O^{ACK}-1}^{ACK}$ 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 PDCCH with 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.

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

Set $j = 0$ - HARQ-ACK 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 *HARQ-ACK-spatial-bundling-PUCCH = FALSE*, *CBG-DL = OFF*, and the UE is configured by higher layer parameter *Number-MCS-HARQ-DL-DCI* with reception of two transport blocks for the active DL BWP of serving cell c,

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

$j = j+1$;

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

$j = j+1$;

elseif *HARQ-ACK-spatial-bundling-PUCCH* = *TRUE*, and the UE is configured by higher layer parameter *Number-MCS-HARQ-DL-DCI* 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 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 *CBG-DL* = *ON*, and $N_{\text{HARQ-ACK},c}^{\text{CBG/TBmax}}$ CBGs indicated by higher layer parameter *CBGs-per-TB-DL* for serving cell c,

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

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

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

if the UE is configured by higher layer parameter *Number-MCS-HARQ-DL-DCI* with reception of two transport blocks for the active DL BWP of serving cell c

$\tilde{o}_{j+n_{\text{CBG}}+N_{\text{HARQ-ACK},c}^{\text{CBG/TBmax}}}^{ACK}$ = HARQ-ACK 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 *Number-MCS-HARQ-DL-DCI* for the active DL BWP of serving cell c;

else

$\tilde{o}_j^{ACK}$ = HARQ-ACK bit of this cell

$j = j+1$;

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 *HARQ-ACK-spatial-bundling-PUCCH = FALSE*, or the number of PDSCH receptions or SPS PDSCH release in PDSCH reception occasion m for serving cell c if *HARQ-ACK-spatial-bundling-PUCCH = TRUE* 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 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 multiplexes HARQ-ACK 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 in any of the M_c occasions for PDSCH reception or SPS PDSCH release on any serving cell c, as described in Subclause 9.1.2.1, the UE does not multiplex HARQ-ACK in the PUSCH transmission;

- else the UE generates the HARQ-ACK codebook as described in Subclause 9.1.2.1 except that *HARQ-ACK-spatial-bundling-PUCCH* is replaced by *HARQ-ACK-spatial-bundling-PUSCH*.

If a UE multiplexes HARQ-ACK 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-spatial-bundling-PUCCH* is replaced by *HARQ-ACK-spatial-bundling-PUSCH*.

The UE does not generate a HARQ-ACK codebook for multiplexing in the PUSCH transmission when $V_{\text{T-DAI},m}^{\text{UL}} = 0$.

9.1.3 Type-2 HARQ-ACK codebook determination

This subclause applies if the UE is configured with *HARQ-ACK-codebook=dynamic*.

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

Based on maximum and minimum PDSCH-to-HARQ_feedback timing values provided to a UE by union of of the set of slot timing values {1, 2, 3, 4, 5, 6, 7, 8} for DCI format 1_0 and the set of slot timing values provided by higher layer parameter *DL-data-DL-acknowledgement* for DCI format 1_1, the UE determines monitoring occasions for PDCCH with DCI format 1_0 or DCI format 1_1 for scheduling on a serving cell c and for which the UE transmits HARQ-ACK in a same PUCCH based on respective PDSCH-to-HARQ_feedback timing values. The PDCCH monitoring occasions for PDSCH scheduling on serving cell c are determined based on the PDCCH monitoring periodicity, the PDCCH monitoring offset, and the PDCCH monitoring pattern within a slot for each search space in the set of search spaces configured to the UE for PDCCH candidates corresponding to DCI format 1_0 or DCI format 1_1 for serving cell c. The set of PDCCH monitoring occasions is defined as the union of PDCCH monitoring occasions across configured cells, ordered in ascending order of start time of the search space 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) associated with DCI format 1_0 or DCI format 1_1 or DCI format 1_0 indicating downlink SPS release 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 $0 \leq m < M$.

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) associated with DCI format 1_0 or DCI format 1_1 or associated with DCI format 1_0 indicating downlink SPS release is present, up to the current PDCCH monitoring occasion m and shall be updated from PDCCH monitoring occasion to PDCCH monitoring occasion.

Denote $V_{\text{C-DAI,c,m}}^{\text{DL}}$ as 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 $V_{\text{T-DAI,m}}^{\text{DL}}$ as the value of the total DAI DCI format 1_1 in PDCCH monitoring occasion m according to Table 9.1.3-1. The UE shall assume a same value of total DAI in all DCI formats 1_1 in PDCCH monitoring occasion m.

If the UE transmits HARQ-ACK in a PUCCH and for any PUCCH format, the UE shall determine 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 indices correspond to lower RRC indices 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 there is a PDSCH on serving cell c associated with PDCCH in PDCCH monitoring occasion m, or there is a PDCCH indicating downlink SPS 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

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

      if the higher layer parameter *HARQ-ACK-spatial-bundling-PUCCH = FALSE* 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 *Number-MCS-HARQ-DL-DCI* 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 bit corresponding to the first transport block of this cell

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

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

elseif the higher layer parameter *HARQ-ACK-spatial-bundling-PUCCH* = *TRUE* and m is a monitoring occasion for PDCCH with DCI format 1_1 and the UE is configured by higher layer parameter *Number-MCS-HARQ-DL-DCI* with reception of two transport blocks in at least one configured DL BWP of a serving cell,

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

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

else

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

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

end if

$c = c+1$

end while

$m = m+1$

end while

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

$j = j+1$

end if

if the higher layer parameter *HARQ-ACK-spatial-bundling-PUCCH* = *FALSE* 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 *Number-MCS-HARQ-DL-DCI* 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

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

Set $c = 0$

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

if SPS PDSCH transmission is activated for a UE and the UE is configured to receive SPS PDSCH in a slot within the M monitoring occasions for serving cell c

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

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

end if

$c = c + 1$;

end while

For a monitoring occasion of a PDCCH with DCI format 1_0 or DCI format 1_1 in at least one serving cell, when a UE receives a PDSCH with one transport block and the value of higher layer parameter *Number-MCS-HARQ-DL-DCI* is 2, the HARQ-ACK response is associated with the first transport block and the UE generates a NACK for the second transport block if spatial bundling is not applied (*HARQ-ACK-spatial-bundling-PUCCH = FALSE*) and generates HARQ-ACK value of ACK for the second transport block if spatial bundling is applied.

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

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

where

- $V^{\mathrm{DL}}_{\mathrm{C-DAI},m_{\mathrm{last}},c}$ 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 serving cell c that the UE detects within the M PDCCH monitoring occasions. $V^{\mathrm{DL}}_{\mathrm{C-DAI},m_{\mathrm{last}},c} = 0$ if the UE does not detect any DCI format 1_0 or DCI format 1_1 scheduling PDSCH reception or indicating downlink SPS release for 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 downlink SPS 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 downlink SPS release for serving cell c in any of the M PDCCH monitoring occasions.

- $N^{\mathrm{DL}}_{\mathrm{TB},c}$ is the value of higher layer parameter *Number-MCS-HARQ-DL-DCI* for serving cell c if *HARQ-ACK-spatial-bundling-PUCCH = FALSE* and $N^{\mathrm{DL}}_{\mathrm{TB},c} = 1$ if *HARQ-ACK-spatial-bundling-PUCCH = TRUE*.

- $N^{\mathrm{received}}_{m,c}$ is the number of transport blocks the UE receives in a PDSCH scheduled by DCI format 1_0 or DCI format 1_1 that the UE detects in PDCCH monitoring occasion m for serving cell c if *HARQ-ACK-spatial-bundling-PUCCH = FALSE*, or the number of DCI format 1_0 and DCI format 1_1 that the UE detects in PDCCH monitoring occasion m for serving cell c if *HARQ-ACK-spatial-bundling-PUCCH = TRUE*, 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 transmits HARQ-ACK using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and the UE is configured with

- higher layer parameter *CBG-DL = ON* for $N^{DL,CBG}_{cells}$ serving cells; and

- higher layer parameter *CBG-DL = OFF*, or is not configured with higher layer parameter *CBG-DL*, for $N_{cells}^{DL,TB}$ serving cells where $N_{cells}^{DL,TB} + N_{cells}^{DL,CBG} = N_{cells}^{DL}$

the UE shall determine 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 release and for TB-based PDSCH receptions scheduled by DCI format 1_0 on the $N_{\text{cells}}^{\text{DL,CBG}}$ serving cells and DCI format 1_0 and DCI format 1_1 on the $N_{\text{cells}}^{\text{DL,TB}}$ 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 $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$ HARQ-ACK information bits, where $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$ is the maximum value of $N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$ across all $N_{cells}^{DL,CBG}$ serving cells and $N_{\text{TB},c}^{\text{DL}}$ is the value of higher layer parameter *Number-MCS-HARQ-DL-DCI* for serving cell c. If for a serving cell c it is $N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}} < N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}}$, the UE generates NACK for the last $N_{\text{HARQ-ACK,max}}^{\text{CBG/TB,max}} - N_{\text{TB},c}^{\text{DL}} \cdot N_{\text{HARQ-ACK},c}^{\text{CBG/TB,max}}$ HARQ-ACK information bits for serving cell c;

  - The pseudo-code operation for *HARQ-ACK-spatial-bundling-PUCCH = TRUE* is not applicable;

- 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 shall also determine $n_{\text{HARQ-ACK}} = n_{\text{HARQ-ACK,TB}} + n_{\text{HARQ-ACK,CBG}}$ for obtaining a PUCCH transmission power, as described in Subclause 7.2.1, with

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

where

- $V_{\text{C-DAI},m_{\text{last}},c}^{\text{DL}}$ is the value of the counter DAI in the last DCI format 1_1 scheduling CBG-based PDSCH reception for serving cell c that the UE detects within the M PDCCH monitoring occasions. $V_{\text{C-DAI},m_{\text{last}},c}^{\text{DL}} = 0$ 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.

- $U_{\text{DAI},c}^{\text{CBG}}$ 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 downlink SPS 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 multiplexes 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 DL 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-spatial-bundling-PUCCH* is replaced by *HARQ-ACK-spatial-bundling-PUSCH*.

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 $0 \leq m < M-1$, $V_{T-DAI,m}^{DL} = \varnothing$ 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-spatial-bundling-PUCCH* is replaced by *HARQ-ACK-spatial-bundling-PUSCH*.

If a UE is scheduled for a PUSCH transmission by DCI format 0_1 with $V_{\mathrm{T-DAI}}^{\mathrm{UL}} = 4$ 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 DL SPS 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.

