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# Contents

Foreword.....	5
1 Scope.....	6
2 References.....	6
3 Definitions, symbols and abbreviations .....	7
3.1 Definitions .....	7
3.2 Symbols .....	7
3.3 Abbreviations.....	7
4 Synchronization procedures .....	9
4.1 Cell search .....	9
4.2 Transmission timing adjustments .....	10
4.3 Timing for secondary cell activation / deactivation .....	11
5 Radio link monitoring .....	12
6 Link recovery procedures.....	13
7 Uplink Power control .....	14
7.1 Physical uplink shared channel.....	14
7.1.1 UE behaviour .....	14
7.2 Physical uplink control channel .....	20
7.2.1 UE behaviour .....	20
7.3 Sounding reference signals .....	25
7.3.1 UE behaviour .....	26
7.4 Physical random access channel .....	28
7.5 Prioritizations for transmission power reductions.....	28
7.6 Dual connectivity.....	29
7.6.1 EN-DC .....	29
7.7 Power headroom report.....	30
7.7.1 Type 1 PH Report.....	30
7.7.2 Type 2 PH report.....	31
7.7.3 Type 3 PH Report.....	31
8 Random access procedure .....	32
8.1 Random access preamble.....	32
8.2 Random access response.....	34
8.3 Msg3 PUSCH .....	35
8.4 PDSCH with UE contention resolution identity .....	36
9 UE procedure for reporting control information .....	36
9.1 HARQ-ACK codebook determination.....	37
9.1.1 CBG-based HARQ-ACK codebook determination.....	37
9.1.2 Type-1 HARQ-ACK codebook determination.....	38
9.1.2.1 Type-1 HARQ-ACK codebook in physical uplink control channel .....	38
9.1.2.2 Type-1 HARQ-ACK codebook in physical uplink shared channel .....	42
9.1.3 Type-2 HARQ-ACK codebook determination.....	42
9.1.3.1 Type-2 HARQ-ACK codebook in physical uplink control channel .....	42
9.1.3.2 Type-2 HARQ-ACK codebook in physical uplink shared channel .....	47
9.2 UCI reporting in physical uplink control channel.....	48
9.2.1 PUCCH Resource Sets .....	48
9.2.2 PUCCH Formats for UCI transmission.....	51
9.2.3 UE procedure for reporting HARQ-ACK .....	51
9.2.4 UE procedure for reporting SR .....	54
9.2.5 UE procedure for reporting multiple UCI types.....	54
9.2.5.1 UE procedure for multiplexing HARQ-ACK or CSI and SR in a PUCCH.....	57
9.2.5.2 UE procedure for multiplexing HARQ-ACK/SR and CSI in a PUCCH.....	58
9.2.6 UCI repetition procedure.....	61
9.3 UCI reporting in physical uplink shared channel.....	62

10	UE procedure for receiving control information .....	66
10.1	UE procedure for determining physical downlink control channel assignment.....	66
10.2	PDCCH validation for DL SPS and UL grant Type 2 .....	73
11	UE-group common signalling .....	74
11.1	Slot configuration .....	74
11.1.1	UE procedure for determining slot format .....	77
11.2	Interrupted transmission indication.....	83
11.3	Group TPC commands for PUCCH/PUSCH.....	84
11.4	SRS switching.....	85
12	Bandwidth part operation .....	85
13	UE procedure for monitoring Type0-PDCCH common search space .....	87
<b>Annex A:</b>	<b>Change history .....</b>	<b>99</b>

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# Foreword

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

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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- z the third digit is incremented when editorial only changes have been incorporated in the document.

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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.