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 downlink SPS release is present, denoted as X and $X \geq 1$
0,0	1	$(X-1) \bmod 4+1=1$
0,1	2	$(X-1) \bmod 4+1=2$
1,0	3	$(X-1) \bmod 4+1=3$
1,1	4	$(X-1) \bmod 4+1=4$

9.2 UCI reporting in physical uplink control channel

UCI types reported in a PUCCH include HARQ-ACK, SR, and CSI. UCI bits include HARQ-ACK information bits, if any, SR information bit, if any, and CSI bits, if any.

9.2.1 PUCCH Resource Sets

If a UE does not have dedicated PUCCH resource configuration, provided by higher layer parameter *PUCCH-Resource-Set*, an initial active UL BWP for PUCCH transmission with HARQ-ACK information is indicated by *SystemInformationBlockType1* and a PUCCH resource set is provided by higher layer parameter *PUCCH-Resource-Common* provided by *SystemInformationBlockType1* through an index to a row of Table 9.2.1-1. A PUCCH resource set includes a PUCCH format, a first symbol, and a duration for a PUCCH transmission. The UE transmits a PUCCH using frequency hopping.. The UE shall transmit the PUCCH using the same spatial domain transmission filter as for the Msg3 PUSCH transmission. The UE is not expected to generate more than one HARQ-ACK information bit.

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

Index	PUCCH format	First symbol	Number of symbols	PRB index
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

If a UE has dedicated PUCCH resource configuration, the UE is provided by higher layers with one or more of the following higher layer parameters:

- *PUCCH-format0* providing a resource for PUCCH transmission with PUCCH format 0;
- *PUCCH-format1* providing a resource for PUCCH transmission with PUCCH format 1;
- *PUCCH-format2* providing a resource for PUCCH transmission with PUCCH format 2;
- *PUCCH-format3* providing a resource for PUCCH transmission with PUCCH format 3;
- *PUCCH-format4* providing a resource for PUCCH transmission with PUCCH format 4.

A PUCCH resource includes one or more of the following parameters:

- an index of the first symbol
  - for PUCCH format 0 or PUCCH format 2 the index of the first symbol index is indicated by higher layer parameter *PUCCH-F0-F2-starting symbol*;
  - for PUCCH format 1, PUCCH format 3, or PUCCH format 4, the index of the first symbol is indicated by higher layer parameter *PUCCH-F1-F3-F4-starting-symbol*;
- a number of symbols
  - for PUCCH format 0 or PUCCH format 2, the number of symbols is indicated by higher layer parameter *PUCCH-F0-F2-number-of-symbols*;

  - for PUCCH format 1 or PUCCH format 3, or PUCCH format 4, the number of symbols is indicated by higher layer parameter *PUCCH-F1-F3-F4-number-of-symbols*;

- an index of the first PRB prior to frequency hopping or for no frequency hopping by higher layer parameter *PUCCH-starting-PRB*;

- an index of the first PRB after frequency hopping by higher layer parameter *PUCCH-2nd-hop-PRB*;

- a number of PRBs (for PUCCH format 2 or PUCCH format 3)

  - for PUCCH format 2, the number of PRBs is indicated by higher layer parameter *PUCCH-F2-number-of-PRBs*;

  - for PUCCH format 3, the number of PRBs is indicated by higher layer parameter *PUCCH-F3-number-of-PRBs*;

- frequency hopping

  - frequency hopping for a PUCCH resource is either enabled or disabled and is indicated by higher layer parameter *PUCCH-frequency-hopping*;

- an index of the cyclic shift (for PUCCH format 0 or PUCCH format 1)

  - for PUCCH format 0 or PUCCH format 1, the index of the cyclic shift is indicated by higher layer parameter *PUCCH-F0-F1-initial-cyclic-shift*;

- an index of an orthogonal cover code in case of PUCCH format 1

  - the index of the orthogonal cover code is from a set determined as described in [4, TS 38.211] and is indicated by higher layer parameter *PUCCH-F1-time-domain-OCC*;

- an index of an orthogonal cover code in case of PUCCH format 4

  - the index of the orthogonal cover code is from a set of {0, 1, 2, 3} as described in [4, TS 38.211] and is indicated by higher layer parameter *PUCCH-F4-preDFT-OCC-index*;

- a spreading factor for an orthogonal cover code in case of PUCCH format 4

  - the spreading factor of PUCCH format 4 is from a set of {2, 4} as described in [4, TS 38.211] and is indicated by higher layer parameter *PUCCH-F4-preDFT-OCC-length*;

- a spatial setting provided by higher layer parameter *PUCCH-Spatialrelationinfo* if it provides a single value for higher layer parameter *Spatialrelationinfo*; otherwise, the spatial setting is provided by a selection command for the value of *Spatialrelationinfo* [11, TS 38.321].

A UE can be configured a number of sets of PUCCH resources by higher layer parameter *PUCCH-Resource-Set*, where the number of PUCCH resources in the first set of PUCCH resources is provided by higher layer parameter *maxNrofPUCCH-ResourcesPerSet*, the number of PUCCH resources in the other sets of PUCCH resources is eight, and where a PUCCH resource in a set of PUCCH resources is indicated by higher layer parameter *PUCCH-ResourceId*.

If the UE transmits N_{UCI} UCI bits, the UE determines a PUCCH resource set to be

- a first set of PUCCH resources if $N_{\text{UCI}} \leq 2$, or

- a second set of PUCCH resources, if any, if $2 < N_{\text{UCI}} < N_2$ where N_2 is provided by higher layer parameter *N_2*, or

- a third set of PUCCH resources, if any, if $N_2 \leq N_{\text{UCI}} < N_3$ where N_3 is provided by higher layer parameter *N_3*, or

- a fourth set of PUCCH resources, if any, if $N_3 \leq N_{\text{UCI}} \leq N_4$.

9.2.2 PUCCH Formats for UCI transmission

If a UE is not transmitting PUSCH, and the UE is transmitting UCI, the UE shall transmit UCI

- on PUCCH format 0 if
  - the transmission is over 1 symbol or 2 symbols,
  - the number of UCI bits is 1 or 2
- on PUCCH format 1 if
  - the transmission is over 4 or more symbols,
  - the number of UCI bits is 1 or 2
- on PUCCH format 2 if
  - the transmission is over 1 symbol or 2 symbols,
  - the number of UCI bits is more than 2
- on PUCCH format 3 if
  - the transmission is over 4 or more symbols,
  - the number of UCI bits is more than 2
- on PUCCH format 4 if
  - the transmission is over 4 or more symbols,
  - the number of UCI bits is more than 2,
  - a PUCCH resource includes an orthogonal cover code

9.2.3 UE procedure for reporting HARQ-ACK

A UE may transmit one or more PUCCHs on a serving cell in different symbols within a slot of $N_{\text{symb}}^{\text{slot}}$ symbols as defined in [4, TS 38.211]. 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 or a DCI format 1_0 indicating aSPS PDSCH release over a number of symbols where the last symbol is within slot n, the UE shall provide 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.

For DCI format 1_1, the PDSCH-to-HARQ-timing-indicator field values map to values for a number of slots indicated by higher layer parameter *DL-data-DL-acknowledgement* as defined in Table 9.2.3-1 from a set of number of slots provided by higher layer parameter *Slot-timing-value-K1*.

For DCI format 1_0, the PDSCH-to-HARQ-timing-indicator field values map to {1, 2, 3, 4, 5, 6, 7, 8}.For a PDSCH reception in slot n without an associated DCI format 1_0 or DCI format 1_1 detection and for HARQ-ACK transmission in a PUCCH, the UE transmits the PUCCH in slot $n+k$ unless the UE is provided higher layer parameter *UL-DL-configuration-common*, or higher layer parameter *UL-DL-configuration-common-Set2* , or higher layer parameter *UL-DL-configuration-dedicated* indicating at least one symbol for the PUCCH transmission in slot $n+k$ as a downlink symbol.

If the UE detects a DCI format that does not include a PDSCH-to-HARQ-timing-indicator field and schedules a PDSCH reception over a number of symbols where the last symbol is within slot n, the UE shall provide corresponding HARQ-ACK information in a PUCCH transmission within slot $n+k$.

HARQ-ACK transmission in a PUCCH 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
'000'	1st value provided by *DL-data-DL-acknowledgement*
'001'	2nd value provided by *DL-data-DL-acknowledgement*
'010'	3rd value provided by *DL-data-DL-acknowledgement*
'011'	4th value provided by *DL-data-DL-acknowledgement*
'100'	5th value provided by *DL-data-DL-acknowledgement*
'101'	6th value provided by *DL-data-DL-acknowledgement*
'110'	7th value provided by *DL-data-DL-acknowledgement*
'111'	8th value provided by *DL-data-DL-acknowledgement*

For transmission of HARQ-ACK information in a PUCCH by a UE, the 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 that the UE detects and for which the UE transmits corresponding HARQ-ACK information in the PUCCH where detected DCI formats are indexed in an ascending order first across serving cells indexes and then across PDCCH monitoring occasion indexes. The PUCCH resource indicator field values map to values of PUCCH resource indexes, as defined in Table 9.2.3-2, provided by higher layer parameter *PUCCH-ResourceId* for PUCCH resources from the set of PUCCH resources provided by higher layer parameter *PUCCH-Resource-Set*.

For the first set of PUCCH resources, if the value of higher layer parameter *maxNrofPUCCH-ResourcesPerSet* is larger than eight, the UE determines a PUCCH resource from the PUCCH resources indicated by the PUCCH resource indicator field value through a mapping function to other parameters that include a CCE index of a corresponding PDCCH.

Table 9.2.3-2: Mapping of PUCCH resource indication field values to a PUCCH resource in a PUCCH resource set other than the first PUCCH resource set

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

If a UE receives a PDSCH without a corresponding PDCCH, a PUCCH resource for corresponding HARQ-ACK transmission is provided by higher layer parameter *n1PUCCH-AN*.

If a UE transmits HARQ-ACK 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 *PUCCH-F0-F1-initial-cyclic-shift* of *PUCCH-F0-resource-config*, and m_{CS} is determined from the value of one HARQ-ACK bit or from the values of two HARQ-ACK 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 bit to sequences

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 bits to sequences

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 O_{ACK} HARQ-ACK 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 *PUCCH-F2-number-of-PRBs* or *PUCCH-F3-number-of-PRBs* and starts from the first PRB from the number of PRBs, that results to $(O_{\text{ACK}} + O_{\text{CRC}}) \le M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb}}^{\text{PUCCH}} \cdot Q_m \cdot r$ and, if $M_{\text{RB}}^{\text{PUCCH}} > 1$, $(O_{\text{ACK}} + O_{\text{CRC}}) > (M_{\text{RB,min}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb}}^{\text{PUCCH}} \cdot Q_m \cdot r$, where $N_{\text{sc,ctrl}}^{\text{RB}}$, $N_{\text{symb}}^{\text{PUCCH}}$, 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 *SchedulingRequestResource-Config* a set of configurations for SR transmission in a PUCCH 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 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 an occasion of a SR transmission 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 setting $m_{\text{CS}} = 0$. For a positive SR transmission using PUCCH format 1, the UE transmits the PUCCH as described in [4, TS 38.211] by setting $b(0) = 0$.