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# 2 References

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

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications"
- [2] 3GPP TS 38.201: "NR; Physical Layer – General Description"
- [3] 3GPP TS 38.202: "NR; Services provided by the physical layer"
- [4] 3GPP TS 38.211: "NR; Physical channels and modulation"
- [5] 3GPP TS 38.212: "NR; Multiplexing and channel coding"
- [6] 3GPP TS 38.214: "NR; Physical layer procedures for data"
- [7] 3GPP TS 38.215: "NR; Physical layer measurements"
- [8-1] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone"
- [8-2] 3GPP TS 38.101-2: "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone"
- [8-3] 3GPP TS 38.101-3: "NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios"
- [9] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"
- [10] 3GPP TS 38.133: "NR; Requirements for support of radio resource management"
- [11] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"
- [12] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification"
- [13] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"

## 3 Definitions, symbols and abbreviations

### 3.1 Definitions

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

### 3.2 Symbols

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

### 3.3 Abbreviations

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

BWP	Bandwidth part
CB	Code block
CBG	Code block group
CCE	Control channel element
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
PRB	Physical resource block
PRG	Physical resource block group
PSCell	Primary secondary cell
PSS	Primary synchronization signal
PUCCH	Physical uplink control channel
PUCCH-SCell	PUCCH SCell
PUSCH	Physical uplink shared channel
QCL	Quasi-collocation
RB	Resource block
RE	Resource element
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 assumes that reception occasions of a physical broadcast channel (PBCH), PSS, and SSS are in consecutive symbols, as defined in [4, TS 38.211], and form a SS/PBCH block. The UE assumes that SSS, PBCH DM-RS, and PBCH data have the same EPRE. The UE may assume that the ratio of PSS EPRE to SSS EPRE in a SS/PBCH block in a corresponding cell is either 0 dB or 3 dB. If the UE has not been provided dedicated higher layer parameters, the UE may assume that the ratio of PDCCH DMRS EPRE to SSS EPRE is within -8 dB and 8 dB when the UE monitors PDCCHs for a DCI format 1\_0 with CRC scrambled by SI-RNTI, P-RNTI, or RA-RNTI.

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

- Case A - 15 kHz subcarrier spacing: the first symbols of the candidate SS/PBCH blocks have indexes of  $\{2, 8\} + 14*n$ . 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,  $n=0, 1, 2, 3, 5, 6, 7, 8$ .

From the above cases, the applicable ones for a cell depend on a respective frequency band, as provided in [8-1, TS 38.101-1] and [8-2, TS 38.101-2]. A same case applies for all SS/PBCH blocks on the cell.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to  $L-1$ . A UE determines the 2 LSB bits, for  $L=4$ , or the 3 LSB bits, for  $L>4$ , of a SS/PBCH block index per half frame from a one-to-one mapping with an index of the DM-RS sequence transmitted in the PBCH. For  $L=64$ , the UE determines the 3 MSB bits of the SS/PBCH block index per half frame 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].

For SS/PBCH blocks providing higher layer parameter *MasterInformationBlock* to a UE, the UE can be configured by higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1*, indexes of the SS/PBCH blocks for which the UE does not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. The UE can also be configured per serving cell, by higher layer parameter *ssb-PositionsInBurst* in *ServingCellConfigCommon*, indexes of the SS/PBCH blocks for which the UE does not receive other signals or channels in REs that overlap with REs corresponding to the SS/PBCH blocks. A configuration by *ssb-PositionsInBurst* in *ServingCellConfigCommon* overrides a configuration by *ssb-PositionsInBurst* in *SystemInformationBlockType1*. A UE can be configured per serving cell by higher layer parameter *ssb-periodicityServingCell* a periodicity of the half frames for reception of the SS/PBCH blocks per serving cell. If the UE is not configured a periodicity of the half frames for receptions of the SS/PBCH blocks, the UE assumes a periodicity of a half frame. A UE assumes that the periodicity is same for all SS/PBCH blocks in the serving cell.

For initial cell selection, a UE may assume that half frames with SS/PBCH blocks occur with a periodicity of 2 frames. Upon detection of a SS/PBCH block, the UE determines that a control resource set for Type0-PDCCH common search space is present if  $k_{SSB} \leq 23$  [4, TS 38.211] for FR1 and if  $k_{SSB} \leq 11$  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  $N_{TA\_offset}$  applies to both carriers. The value of  $N_{TA\_offset}$  is determined from the non-supplementary UL carrier.  $N_{TA\_offset}$  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 adjusts 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/PUCCH 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  $N_{TA} \geq 25560$  for FR1 and  $N_{TA} \geq 13763$  for FR2 [10, TS 38.133].