9.2.5 UE procedure for reporting multiple UCI types

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

In the following, a SR transmission occasion from a UE is assumed to have a same first symbol as a HARQ-ACK transmission from the UE or a same first symbol with a CSI transmission from the UE.

If a UE transmits positive SR and $N_{\text{UCI}} \le 2$ HARQ-ACK information bits using PUCCH format 0, the UE transmits the PUCCH format 0 in PRB(s) indicated by DCI format 1_0 or DCI format 1_1 for HARQ-ACK transmission 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 *PUCCH-F0-F1-initial-cyclic-shift*, and m_{CS} is determined from the value of one HARQ-ACK bit or from the values of two HARQ-ACK bits as in Table 9.2.5-1 and Table 9.2.5-2, respectively.

If the UE transmits negative SR and $N_{UCI} \leq 2$ HARQ-ACK information bits using PUCCH format 0, the UE transmits the PUCCH format 0 for HARQ-ACK transmission as described in Subclause 9.2.3.

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

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

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

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

If a UE transmits negative SR and $N_{UCI} \leq 2$ HARQ-ACK information bits using PUCCH format 1, the UE transmits the PUCCH format 1 using a PUCCH resource indicated by DCI format 1_0 or DCI format 1_1 for HARQ-ACK transmission as described in Subclause 9.2.3. If the UE transmits positive SR and N_{UCI} HARQ-ACK information bits using PUCCH format 1, the UE transmits the PUCCH format 1 using a PUCCH resource for SR transmission as described in Subclause 9.2.4.

If a UE transmits N_{UCI} HARQ-ACK information bits in a PUCCH using PUCCH format 2 or PUCCH format 3 or PUCCH format 4, as described in Subclause 9.2.3, and the UE is configured to transmit K PUCCHs for respective K SR transmission occasions, as determined by a set of higher layer parameters *schedulingRequestResourceId*, with a same first symbol as for PUCCH format 2 or PUCCH format 3 or PUCCH format 4s, $\lceil \log_2(K+1) \rceil$ bits representing a SR transmission occasion, in ascending order, and the SR value are appended to the HARQ-ACK bits. An all-zero value for the $\lceil \log_2(K+1) \rceil$ bits represents a negative SR value across all K SR transmission occasions.

If a UE transmits periodic CSI or semi-persistent CSI in a PUCCH using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and, respectively, *PUCCH-F2-simultaneous-HARQ-ACK-CSI* = TRUE, *PUCCH-F3-simultaneous-HARQ-ACK-CSI* = TRUE, or *PUCCH-F4-simultaneous-HARQ-ACK-CSI* = TRUE, and the UE is configured to transmit PUCCHs for K occasions for SR transmission with a same first symbol as for PUCCH format 2 or PUCCH format 3 or PUCCH format 4, $\lceil \log_2(K+1) \rceil$ bits representing the corresponding SR transmission occasion and the SR value are appended to the HARQ-ACK bits as described in Subclause 9.2.5.2.

If a UE transmits O_{ACK} HARQ-ACK bits, $O_{SR} = \lceil \log_2(K+1) \rceil$ SR bits, and O_{CRC} CRC bits using PUCCH format 2 or PUCCH format 3 in a PUCCH resource that includes M_{RB}^{PUCCH} PRBs, the UE determines a number of PRBs $M_{RB,min}^{PUCCH}$ 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 *PUCCH-F2-number-of-PRBs* or *PUCCH-F3-number-of-PRBs* and starts from the first PRB from the number of PRBs, that results to $(O_{ACK} + O_{SR} + O_{CRC}) \leq M_{RB,min}^{PUCCH} \cdot N_{sc,ctrl}^{RB} \cdot N_{symb}^{PUCCH} \cdot Q_m \cdot r$ and, if $M_{RB}^{PUCCH} > 1$, $(O_{ACK} + O_{SR} + O_{CRC}) > (M_{RB,min}^{PUCCH} - 1) \cdot N_{sc,ctrl}^{RB} \cdot N_{symb}^{PUCCH} \cdot Q_m \cdot r$, where $N_{sc,ctrl}^{RB}$, N_{symb}^{PUCCH}, Q_m, and r are defined in Subclause 9.2.5.2. If $(O_{ACK} + O_{SR} + O_{CRC}) > (M_{RB}^{PUCCH} - 1) \cdot N_{sc,ctrl}^{RB} \cdot N_{symb-UCI}^{PUCCH} \cdot Q_m \cdot r$, the UE transmits the PUCCH over the M_{RB}^{PUCCH} PRBs.

9.2.5.2 UE procedure for multiplexing HARQ-ACK/SR and CSI

In the following, a periodic/semi-persistent CSI transmission occasion from a UE is assumed to have a same first symbol as a HARQ-ACK/SR transmission from the UE as described in Subclause 9.2.5.1.

For a UE transmitting a PUCCH using PUCCH format 2, PUCCH format 3, or PUCCH format 4 to convey HARQ-ACK/SR and periodic/semi-persistent CSI reports

- if the UE transmits PUCCH using PUCCH format 2 to convey the HARQ-ACK/SR and periodic/semi-persistent CSI, the UE transmits HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in the PUCCH if the parameter *PUCCH-F2-simultaneous-HARQ-ACK-CSI* provided by higher layers is set *TRUE*; otherwise, the UE drops the periodic/semi-persistent CSI report(s) and conveys only HARQ-ACK/SR in the PUCCH as described in Subclause 9.2.5.1;

- if the UE transmits PUCCH using PUCCH format 3 to convey the HARQ-ACK/SR and periodic/semi-persistent CSI, the UE transmits HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in the PUCCH if the parameter *PUCCH-F3-simultaneous-HARQ-ACK-CSI* provided by higher layers is set *TRUE*; otherwise, the UE drops the periodic/semi-persistent CSI report(s) and conveys only HARQ-ACK/SR in the PUCCH as described in Subclause 9.2.5.1;

- if the UE transmits PUCCH using PUCCH format 4 to convey the HARQ-ACK/SR and periodic/semi-persistent CSI, the UE transmits HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in the PUCCH if the parameter *PUCCH-F4-simultaneous-HARQ-ACK-CSI* provided by higher layers is set *TRUE*; otherwise, the UE drops the periodic/semi-persistent CSI report(s) and conveys only HARQ-ACK/SR in the PUCCH as described in Subclause 9.2.5.1.

A UE is configured by higher layer parameter *PUCCH-F2-maximum-coderate* a code rate for transmission of HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in PUCCH format 2.

A UE is configured by higher layer parameter *PUCCH-F3-maximum-coderate* a code rate for transmission of HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in PUCCH format 3.

A UE is configured by higher layer parameter *PUCCH-F4-maximum-coderate* a code rate for transmission of HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in PUCCH format 4.

If

- a UE has periodic/semi-persistent CSI reports and zero or more HARQ-ACK/SR information bits to transmit in a PUCCH, and

- the HARQ-ACK information, if any, is in response to a PDSCH reception without a corresponding PDCCH, and

- the UE is configured to transmit periodic/semi-persistent CSI report(s) in a PUCCH using PUCCH format 2 or PUCCH format 3 or PUCCH format 4, and

- *PUCCH-F2-simultaneous-HARQ-ACK-CSI = TRUE*, or *PUCCH-F3-simultaneous-HARQ-ACK-CSI = TRUE*, or *PUCCH-F4-simultaneous-HARQ-ACK-CSI = TRUE*, respectively,

then

- if the UE is configured with $J \le 2$ PUCCH format 2 resources, or with $J \le 2$ PUCCH format 3 resources, or with $J \le 2$ PUCCH format 4 resources, 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, modulation order Q_m, and configured code rate r;

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

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

  - else the PUCCH uses PUCCH format 2 resource $J-1$, or the PUCCH format 3 resource $J-1$, or the PUCCH format 4 resource $J-1$, where

    - O_{ACK} is the total number of HARQ-ACK bits, if any;

    - $O_{\text{SR}} = 0$ if there is no scheduling request bit; otherwise, $O_{\text{SR}} = \lceil \log_2(K+1) \rceil$;

- O_{CSI} is the total number of CSI reports bits;
- O_{CRC} is the total number of CRC bits, if any;
- r is the code rate given by higher layer parameter *PUCCH-F2-maximum-coderate* for PUCCH format 2, or *PUCCH-F3-maximum-coderate* for PUCCH format 3, or *PUCCH-F4-maximum-coderate* for PUCCH format 4, respectively, as in Table 9.2.5.2-1.
- $M_{\text{RB}}^{\text{PUCCH}}$ is the 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 *PUCCH-F2-number-of-PRBs* for PUCCH format 2 or by higher layer parameter *PUCCH-F3-number-of-*PRBs 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;
- $N_{\text{symb-UCI}}^{\text{PUCCH}}$ is equal to the number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,2}}$ for PUCCH format 2 provided by higher layer parameter *PUCCH-F0-F2-number-of-symbols*. For PUCCH format 3 or for PUCCH format 4, $N_{\text{symb-UCI}}^{\text{PUCCH}}$ is equal to the number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,3}}$ for PUCCH format 3 or equal to the number of PUCCH symbols $N_{\text{symb}}^{\text{PUCCH,4}}$ for PUCCH format 4 provided by higher layer parameter *PUCCH-F1-F3-F4-number-of-symbols* for PUCCH format 3 or for PUCCH format 4, 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 *PUCCH-PF3-PF4-pi/2BPSK* for PUCCH format 3 or PUCCH format 4. For PUCCH format 2, $Q_m=2$.

If a UE has HARQ-ACK information to transmit in response to a PDSCH reception with a corresponding PDCCH or in response to a PDCCH indicating SPS PDSCH release, and the UE has wideband periodic/semi-persistent CSI reports [6, TS 38.214] to transmit in a PUCCH and the UE determines a PUCCH format 2 or a PUCCH format 3 or a PUCCH format 4 to transmit HARQ-ACK/SR and the wideband periodic/semi-persistent CSI reports by determining a PUCCH resource set with $N_{\text{UCI}}=\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)$ as described in Subclause 9.2.1 and Subclause 9.2.3, and *PUCCH-F2-simultaneous-HARQ-ACK-CSI = TRUE*, or *PUCCH-F3-simultaneous-HARQ-ACK-CSI = TRUE* or *PUCCH-F4-simultaneous-HARQ-ACK-CSI = TRUE*, respectively,

- if $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)\le M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb}}^{\text{PUCCH}}\cdot Q_m\cdot r$, the UE shall transmit the HARQ-ACK/SR and periodic/semi-persistent CSI bits using PUCCH format 2 by selecting the minimum number $M_{\text{RB,min}}^{\text{PUCCH}}$ of the $M_{\text{RB}}^{\text{PUCCH}}$ PRBs satisfying $\left(O_{\text{ACK}}+O_{\text{SR}}+O_{\text{CSI}}+O_{\text{CRC}}\right)\le M_{\text{RB,min}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb}}^{\text{PUCCH}}\cdot Q_m\cdot r$ 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/SR in ascending order of $\text{Pri}_{\text{CSI}}(y,s,c,t)$, where $\text{Pri}_{\text{CSI}}(y,s,c,t)$ is determined according to [6, TS 38.214]; the value of $N_{\text{CSI}}^{\text{reported}}$ satisfies $\left(O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}}O_{\text{CSI},n}+O_{\text{CRC}}\right)\le M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb}}^{\text{PUCCH}}\cdot Q_m\cdot r$ and $\left(O_{\text{ACK}}+O_{\text{SR}}+\sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}+1}O_{\text{CSI},n}+O_{\text{CRC}}\right)>M_{\text{RB}}^{\text{PUCCH}}\cdot N_{\text{sc,ctrl}}^{\text{RB}}\cdot N_{\text{symb}}^{\text{PUCCH}}\cdot Q_m\cdot r$, where $O_{\text{CSI},n}$ is the number of CSI report bits for the n_{th} CSI report in ascending order of $\text{Pri}_{CSI}(y,s,c,t)$.

If a UE has HARQ-ACK information to transmit in response to a PDSCH reception with a corresponding PDCCH or in response to a SPS PDSCH release and $N_{\text{CSI}}^{\text{total}}$ sub-band [6, TS 38.214] periodic/semi-persistent CSI reports to transmit in

a PUCCH and the UE determines either a PUCCH format 3 or a PUCCH format 4 to transmit HARQ-ACK/SR and the $N_{\text{CSI}}^{\text{total}}$ sub-band periodic/semi-persistent CSI reports by determining a PUCCH resource set with $N_{\text{UCI}} = \left(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}\right)$ as described in Subclause 9.2.1 and Subclause 9.2.3, and *PUCCH-F3-simultaneous-HARQ-ACK-CSI = TRUE*, or *PUCCH-F4-simultaneous-HARQ-ACK-CSI = TRUE*, respectively

- if $\left(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}\right) \le M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc}}^{\text{RB}} \cdot N_{\text{symb}}^{\text{PUCCH}} \cdot Q_m \cdot r$ for the $N_{\text{CSI}}^{\text{total}}$ periodic/semi-persistent CSI reports, where $\sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} \left(O_{\text{CSI-part1},n} + O_{\text{CSI-part2},n}\right) = O_{\text{CSI}}$ and $O_{\text{CRC},1} + O_{\text{CRC},2} = O_{\text{CRC}}$, where $O_{\text{CRC},1}$ is the number of CRC bits for encoding HARQ-ACK/SR and CSI part 1 and $O_{\text{CRC},2}$ is the number of CRC bits for encoding CSI part 2, the UE shall transmit the HARQ-ACK/SR and the $N_{\text{CSI}}^{\text{total}}$ periodic/semi-persistent CSI report bits using either PUCCH format 3 or PUCCH format 4 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

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

and

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

    the UE selects $N_{\text{CSI-part2}}^{\text{reported}}$ 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 using either PUCCH format 3 or PUCCH format 4, 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, and $O_{\text{CRC,CSI-part1}} + O_{\text{CRC,CSI-part2}} = O_{\text{CRC}}$;
  - else, the UE drops all CSI part2 reports and selects $N_{\text{CSI,part1}}^{\text{reported}}$ CSI part 1 report(s), in ascending order of $\text{Pri}_{\text{CSI}}(y,s,c,t)$, where $\text{Pri}_{\text{CSI}}(y,s,c,t)$ is determined according to [6, TS 38.214], for transmission together with the HARQ-ACK/SR bits using either in PUCCH format 3 or in PUCCH format 4 where the value of $N_{\text{CSI,pat1}}^{\text{reported}}$ satisfies $\left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}} O_{\text{CSI-part1},n} + O_{\text{CRC}} \right) \le M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc}}^{\text{RB}} \cdot N_{\text{symb}}^{\text{PUCCH}} \cdot Q_m \cdot r$ and $\left(O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}+1} O_{\text{CSI-part1},n} + O_{\text{CRC}} \right) > M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc}}^{\text{RB}} \cdot N_{\text{symb}}^{\text{PUCCH}} \cdot Q_m \cdot r$, where $O_{\text{CSI-part1},n}$ is the number of CSI report bits for the n_{th} CSI part 1 report in ascending order of $\text{Pri}_{CSI}(y,s,c,t)$ and $O_{\text{CRC,CSI-part1}} = O_{\text{CRC}}$.

Table 9.2.5.2-1: Code rate r corresponding to higher layer parameter *PUCCH-F2-maximum-coderate, or PUCCH-F3-maximum-coderate, or PUCCH-F4-maximum-coderate*

Value of *PUCCH-F2-maximum-coderate*	**Code rate r**
Value of *PUCCH-F3-maximum-coderate*	
Value of *PUCCH-F4-maximum-coderate*	

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 UCI 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 *PUCCH-F1-number-of-slots* , *PUCCH-F3-number-of-slots*, or *PUCCH-F4-number-of-slots*.

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

- the UE repeats the UCI in the PUCCH transmission in the first slot of the $N_{\text{PUCCH}}^{\text{repeat}}$ slots in the PUCCH transmission in each of the remaining $N_{\text{PUCCH}}^{\text{repeat}} - 1$ slots;
- a PUCCH transmission has the same number of consecutive symbols, as provided by higher layer parameter *PUCCH-F1-F3-F4-number-of-symbols*, in each of the $N_{\text{PUCCH}}^{\text{repeat}}$ slots;
- a PUCCH transmission has a same first symbol, as provided by higher layer parameter *PUCCH-F1-F3-F4-starting-symbol*, in each of the $N_{\text{PUCCH}}^{\text{repeat}}$ slots;
- the UE is configured by higher layer parameter *PUCCH-F1-F3-F4-interslot-FH* whether or not to perform frequency hopping for PUCCH transmissions in different slots. If *PUCCH-F1-F3-F4-interslot-FH = ON*, a first PRB for a PUCCH transmission is provided by higher layer parameter *PUCCH-starting-PRB* and a second PRB for a PUCCH transmission is provided by higher layer parameter *PUCCH-2nd-hop-PRB*.
  - If the UE is configured to perform frequency hopping for PUCCH transmissions in different slots,
    - the UE performs frequency hopping per slot;
    - the UE transmits the PUCCH starting from the first PRB in slots with even number and starting from the second PRB 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 is not expected to be configured to perform frequency hopping for a PUCCH transmission within a slot.
  - 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*, the UE does not transmit the PUCCH in the slot.

If a UE is provided higher layer parameter *UL-DL-configuration-common*, or is additionally provided higher layer parameter *UL-DL-configuration-common-set2*, or is additionally provided higher layer parameter *UL-DL-configuration-dedicated* for the slot format per slot over the number of slots, 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 *PUCCH-F1-F3-F4-starting-symbol* 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 *PUCCH-F1-F3-F4-number-of-symbols*.

If a UE is not provided higher layer parameter *UL-DL-configuration-common* or higher layer parameter *UL-DL-configuration-common-set2*, 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.

9.3 UCI reporting in physical uplink shared channel

If a UE has a PUSCH transmission with a same first symbol as a PUCCH transmission that includes HARQ-ACK, or semi-persistent CSI, or periodic CSI information, the UE multiplexes the HARQ-ACK or the semi-persistent CSI, or periodic CSI information in the PUSCH.

Offset values are defined for a UE to determine a number of resources for multiplexing HARQ-ACK and for multiplexing CSI 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 and/or CSI part 1 and CSI part 2 payloads.

HARQ-ACK offsets $\beta_{\text{offset}}^{\text{HARQ-ACK}}$ shall be configured to values according to Table 9.3-1. The higher layer parameters *betaOffsetACK-Index0*, *betaOffsetACK-Index1*, and *betaOffsetACK-Index2* 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 bits, more than 2 and up to 11 HARQ-ACK bits, and more than 11 bits in the PUSCH, respectively.

CSI part 1 and CSI part 2 offsets $\beta_{\text{offset}}^{\text{CSI-1}}$ and $\beta_{\text{offset}}^{\text{CSI-2}}$, respectively, shall be configured to values according to Table 9.3-2. Higher layer parameters *betaOffsetCSIPart1-Index0* and *betaOffsetCSIPart2-Index0* 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 or CSI part 2 in the PUSCH. Higher layer parameters *betaOffsetCSIPart1-Index1* and *betaOffsetCSIPart2-Index1* respectively provide indexes $I_{\text{offset},1}^{\text{CSI-1}}$ or $I_{\text{offset},1}^{\text{CSI-2}}$, respectively, for the UE to use if the UE multiplexes more than 11 bits for CSI part 1 or CSI part 2 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, the UE is provided by each of higher layer parameters {*betaOffsetACK-Index0*, *betaOffsetACK-Index1*, *betaOffsetACK-Index2*} a set of four $I_{\text{offset}}^{\text{HARQ-ACK}}$ indexes, by each of higher layer parameters {*betaOffsetCSIPart1-Index0*, *betaOffsetCSIPart1-Index1*} a set of four $I_{\text{offset}}^{\text{CSI-1}}$ indexes and by each of higher layer parameters {*betaOffsetCSIPart2-Index0*, *betaOffsetCSIPart2-Index1*} 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, CSI part 1, and CSI part 2, 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 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
20.000	20.000
19	Reserved
20	Reserved
21	Reserved
22	Reserved
23	Reserved
24	Reserved
25	Reserved
26	Reserved
27	Reserved
28	Reserved
29	Reserved
30	Reserved
31	Reserved

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

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

10 UE procedure for receiving control information

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

- 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 shall monitor a set of PDCCH candidates in one or more control resource sets on the active DL BWP on each activated serving cell according to corresponding search spaces where monitoring implies decoding each PDCCH candidate according to the monitored DCI formats.

A UE can be configured by higher layer parameter *SSB-periodicity-ServingCell* a periodicity of half frames for reception of SS/PBCH blocks in a serving cell.