If the UE is configured with a SCG, the UL transmission timing for PUSCH/SRS/PUCCH 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 adjusts uplink transmission timing for PUSCH/SRS/PUCCH 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/PUCCH 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 adjusts uplink transmission timing for PUSCH/SRS/PUCCH of all the secondary cells in the TAG by using  $N_{TA\_offset} = 25560$  for FR1 and  $N_{TA\_offset} = 13763$  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/PUCCH is the same for all the secondary cells in the TAG.

For carrier aggregation operation with paired spectrum operation on one or more serving cells and unpaired spectrum operation on one or more other serving cells and in a TAG without PCell or PSCell, a UE adjusts a transmission time for all SCells in the TAG using the largest TA offset value within the TAG.

The timing adjustment indication specified in [11, TS 38.321] 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  $T_A = 0, 1, 2, \dots, 3846$ , where an amount of the time alignment for the TAG for subcarrier spacing of  $2^\mu \cdot 15$  kHz is given by  $N_{TA} = T_A \cdot 16 \cdot 64 / 2^\mu$ .  $N_{TA}$  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,  $N_{TA\_old}$ , to the new  $N_{TA}$  value,  $N_{TA\_new}$ , by index values of  $T_A = 0, 1, 2, \dots, 63$ , where for a subcarrier spacing of  $2^\mu \cdot 15$  kHz,  $N_{TA\_new} = N_{TA\_old} + (T_A - 31) \cdot 16 \cdot 64 / 2^\mu$ .

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

Adjustment of  $N_{TA}$  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 uplink slot  $n$ , the corresponding adjustment of the uplink transmission timing applies from the beginning of uplink slot  $n+k$  where  $k = \left\lceil N_{slot}^{subframe,\mu} \cdot (N_{T,1} + N_{T,2} + N_{TA,max} + 0.5) / T_{sf} \right\rceil$ ,  $N_{T,1}$  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],  $N_{TA,max}$  is the maximum timing advance value that can be provided by the TA command field of 12 bits,  $N_{slot}^{subframe,\mu}$  is a number of slots per subframe, and  $T_{sf}$  is the subframe duration of 1 msec.  $N_1$  and  $N_2$  are determined with respect to the minimum subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in a TAG and of their corresponding configured DL BWPs as described in Subclause 12. Slot  $n$  and  $N_{slot}^{subframe,\mu}$  are determined with respect to the minimum subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in the TAG.  $N_{TA,max}$  is determined with respect to the minimum subcarrier spacing among the subcarrier spacings of all configured UL BWPs for all uplink carriers in the TAG and of the initial UL BWP provided by higher layer parameter *initialuplinkBWP*.

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

If the received downlink timing changes and is not compensated or is only partly compensated by the uplink timing adjustment without timing advance command as 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 is monitored by a UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP on the primary cell.

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

A UE can be configured for each DL BWP of a SpCell [11, TS 38.321] with a set of resource indexes, through a corresponding set of higher layer parameters *RadioLinkMonitoringRS*, for radio link monitoring by higher layer parameter *failureDetectionResources*. The UE is provided by higher layer parameter *RadioLinkMonitoringRS*, with either a CSI-RS resource configuration index, by higher layer parameter *csi-RS-Index*, or a SS/PBCH block index, by higher layer parameter *ssb-Index*. The UE can be configured with up to  $N_{\text{LR-RLM}}$  *RadioLinkMonitoringRS* for link recovery procedures, as described in Subclause 6, and radio link monitoring. From the  $N_{\text{LR-RLM}}$

*RadioLinkMonitoringRS*, up to  $N_{\text{RLM}}$  *RadioLinkMonitoringRS* can be used for radio link monitoring depending on a maximum number  $L$  of candidate SS/PBCH blocks per half frame as described in Subclause 4.1, and up to two *RadioLinkMonitoringRS* can be used for link recovery procedures.

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

- the UE uses for radio link monitoring the RS provided for the active TCI state for PDCCH if the active TCI state for PDCCH includes only one RS
- if the active TCI state for PDCCH includes two RS, the UE expects that one RS has QCL-TypeD and the UE uses the one RS for radio link monitoring; the UE does not expect both RS to have QCL-TypeD
- the UE is not required to use for radio link monitoring an aperiodic RS

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

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

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

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

For a CSI-RS resource configuration, the higher layer parameter *powerControlOffsetSS* is not applicable and a UE expects to be provided only 'No CDM' from higher layer parameter *cdm-Type*, only '1' and '3' from higher layer parameter *density*, and only '1 port' from higher layer parameter *nrofPorts* [6, TS 38.214].