For monitoring of a PDCCH candidate

- If the UE has received *SSB-transmitted-SIB1* and has not received *SSB-transmitted* for a serving cell and if at least one RE for monitoring a PDCCH candidate for a DCI format with CRC not scrambled by SI-RNTI on the serving cell overlaps with respective at least one RE corresponding to a SS/PBCH block index provided by *SSB-transmitted-SIB1*, the UE is not required to monitor the PDCCH candidate.
- If a UE has received *SSB-transmitted* for a serving cell and if at least one RE for monitoring a PDCCH candidate for a DCI format with CRC not scrambled by SI-RNTI on the serving cell overlaps with respective at least one RE corresponding to a SS/PBCH block index provided by *SSB-transmitted*, the UE is not required to monitor the PDCCH candidate.
- If the has not received both *SSB-transmitted-SIB1* and *SSB-transmitted* for a serving cell and 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 a carrier aggregation capability for a UE, as included in *UE-NR-Capability*, is larger than 4, 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 is not expected to be configured with a number of PDCCH candidates to monitor per slot 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 spaces. A search space can be a common search space or a UE-specific search space. A UE shall monitor PDCCH candidates in one or more of the following search spaces

- a Type0-PDCCH common search space for a DCI format with CRC scrambled by a SI-RNTI on a primary cell;

- a Type0A-PDCCH common search space for a DCI format with CRC scrambled by a SI-RNTI on a primary cell;

- a Type1-PDCCH common search space for a DCI format with CRC scrambled by a RA-RNTI, or a TC-RNTI, or a C-RNTI on a primary cell;

- a Type2-PDCCH common search space for a DCI format with CRC scrambled by a P-RNTI on a primary cell;

- a Type3-PDCCH common search space for a DCI format with CRC scrambled by INT-RNTI, or SFI-RNTI, or TPC-PUSCH-RNTI, or TPC-PUCCH-RNTI, or TPC-SRS-RNTI, or C-RNTI, or CS-RNTI(s), or SP-CSI-RNTI; and

- a UE-specific search space for a DCI format with CRC scrambled by C-RNTI, or CS-RNTI(s), or SP-CSI-RNTI.

A UE is provided a configuration for a control resource set for Type0-PDCCH common search space by higher layer parameter *RMSI-PDCCH-Config* and a subcarrier spacing by higher layer parameter *RMSI-scs* for PDCCH reception. The UE determines the control resource set and the monitoring occasions for Type0-PDCCH common search space as described in Subclause 13. The Type0-PDCCH common search space 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 has control resource set index 0. The Type0-PDCCH common search space has search space index 0.

For Type0A-PDCCH common search space or for Type2-PDCCH common search space, the control resource set is same as the control resource set for Type0-PDCCH common search space. A UE is provided a configuration for Type0A-PDCCH common search space by higher layer parameter *osi-SearchSpace* and the CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level is given in Table 10.1-1. A UE is provided a configuration for Type2-PDCCH common search space by higher layer parameter *paging-SearchSpace* and the CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level are given in Table 10.1-1.

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

If a UE is not provided higher layer parameter *osi-SearchSpace* for Type0A-PDCCH common search space, the association between monitoring occasions for Type0A-PDCCH common search space and the SS/PBCH block index is the same as the association of monitoring occasions for Type0-PDCCH common search space as described in Subclause 13.

If a UE is not provided higher layer parameter *paging-SearchSpace* for Type2-PDCCH common search space, the association between monitoring occasions for Type2-PDCCH common search space and the SS/PBCH block index is the same as the association of monitoring occasions for Type0-PDCCH common search space as described in Subclause 13.

If a UE is not provided higher layer parameter *ra-SearchSpace* for Type1-PDCCH common search space, the association between monitoring occasions for Type1-PDCCH common search space and the SS/PBCH block index is the same as the association of monitoring occasions for Type0-PDCCH common search space as described in Subclause 13.

The UE may assume that the DM-RS antenna port associated with PDCCH reception in the Type0-PDCCH common search space, the Type0A-PDCCH common search space, and the Type2-PDCCH common search space, and for corresponding PDSCH receptions, and the DM-RS antenna port associated with SS/PBCH reception are quasi co-located with respect to delay spread, Doppler spread, Doppler shift, average delay, and spatial Rx parameters. The value for the DM-RS scrambling sequence initialization is the cell ID.

The subcarrier spacing and the CP length for PDCCH reception with Type0A-PDCCH common search space, or Type1-PDCCH common search space, or Type2-PDCCH common search space are the same as for PDCCH reception with Type0-PDCCH common search space.

A UE may assume that the DM-RS antenna port associated with PDCCH reception and associated PDSCH reception in the Type1-PDCCH common search space are quasi co-located with the SS/PBCH block identified in initial access procedure or with a received CSI-RS with respect to delay spread, Doppler spread, Doppler shift, average delay, and spatial Rx parameters, when applicable.

If a value for the DM-RS scrambling sequence initialization for Type0A-PDCCH common search space, or Type1-PDCCH common search space, or Type2-PDCCH common search space is not provided by higher layer parameter *PDCCH-DMRS-Scrambling-ID* in *SystemInformationBlockType1*, the value is the cell ID.

If a UE is configured for downlink bandwidth part (BWP) operation, as described in Subclause 12, the above configurations for the common search spaces apply for the initial active DL BWP. The UE can be additionally configured a control resource set for Type0-PDCCH common search space, Type0A-PDCCH common search space, Type1-PDCCH common search space, or Type2-PDCCH common search space for each configured DL BWP on the primary cell, other than the initial active DL BWP, as described in Subclause 12.

Table 10.1-1: CCE aggregation levels and maximum number of PDCCH candidates per CCE aggregation level for Type0/Type0A/Type2-PDCCH common search space

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 control resource sets where $P \le 3$. For control resource set p, $0 \le p < P$, the higher layer signalling provides:

- a control resource set index by higher layer parameter *CORESET-ID*;
- a DM-RS scrambling sequence initialization value by higher layer parameter *PDCCH-DMRS-Scrambling-ID*;
- a number of consecutive symbols provided by higher layer parameter *CORESET-time-duration*;
- a set of resource blocks provided by higher layer parameter *CORESET-freq-dom*;
- a CCE-to-REG mapping provided by higher layer parameter *CORESET-CCE-to-REG-mapping-type*;
- a REG bundle size, in case of interleaved CCE-to-REG mapping, provided by higher layer parameter *CORESET-REG-bundle-size*;
- a cyclic shift for the REG bundle interleaver [4, 38.211] by higher layer parameter *CORESET-shift-index*;
- an antenna port quasi co-location, from a set of antenna port quasi co-locations provided by higher layer parameter *TCI-StatesPDCCH*, indicating quasi co-location information of the DM-RS antenna port for PDCCH reception;
- an indication for a presence or absence of a transmission configuration indication (TCI) field for DCI format 1_0 or DCI format 1_1 transmitted by a PDCCH in control resource set p, by higher layer parameter *TCI-PresentInDCI*.

For each control resource set in a DL BWP of a serving cell, a respective higher layer parameter *CORESET-freq-dom* provides a bitmap. The bits of the bitmap have a one-to-one mapping with non-overlapping groups of 6 PRBs, in ascending order of the PRB index in the DL BWP bandwidth of $N_{\mathrm{RB}}^{\mathrm{BWP}}$ PRBs with starting position $N_{\mathrm{BWP}}^{\mathrm{start}}$ where the first PRB of the first group of 6 PRBs has index $6 \cdot \left\lceil N_{\mathrm{BWP}}^{\mathrm{start}} / 6 \right\rceil$. 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 by higher layer parameter *TCI-StatesPDCCH* containing more than one TCI states but has not received a MAC CE activation for one of the TCI states, the UE assumes that the DM-RS antenna port associated with PDCCH reception in the UE-specific search space is quasi co-located with the SS/PBCH block the UE identified during the initial access procedure with respect to delay spread, Doppler spread, Doppler shift, average delay, and spatial Rx parameters, when applicable.

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

For each DL BWP of a serving cell where a UE is configured to monitor PDCCH in a search space, the UE is configured the following by higher layer parameter *search-space-config*:

- an association between a search space set index s, $0 \le s < S$, where $S \le 10$, and a control resource set index p;
- for the search space set s in the control resource set p:
  - an indication that the search space set is a common search space set or a UE-specific search space set by higher layer parameter *Common-search-space-flag*;
  - if the search space set s is for a common search space, an indication by higher layer parameter *RNTI-monitoring* to monitor PDCCH for one or more of DCI format 0_0 and DCI format 1_0 with CRC scrambled by a RNTI from RNTIs described in [5, TS 36.212], DCI format 2_0, DCI format 2_1, DCI format 2_2, and DCI format 2_3;
  - if the search space set s is a UE-specific search space, an indication by higher layer parameter *USS-DCI-format* to monitor PDCCH either for DCI format 0_0 and DCI format 1_0, or for DCI format 0_1 and DCI format 1_1;
  - 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;
  - a PDCCH monitoring periodicity of $k_{p,s}$ slots by higher layer parameter *monitoringSlotPeriodicityAndOffset*;
  - a PDCCH monitoring offset of $o_{p,s}$ slots, where $0 \le o_{p,s} < k_{p,s}$, 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*.

If the higher layer parameter *monitoringSymbolsWithinSlot* indicates to a UE only one PDCCH monitoring occasion within a slot, the UE is not expected to be configured a corresponding search space set s for a PDCCH subcarrier spacing other than 15 kHz if the control resource set p associated with the search space s includes at least one symbol after the third slot symbol.

For a subcarrier spacing of 15 KHz, if the higher layer parameter *monitoringSymbolsWithinSlot* for a search space set s indicates to the UE only one PDCCH monitoring occasion in a slot for a corresponding control resource set p and the control resource set p includes at least one symbol after the third slot symbol, the UE expects that all control resource sets configured to the UE are located within at most three same consecutive symbols in the slot.

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 $\left(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - o_{p,s}\right) \bmod k_{p,s} = 0$.

A PDCCH UE-specific search space $S_{k_{p,s}}^{(L)}$ 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 shall monitor 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 shall monitor the PDCCH candidates with carrier indicator field.

A UE is not expected 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 shall monitor PDCCH candidates at least for the same serving cell.

Table 10.1-2 provides the maximum number of PDCCH candidates, $M_{\text{PDCCH}}^{\max,\text{slot}}$, across all CCE aggregation levels and across all DCI formats with different size in a same search space that a UE is expected to monitor per slot and per serving cell as a function of the subcarrier spacing.