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

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

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

## 6 Link recovery procedures

A UE can be provided, for a serving cell, with a set  $\bar{q}_0$  of periodic CSI-RS resource configuration indexes by higher layer parameter *failureDetectionResources* and with a set  $\bar{q}_1$  of periodic CSI-RS resource configuration indexes and/or SS/PBCH block indexes by higher layer parameter *candidateBeamRSList* for radio link quality measurements on the serving cell. If the UE is not provided with higher layer parameter *failureDetectionResources*, the UE determines the set  $\bar{q}_0$  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 uses for monitoring PDCCH. The UE expects the set  $\bar{q}_0$  to include up to two RS indexes and, if there are two RS indexes, the set  $\bar{q}_0$  includes only RS indexes with QCL-TypeD configuration for the corresponding TCI states. The UE expects single port RS in the set  $\bar{q}_0$ .

The threshold  $Q_{\text{out,LR}}$  corresponds to the default value of higher layer parameter *rlmInSyncOutOfSyncThreshold* and to the value provided by higher layer parameter *rsrp-ThresholdSSB*, respectively..

The physical layer in the UE assesses the radio link quality according to the set  $\bar{q}_0$  of resource configurations against the threshold  $Q_{\text{out,LR}}$  [10, TS 38.133]. For the set  $\bar{q}_0$ , the UE assesses the radio link quality only according to periodic CSI-RS resource configurations or SS/PBCH blocks that are quasi co-located, as described in [6, TS 38.214], with the DM-RS of PDCCH receptions monitored by the UE. The UE applies the  $Q_{\text{in,LR}}$  threshold to the L1-RSRP measurement obtained from a SS/PBCH block. The UE applies the  $Q_{\text{in,LR}}$  threshold to the L1-RSRP measurement obtained for a CSI-RS resource after scaling a respective CSI-RS reception power with a value provided by higher layer parameter *powerControlOffsetSS*.

The physical layer in the UE provides an indication to higher layers when the radio link quality for all corresponding resource configurations in the set  $\bar{q}_0$  that the UE uses to assess the radio link quality is worse than the threshold  $Q_{\text{out,LR}}$ . The physical layer informs the higher layers when the radio link quality is worse than the threshold  $Q_{\text{out,LR}}$  with a periodicity determined by the maximum between the shortest periodicity of periodic CSI-RS configurations or SS/PBCH blocks in the set  $\bar{q}_0$  that the UE uses to assess the radio link quality and 2 msec.

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

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

The UE may receive by higher layer parameter *PRACH-ResourceDedicatedBFR*, a configuration for PRACH transmission as described in Subclause 8.1. For PRACH transmission in slot  $n$  and according to antenna port quasi co-location parameters associated with periodic CSI-RS configuration or SS/PBCH block with index  $q_{\text{new}}$  provided by higher layers [11, TS 38.321], the UE monitors PDCCH in a search space provided by higher layer parameter *recoverySearchSpaceId* 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 *BeamFailureRecoveryConfig*. For the PDCCH monitoring and for the corresponding PDSCH reception, the UE assumes the same antenna port quasi-collocation parameters with index  $q_{\text{new}}$  until the UE receives by higher layers an activation for a TCI state or any of the parameters *TCI-StatesPDCCH-ToAddlist* and/or *TCI-StatesPDCCH-ToReleaseList*. After the UE detects a DCI format with CRC scrambled by C-RNTI in the search space provided by *recoverySearchSpaceId*, the UE monitors PDCCH candidates in the search space provided by *recoverySearchSpaceId* until the UE receives a MAC CE activation command for a TCI state or higher layer parameters *TCI-StatesPDCCH-ToAddlist* and/or *TCI-StatesPDCCH-ToReleaseList*.