Table 10.1-2: Maximum number of PDCCH candidates per slot and per serving cell as a function of the subcarrier spacing value $2^{\mu}\cdot 15$ kHz, $\mu \in \{0,1,2,3\}$.

μ	Maximum number of PDCCH candidates per slot and per serving cell $M_{\text{PDCCH}}^{\max,\text{slot}}$
0	44
1	36
2	22
3	20

Table 10.1-3 provides the maximum number of non-overlapped CCEs, $C_{\text{PDCCH}}^{\max,\text{slot}}$, that a UE is expected to monitor per slot and per serving cell as a function of the subcarrier spacing, if the higher layer parameter *Monitoring-symbols-PDCCH-within-slot* indicates to a UE only one PDCCH monitoring occasion within a slot.

CCEs are non-overlapped if the 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 of non-overlapped CCEs per slot and per serving cell as a function of the subcarrier spacing value $2^{\mu}\cdot 15$ kHz, $\mu \in \{0,1,2,3\}$.

μ	Maximum number of non-overlapped CCEs per slot and per serving cell $C_{\text{PDCCH}}^{\max,\text{slot}}$
0	56
1	56
2	48
3	32

Denote by S_{css} a set of search space sets s_{css} for common search spaces in a corresponding set P_{css} of control resource sets p_{css} and by S_{uss} a set of search space sets s_{uss} for UE-specific search spaces in a corresponding set P_{uss} of control resource sets p_{uss} where a UE monitors PDCCH candidates in a slot. If $\sum_{\substack{s_{\text{css}}\in S_{\text{css}}\\ p_{\text{css}}\in P_{\text{css}}}}\sum_{L} M_{p_{\text{css}},s_{\text{css}}}^{(L)} + \sum_{\substack{s_{\text{uss}}\in S_{\text{uss}}\\ p_{\text{uss}}\in P_{\text{uss}}}}\sum_{L} M_{p_{\text{uss}},s_{\text{uss}}}^{(L)} > M_{\text{PDCCH}}^{\max,\text{slot}}$, the UE monitors $M_{\text{PDCCH}}^{\text{css}} = \min\left(M_{\text{PDCCH}}^{\max,\text{slot}}, \sum_{\substack{s_{\text{css}}\in S_{\text{css}}\\ p_{\text{css}}\in P_{\text{css}}}}\sum_{L} M_{p_{\text{css}},s_{\text{css}}}^{(L)}\right)$ PDCCH candidates for the common search spaces and $M_{\text{PDCCH}}^{\text{uss}} = M_{\text{PDCCH}}^{\max,\text{slot}} - M_{\text{PDCCH}}^{\text{css}}$ PDCCH candidates for UE-specific search spaces in the slot. 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, $Y_{p,n_{s,f}^{\mu}} = \left(A_p \cdot Y_{p,n_{s,f}^{\mu}-1}\right) \bmod D$, $Y_{p,-1} = n_{\mathrm{RNTI}} \neq 0$, $A_0 = 39827$, $A_1 = 39829$, $A_2 = 39839$, 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 for a serving cell corresponding to n_{CI} and a search space set s;

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 defined in [5, TS 38.212] and in [6, TS 38.214].

If, for a UE, any CCE index for PDCCH candidate with index $m_{s,n_{CI},2}$ with aggregation level L in control resource set p overlaps with any CCE index for PDCCH candidate with index $m_{s,n_{CI},1}$ with aggregation level L in control resource set p, where $m_{s,n_{CI},1} < m_{s,n_{CI},2}$, the UE is not expected to monitor the PDCCH candidate with index $m_{s,n_{CI},2}$.

A UE is not expected to be configured to monitor DCI format 0_1 or DCI format 1_1 in a common search space.

A UE configured to monitor PDCCH candidates in a serving cell with a DCI format size with carrier indicator field and CRC scrambled by C-RNTI, where the PDCCH candidates may have one or more possible values of carrier indicator field for the DCI format size, shall assume that an PDCCH candidate with the DCI format size may be transmitted in the serving cell in any PDCCH UE specific search space corresponding to any of the possible values of carrier indicator field for the DCI format size if the UE includes in *UE-NR-Capability* an indication for a corresponding capability.

A UE configured with a bandwidth part indicator in DCI formats 0_1 or 1_1 shall, in case of an active DL BWP or of an active UL BWP change, determine 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 is not expected 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.

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.

For each serving cell

If a UE is provided higher layer parameter *UL-DL-configuration-common*, the UE shall set the slot format per slot over a number of slots as indicated by higher layer parameter *UL-DL-configuration-common*. If the UE is provided higher layer parameter *UL-DL-configuration-common-Set2*, the UE shall set the slot format per slot over a first number of slots as indicated by higher layer parameter *UL-DL-configuration-common* and the UE shall set the slot format per slot over a second number of slots as indicated by *UL-DL-configuration-common-Set2*. If the UE is additionally provided higher layer parameter *UL-DL-configuration-dedicated* for the slot format per slot over the number of slots, the parameter *UL-DL-configuration-dedicated* overrides only flexible symbols per slot over the number of slots as provided by *UL-DL-configuration-common* or *UL-DL-configuration-common-Set2*.

The UE expects that 20 msec is an integer multiple of the sum of the value provided by *DL-UL-transmission-periodicity* in *UL-DL-configuration-common* and the value provided by *DL-UL-transmission-periodicity* in *UL-DL-configuration-common-Set2*.

A first symbol for any even frame number n_f starts at the same time as a first symbol for a number of slots provided by higher layer parameter *UL-DL-configuration-common*.

The UE determines a duration a downlink duration, a flexible duration, and an uplink duration over a number of slots based on a subcarrier spacing configuration [4, TS38.211] provided by higher layer parameter *ref-scs*. The downlink duration, the flexible duration, and the uplink duration are common to each configured BWP.

If a UE is not configured with higher layer parameter *sfi-CelltoSFI* or if a serving cell is not included in the set of serving cells provided by higher layer parameter *sfi-CelltoSFI*, the UE considers symbols in a slot indicated as downlink by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated* as available for receptions. The UE considers symbols in a slot indicated as uplink by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common*-Set2, or by *UL-DL-configuration-dedicated* as available for transmissions.

For a set of symbols of a slot that are indicated as flexible by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, when provided to a UE, or when *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, and *UL-DL-configuration-dedicated* are not provided to the UE

- The UE shall receive PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format with CRC scrambled by C-RNTI or CS-RNTI or a configuration by higher layers.

- The UE shall transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format with CRC scrambled by C-RNTI or CS-RNTI or SP-CSI-RNTI or TPC-SRS-RNTI and triggering SRS transmission as described in Subclause 11.3, or a configuration by higher layers.

- If the 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 shall receive the PDCCH, the PDSCH, or the CSI-RS if the UE does not detect a DCI format with CRC scrambled by C-RNTI or CS-RNTI or SP-CSI-RNTI or TPC-SRS-RNTI that indicates to the UE to transmit a PUSCH, a PUCCH, a PRACH, or a SRS in the set of symbols of the slot. Otherwise, the UE shall not receive the PDCCH, or the PDSCH, or the CSI-RS in the set of symbols of the slot and shall transmit the PUSCH, the PUCCH, the PRACH, or the SRS in the set of symbols of the slot.

- If the UE is configured by higher layers to transmit a periodic SRS, or a PUCCH, or a PUSCH, or a PRACH in the set of symbols in the slot, the UE shall transmit the periodic SRS or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot if the UE does not detect a DCI format with CRC scrambled by C-RNTI or CS-RNTI that indicates to the UE to receive PDSCH or CSI-RS in the set of symbols in the slot. Otherwise, the UE shall not transmit the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot.

For a set of symbols of a slot that are indicated as uplink by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, when provided to a 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 *UL-DL-configuration-common*, or *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, when provided to a 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 by higher layer parameters *SSB-transmitted-SIB1* or *SSB-transmitted*, when provided to a UE, for reception of SS/PBCH blocks, the UE does not transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot.

If a UE is scheduled by a DCI format 1_1 to receive PDSCH over multiple slots, and if higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, 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 for a PUSCH transmission over multiple slots, and if higher layer parameter *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, when provided to a UE, indicate 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 where a UE is configured with higher layer parameter *SFI-applicable-cells*.

If a UE is configured by higher layers with parameter *SFI-PDCCH*, the UE is configured with a SFI-RNTI provided by higher layer parameter *SFI-RNTI* and with a set of serving cells by higher layer parameter *SFI-cell-to-SFI* for monitoring PDCCH conveying DCI format 2_0. Per serving cell in the set of serving cells, the UE can be provided:

- a payload size of DCI format 2_0by higher layer parameter *SFI-DCI-payload-length*;
- a location of a SFI-index field in DCI format 2_0 by higher layer parameter *cell-to-SFI*;
- a set of combinations for slot formats by higher layer parameter *SFI-set*;
- a CCE aggregation level L_{SFI} for the PDCCH candidates by higher layer parameter *SFI-aggregation-level*;
- a number of $M_{p,s}^{(L_{\mathrm{SFI}})}$ PDCCH candidates for CCE aggregation level L_{SFI} by higher layer parameter *SFI-Num-PDCCH-cand*;

The $M_{p,s}^{(L_{\mathrm{SFI}})}$ PDCCH candidates are the first $M_{p,s}^{(L_{\mathrm{SFI}})}$ PDCCH candidates for CCE aggregation level L_{SFI} for search space set s in control resource set p provided to the UE as described in Subclause 10.1 for Type3-PDCCH common search space.

A DCI format 2_0 indicates a slot format for each slot in a number of slots for each DL BWP or each UL BWP of a serving cell. The indication is by mapping a value of a SFI-index field in DCI format 2_0 for the serving cell to a combination of slot formats for the number of slots as provided by higher layer parameter *slot-format-combination*. The mapping between values of the SFI-index field and combinations of slot formats is provided by higher layer parameter *slot-format-combination-index*. A slot format is identified by a corresponding index [4, TS 38.211].

For unpaired spectrum operation for a UE on a serving cell, the UE is provided by higher layer parameter *SFI-scs* a reference subcarrier spacing configuration of μ_{SFI} for each slot format in a combination of slot formats indicated by a SFI-index field in DCI format 2_0. The UE is expected to be provided with a reference subcarrier spacing configuration of μ_{SFI} so that for an active DL BWP and UL BWP pair with subcarrier spacing configuration of μ, it is $\mu \geq \mu_{\text{SFI}}$. Each slot format in the combination of slot formats indicated by the SFI-index field in DCI format 2_0 is applicable to $2^{(\mu-\mu_{\text{SFI}})}$ consecutive slots in the active DL BWP and UL BWP pair where the first slot starts at a same time as a first slot for the reference subcarrier spacing configuration of μ_{SFI} and each downlink or flexible or uplink symbol for the reference subcarrier spacing configuration of 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 *SFI-scs* a reference subcarrier spacing configuration of $\mu_{\text{SFI, DL}}$ for the combination of slot formats indicated by the SFI-index field in DCI format 2_0 for the reference DL BWP of the serving cell. The UE is provided by higher layer parameter *SFI-scs2* a reference subcarrier spacing configuration of $\mu_{\text{SFI, UL}}$ for the combination of slot formats indicated by the SFI-index field 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, 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, 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.

For unpaired spectrum operation with a second UL carrier 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 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 *SFI-scs* a reference subcarrier spacing configuration of 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 *SFI-scs2* a reference subcarrier spacing configuration of $\mu_{\text{SFI,SUL}}$ for the combination of slot formats indicated by the SFI-index field 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, 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 is expected to be provided with a reference subcarrier spacing configuration of $\mu_{\text{SFI, DL}}$ so that for an active DL BWP with subcarrier spacing configuration of μ_{DL}, it is $\mu_{\text{DL}} \geq \mu_{\text{SFI, DL}}$. The UE is expected to be provided with a reference subcarrier spacing configuration of $\mu_{\text{SFI, UL}}$ so that for an active UL BWP with subcarrier spacing configuration of 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 in DCI format 2_0 for the reference DL BWP 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 of μ_{SFI} corresponds to $2^{(\mu_{\text{DL}}-\mu_{\text{SFI,DL}})}$ consecutive downlink or flexible symbols for the subcarrier spacing configuration μ. 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 of μ_{SFI} corresponds to $2^{(\mu_{\text{UL}}-\mu_{\text{SFI,UL}})}$ consecutive uplink or flexible symbols for the subcarrier spacing configuration μ.

The UE is expected to be provided with a reference subcarrier spacing configuration of μ_{SFI} so that for an active DL BWP and UL BWP pair in the first UL carrier with subcarrier spacing configuration of μ, it is $\mu \geq \mu_{\text{SFI}}$. The UE is expected to be provided with a reference subcarrier spacing configuration of $\mu_{\text{SFI, SUL}}$ so that for an active UL BWP in the second UL carrier with subcarrier spacing configuration of 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 $2^{(\mu-\mu_{SFI})}$ consecutive slots for the active DL BWP and UL BWP pair in the first UL carrier where the first slot starts at a same time as a first slot in the reference first UL carrier. Each slot format for the combination of slot formats for the reference second UL carrier is applicable to $2^{(\mu_{SUL}-\mu_{SFI,SUL})}$ consecutive slots for the active UL BWP in the second UL carrier where the first slot starts at a same time as a first slot in the reference second UL carrier.

A reference subcarrier spacing configurations of μ_{SFI}, or $\mu_{SFI,DL}$, or $\mu_{SFI,UL}$, or $\mu_{SFI,SUL}$ 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 is not expected to detect a DCI format 2_0 indicating the set of symbols of the slot as uplink and to detect a DCI format with CRC scrambled by C-RNTI 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 is not expected to detect a DCI format 2_0 indicating the set of symbols in the slot as downlink and to detect a DCI format with CRC scrambled by C-RNTI 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 *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, or *UL-DL-configuration-dedicated*, when provided to a UE, the UE is not expected to detect a DCI format 2_0 indicating the set of symbols of the slot as uplink/downlink, respectively, or as flexible.

For a set of symbols of a slot that are indicated as flexible by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, and *UL-DL-configuration-dedicated*, when provided to a UE, or when higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, and *UL-DL-configuration-dedicated* are not provided to the UE, and if the UE detects a DCI format 2_0 providing a format for the slot

- If one or more symbols from the sets 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 DCI format 2_0 indicates that the one or more symbols are downlink symbols.

- If DCI format 2_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format with CRC scrambled by C-RNTI indicating to the UE to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE follows the indication of the DCI format with CRC scrambled by C-RNTI.

- If DCI format 2_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format with CRC scrambled by C-RNTI indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot the UE follows the indication of the DCI format with CRC scrambled by C-RNTI.

- If DCI format 2_0 indicates the set of symbols of the slot as flexible, and the UE does not detect a DCI format with CRC scrambled by C-RNTI or CS-RNTI indicating to the UE to receive PDSCH or CSI-RS, or the UE does not detect a DCI format with CRC scrambled by C-RNTI or CS-RNTI or SP-CSI-RNTI or TPC-SRS-RNTI 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.

- If the UE is configured by higher layers transmission of periodic SRS, or PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE shall transmit the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot only if DCI format 2_0 indicates the set of symbols of the slot as uplink.

If a UE is configured by higher layers a transmission of 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 indicating a subset of symbols from the set of symbols as downlink or flexible, then

- the UE is not expected 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, after a number of symbols that is smaller than the PUSCH preparation time N_2 for the corresponding PUSCH timing capability [6, TS 38.214];

- the UE cancels the transmission in the remaining symbols of the slot.

If a UE is configured by higher layers reception of CSI-RS or PDSCH in the set of symbols of the slot, the UE shall receive CSI-RS or PDSCH in the set of symbols of the slot only if the UE detects a DCI format 2_0 that indicates the set of symbols of the slot as downlink.

If a UE is configured by higher layers transmission of periodic SRS, or PUCCH, or PUSCH without UL grant, or PRACH in the set of symbols of the slot, the UE shall transmit the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot only if the UE detects a DCI format 2_0 that indicates

- the set of symbols of the slot as uplink, or
- the set of symbols of the slot as downlink or flexible, and a number of symbols between a last symbol of a control resource set where the UE detects the DCI format 2_0 and a first symbol in the set of symbols is smaller than the PUSCH preparation time N_2 for the corresponding PUSCH timing capability [6, TS 38.214].

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 a DCI format 2_0 indicating the set of symbols of the slot as flexible or uplink.

For a set of symbols of a slot that are indicated as flexible by higher layer parameters *UL-DL-configuration-common*, *UL-DL-configuration-common-Set2*, and *UL-DL-configuration-dedicated*, when provided to a UE, or when higher layer parameters *UL-DL-configuration-common*, or *UL-DL-configuration-common-Set2*, and *UL-DL-configuration-dedicated* are not provided to the UE, and if the UE does not detect a DCI format 2_0 providing a format for the slot.

- The UE shall receive PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format with CRC scrambled by C-RNTI or CS-RNTI, or a configuration by higher layers.
- The UE shall transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format with CRC scrambled by C-RNTI or CS-RNTI or SP-CSI-RNTI or TPC-SRS-RNTI and triggering SRS transmission as described in Subclause 11.3, or a configuration by higher layers.
- The UE shall receive PDCCH as described in Subclause 11.1.
- If the UE is configured by higher layers for reception of PDSCH or CSI-RS in the set of symbols of the slot, the UE shall not receive the PDSCH or the CSI-RS in the set of symbols of the slot.
- If the UE is configured by higher layers for transmission of periodic SRS, or PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE shall not transmit the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot.

11.2 Interrupted transmission indication

If a UE is provided higher layer parameter *Preemp-DL* and *Preemp-DL= ON*, 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-cell-to-INT*;
- a mapping for each serving cell in the set of serving cells to a field in DCI format 2_1 by higher layer parameter *cell-to-INT*;
- an information payload size for DCI format 2_1 by higher layer parameter *INT-DCI-payload-length*;
- an indication granularity for time-frequency resources by higher layer parameter *INT-TF-unit* for each serving cell in the set of serving cells..

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, from a set of PRBs and a set of symbols of the last monitoring period, that are indicated by the DCI format 2_1. 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 indicated by a field in DCI format 2_1 includes 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 where T_{INT} is the value of higher layer parameter *Monitoring-periodicity-PDCCH-slot*, $N_{\text{symb}}^{\text{slot}}$ 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 conveying the DCI format 2_1, and m is a natural number. If the UE is configured with higher layer parameters *UL-DL-configuration-common* or *UL-DL-configuration-common-Set2*, symbols indicated as uplink by *UL-DL-configuration-common* or *UL-DL-configuration-common-Set2* 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 is not expected 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.

A UE is provided the indication granularity for the set of PRBs and for the set of symbols by higher layer parameter *INT-TF-unit*.

If the value of *INT-TF-unit* 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 *INT-TF-unit* 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

If a UE is configured by higher layers with parameter *PUCCH-TPC-PDCCH-Config*, the UE is configured with a TPC-PUCCH-RNTI provided by higher layer parameter *TPC-PUCCH-RNTI* and with a set of serving cells by higher layer parameter *PUCCH-monitoring-cells* for monitoring PDCCH conveying DCI format 2_2 with CRC scrambled by PUCCH-TPC-RNTI. A field in DCI format 2_2 is a TPC command of 2 bits mapping to $\delta_{\text{PUSCH},c}$ values or $\delta_{\text{PUCCH},c}$ values as described in Subclause 7.2.1.

For the PCell or for the PSCell, or per carrier of the PCell or the PSCell, the UE is configured

- control resource set(s) and respective search space sets for monitoring PDCCH with DCI format 2_2 for PUCCH;
- a mapping for PUCCH power control adjustment state(s) $l \in \{0, 1\}$ for the PCell, or for a carrier of the PCell, to respective field(s) in DCI format 2_2 by higher layer parameter *tpc-Index-PUCCH-PCell*, and a mapping for PUCCH power control adjustment state(s) $l \in \{0, 1\}$ for the PSCell, or for a carrier of the PSCell, to respective field(s) in DCI format 2_2 by higher layer parameter *tpc-Index-PUCCH-SCell*.

If a UE is configured by higher layers with parameter *PUSCH-TPC-PDCCH-Config*, the UE is configured with a TPC-PUSCH-RNTI provided by higher layer parameter *TPC-PUSCH-RNTI* and with a set of serving cells by higher layer parameter *PUSCH-monitoring-cells* for monitoring PDCCH conveying DCI format 2_2 with CRC scrambled by PUSCH-TPC-RNTI. A field in DCI format 2_2 is a TPC command of 2 bits mapping to $\delta_{\text{PUSCH},c}$ values as described in Subclause 7.1.1. Per serving cell, or per carrier of a serving cell, the UE is configured

- control resource set(s) and respective search space sets for monitoring PDCCH with DCI format 2_2 for PUSCH;
- a mapping for PUSCH power control adjustment state(s) $l \in \{0, 1\}$ a for the serving cell, or for the carrier of the serving cell, to respective field(s) in DCI format 2_2 by higher layer parameter *tpc-index-PUCCH-cell*.

11.4 SRS switching

If a UE is configured by higher layers with parameter *SRS-TPC-PDCCH-Config*, the UE is configured with a TPC-SRS-RNTI provided by higher layer parameter *srs-TPC-RNTI* and with a set of serving cells by higher layer parameter *SRS-monitoring-cells* for monitoring PDCCH conveying DCI format 2_3 with CRC scrambled by TPC-SRS-RNTI. Per serving cell the UE is configured

- control resource set(s) and respective search space sets for monitoring PDCCH with DCI format 2_3;
- a mapping for a serving cell to a field in DCI format 2_3 by higher layer parameter *SRS-cell-to-SRS*;
- a location of a field in DCI format 2_3 for a serving cell by higher layer parameter *startingBitOfFormatX*.

For a serving cell 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, DCI format 2_3 includes one block of bits for {SRS request, TPC command, … TPC command} fields for the UE if the UE is configured with higher layer parameter *typeA-SRS-TPC-PDCCH-Group* where the SRS request field applies to a set of serving cells provided by higher layer parameter *cc-SetIndex* and each TPC command applies to a respective serving cell index provided by higher layer parameter *cc-IndexInOneCC-Set*. Otherwise, if the UE is configured with higher layer parameter *typeB-SRS-TPC-PDCCH-Group*, DCI format 2_3 includes one or more blocks of bits for {SRS request, TPC command} as described in [5, TS 38.212] where each block applies to a serving cell. The SRS request field is not present if a value of higher layer parameter *fieldTypeFormat2_3* is 0; otherwise, the SRS request field is present in DCI format 2_3.

A UE configured with higher layer parameter *typeA-SRS-TPC-PDCCH-Group* is provided by higher layer parameter *srs-CC-SetIndexlist* a number of sets of serving cells without PUSCH/PUCCH transmission. For each set of serving cells, the UE is provided an index for the set by higher layer parameter *cc-SetIndex* and an index for each serving cell in the set by higher layer parameter *cc-IndexInOneCC-Set*.

For a 2 bit SRS request field in DCI format 2_3 for serving cells without PUSCH/PUCCH transmission, the SRS request field indicates the SRS parameter set given in Table 11.3-1 with the three sets of SRS parameters are provided by higher layer parameter *SRS-cell-to-SRI* for a serving cell if type 1 SRS is triggered.

Table 11.3-1: SRS request value for trigger type 1 in DCI format 2_3 for serving cells without PUSCH/PUCCH transmissions

Value of SRS request field	Description
'00'	No type 1 SRS trigger
'01'	Type 1 SRS trigger for a 1st set of serving cells configured by higher layers
'10'	Type 1 SRS trigger for a 2nd set of serving cells configured by higher layers
'11'	Type 1 SRS trigger for a 3rd set of serving cells configured by higher layers

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

An initial active DL BWP is defined by a location and number of contiguous PRBs, a subcarrier spacing, and a cyclic prefix, for the control resource set for Type0-PDCCH common search space. For operation on the primary cell, a UE is

provided by higher layer parameter *initial-UL-BWP* an initial active UL BWP for a random access procedure. If the UE is configured with a secondary carrier on the primary cell, the UE can be configured with an initial BWP for random access procedure on the secondary carrier.

If a UE has dedicated BWP configuration, the UE can be provided by higher layer parameter *Active-BWP-DL-Pcell* a first active DL BWP for receptions and by higher layer parameter *Active-BWP-UL-Pcell* 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 configured the following parameters for the serving cell as defined in [4, TS 38.211] or [6, TS 38.214]:

- a subcarrier spacing provided by higher layer parameter *DL-BWP-mu* or *UL-BWP-mu*;
- a cyclic prefix provided by higher layer parameter *DL-BWP-CP* or *UL-BWP-CP*;
- a PRB offset with respect to the PRB determined by higher layer parameters *offset-pointA-low-scs* and *ref-scs* and a number of contiguous PRBs provided by higher layer parameter *DL-BWP-BW* or *UL-BWP-BW*;
- an index in the set of DL BWPs or UL BWPs by respective higher layer parameters *DL-BWP-index* or *UL-BWP-index*;
- DCI format 1_0 or DCI format 1_1 detection to a PDSCH reception timing values by higher layer parameter *DL-data-time-domain*, PDSCH reception to a HARQ-ACK transmission timing values by higher layer parameter *DL-data-DL-acknowledgement*, and DCI format 0_0 or DCI format 0_1 detection to a PUSCH transmission timing values by higher layer parameter *UL-data-time-domain*;

For unpaired spectrum operation, a DL BWP from the set of configured DL BWPs with index provided by higher layer parameter *DL-BWP-index* is paired with an UL BWP from the set of configured UL BWPs with index provided by higher layer parameter *UL-BWP-index* when the DL BWP index and the UL BWP index are equal. For unpaired spectrum operation, a UE is not expected to receive a configuration where the center frequency for a DL BWP is different than the center frequency for an UL BWP when the *DL-BWP-index* of the DL BWP is equal to the *UL-BWP-index* of the UL BWP.

For each DL BWP in a set of DL BWPs 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 is not expected to be configured without a common search space on the PCell, or on the PSCell, 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.

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. 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.

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 shall prepend 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 shall use 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 is expected 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 *Default-DL-BWP* a default DL BWP among the configured DL BWPs. If a UE is not provided a default DL BWP by higher layer parameter *Default-DL-BWP*, the default DL BWP is the initial active DL BWP.

If a UE is configured for a secondary cell with higher layer parameter *Default-DL-BWP* 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 UE does not detect a DCI format 1_1 for paired spectrum operation or if the UE does not detect a DCI format 1_1 or DCI format 0_1 for unpaired spectrum operation during the interval.

If a UE is configured by higher layer parameter *Active-BWP-DL-SCell* a first active DL BWP and by higher layer parameter *Active-BWP-UL-SCell* a first active UL BWP on a secondary cell or carrier, the UE uses the indicated DL BWP and the indicated UL BWP on the secondary cell as the respective first active DL BWP and first active UL BWP on the secondary cell or carrier.

For paired spectrum operation, a UE is not expected to transmit HARQ-ACK 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 HARQ-ACK transmission on the PUCCH.

A UE is not expected 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 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 *RMSI-PDCCH-Config* as described in Tables 13-1 through 13-10 and determines PDCCH monitoring occasions from the four least significant bits of *RMSI-PDCCH-Config*, included in *MasterInformationBlock*, as described in Tables 13-11 through 13-15. SFN_{C} and n_{C} are the SFN and slot index 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 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 SS/PBCH block. Condition A or condition B in Tables 13-7 through 13-10 corresponds to the case of $k_{\text{SSB}} = 0$ or $k_{\text{SSB}} > 0$ [4, TS 38.211], respectively.

For the SS/PBCH block and control resource set (CORESET) 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 $n_0 = \left(O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor\right) \bmod N_{\text{slot}}^{\text{frame},\mu}$ located in a frame with system frame number (SFN) SFN_{C} satisfying $\text{SFN}_{\text{C}} \bmod 2 = 0$ if $\left\lfloor \left(O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \right\rfloor \bmod 2 = 0$ or in a frame with SFN satisfying $\text{SFN}_{\text{C}} \bmod 2 = 1$ if $\left\lfloor \left(O \cdot 2^{\mu} + \lfloor i \cdot M \rfloor\right) / N_{\text{slot}}^{\text{frame},\mu} \right\rfloor \bmod 2 = 1$. 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 a SS/PBCH block with index i, the UE determines the slot index n_C and SFN_C based on parameter 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 with minimum channel bandwidth 5 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	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 with minimum channel bandwidth 5 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	6
1	1	24	2	7
2	1	24	2	8
3	1	24	3	6
4	1	24	3	7
5	1	24	3	8
6	1	48	1	18
7	1	48	1	20
8	1	48	2	18
9	1	48	2	20
10	1	48	3	18
11	1	48	3	20
12	Reserved			
13	Reserved			
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 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	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 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	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 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 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 $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	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 condition A -42 if condition B
9	2	48	1	49
10	2	96	1	-41 if condition A -42 if condition B
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 $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	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 condition A -21 if condition B
5	3	24	2	24
6	3	48	2	-20 if condition A -21 if condition B
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 $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	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 $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	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 condition A -42 if condition B
5	2	24	1	25
6	2	24	2	-41 if condition A -42 if condition B
7	2	24	2	25
8	2	48	1	-41 if condition A -42 if condition B
9	2	48	1	49
10	2	48	2	-41 if condition A -42 if condition B
11	2	48	2	49
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	$SFN_C = SFN_{SSB,i}$ $n_C = n_{SSB,i}$	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	$SFN_C = SFN_{SSB,i}$ $n_C = n_{SSB,i}$ or $n_C = n_{SSB,i} - 1$	0, 1, 2, 3, 0, 1 in $i = 8k$, $i = 8k+1$, $i = 8k+2$, $i = 8k+3$, $i = 8k+6$, $i = 8k+7$ ($n_C = n_{SSB,i}$) 12, 13 in $i = 8k+4$, $i = 8k+5$ ($n_C = n_{SSB,i} - 1$)
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	$SFN_C = SFN_{SSB,i}$ $n_C = n_{SSB,i}$	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 $24 \le k_{SSB} \le 29$ for FR1 or for $12 \le k_{SSB} \le 13$ for FR2, the UE determines the 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 $N_{GSCN}^{Reference} + N_{GSCN}^{Offset}$. $N_{GSCN}^{Reference}$ is the GSCN of the first SS/PBCH block and N_{GSCN}^{Offset} is a GSCN offset provided by Table 13-16 for FR1 and Table 13-17 for FR2.

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 $k_{SSB} = 31$ for FR1 or for $k_{SSB} = 15$ for FR2, the UE determines that there is no SS/PBCH block having an associated Type0-PDCCH common search space within a GSCN range $[N_{GSCN}^{Reference} - N_{GSCN}^{Start}, N_{GSCN}^{Reference} + N_{GSCN}^{End}]$. N_{GSCN}^{Start} and N_{GSCN}^{End} are respectively determined by the four most significant bits and the four least significant bits of *RMSI-PDCCH-Config*.

Table 13-16: Mapping between the combination of k_{SSB} and *RMSI-PDCCH-Config* to N_{GSCN}^{Offset} for FR1

k_{SSB}	RMSI-PDCCH-Config	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 *RMSI-PDCCH-Config* to N_{GSCN}^{Offset} for FR2

k_{SSB}	**RMSI-PDCCH-Config**	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 (informative): Change history

Date	TSG #	TSG Doc.	CR	Rev	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	-	CR capturing the NR ad-hoc 1801 and RAN1#92 meeting agreements	15.1.0