If the UE is not provided a control resource set for a search space set provided *recoverySearchSpaceId* or if the UE is not provided *recoverySearchSpaceId*, the UE does not expect to receive a PDCCH order triggering a PRACH transmission.

## 7 Uplink Power control

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

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

### 7.1 Physical uplink shared channel

For PUSCH, a UE first scales a linear value  $\hat{P}_{\text{PUSCH},b,f,c}(i,j,q_d,l)$  of the transmit power  $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$  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. The UL BWP  $b$  is the active UL BWP.

#### 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 determines the PUSCH transmission power  $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$  in PUSCH transmission occasion  $i$  as

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

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 occasion  $i$ .
- $P_{\text{O\_PUSCH},b,f,c}(j)$  is a parameter composed of the sum of a component  $P_{\text{O\_NOMINAL\_PUSCH},f,c}(j)$  and a component  $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$  where  $j \in \{0, 1, \dots, J-1\}$ .
  - If a UE is not provided with higher layer parameter *P0-PUSCH-AlphaSet* or for a Msg3 PUSCH transmission as described in Subclause 8.3,  $j = 0$ ,  $P_{\text{O\_UE\_PUSCH},b,f,c}(0) = 0$ , and  $P_{\text{O\_NOMINAL\_PUSCH},f,c}(0) = P_{\text{O\_PRE}} + \Delta_{\text{PREAMBLE\_Msg3}}$ , where the parameter *preambleReceivedTargetPower* [11, TS 38.321] (for  $P_{\text{O\_PRE}}$ ) and *msg3-DeltaPreamble* (for  $\Delta_{\text{PREAMBLE\_Msg3}}$ ) are provided by higher layers for carrier  $f$  of serving cell  $c$ .
  - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*,  $j = 1$ ,  $P_{\text{O\_NOMINAL\_PUSCH},f,c}(1)$  is provided by higher layer parameter *p0-NominalWithoutGrant*, and  $P_{\text{O\_UE\_PUSCH},b,f,c}(1)$  is provided by higher layer parameter *p0* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* that provides an index *P0-PUSCH-AlphaSetId* to a set of higher layer parameters *P0-PUSCH-AlphaSet* for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - For  $j \in \{2, \dots, J-1\} = S_j$ , a  $P_{\text{O\_NOMINAL\_PUSCH},f,c}(j)$  value, applicable for all  $j \in S_j$ , is provided by higher layer parameter *p0-NominalWithGrant* for each carrier  $f$  of serving cell  $c$  and a set of  $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$

values are provided by a set of higher layer parameters  $p0$  in  $P0-PUSCH-AlphaSet$  indicated by a respective set of higher layer parameters  $p0-PUSCH-AlphaSetId$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .

- If the UE is provided by higher layer parameter  $SRI-PUSCH-PowerControl$  more than one values of  $p0-PUSCH-AlphaSetId$  and if DCI format 0\_1 includes a SRI field, the UE obtains a mapping from higher layer parameter  $sri-PUSCH-PowerControlId$  in  $SRI-PUSCH-PowerControl$  between a set of values for the SRI field in DCI format 0\_1 [5, TS 38.212] and a set of indexes provided by higher layer parameter  $p0-PUSCH-AlphaSetId$  that map to a set of  $P0-PUSCH-AlphaSet$  values. If the PUSCH transmission is scheduled by a DCI format 0\_1, the UE determines the values of  $P_{O,UE\_PUSCH,b,f,c}(j)$  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,  $j = 2$ , and the UE determines  $P_{O,UE\_PUSCH,b,f,c}(j)$  from the first  $p0-pusch-alpha-set$  in  $p0-pusch-alpha-setconfig$ .
- For  $\alpha_{b,f,c}(j)$ 
  - For  $j = 0$ ,  $\alpha_{b,f,c}(0)$  is a value of higher layer parameter  $msg3-Alpha$ , when provided; otherwise,  $\alpha_{b,f,c}(0) = 1$ .
  - For  $j = 1$ ,  $\alpha_{b,f,c}(1)$  is provided by higher layer parameter  $alpha$  obtained from  $p0-PUSCH-Alpha$  in  $ConfiguredGrantConfig$  providing an index  $P0-PUSCH-AlphaSetId$  to a set of higher layer parameters  $P0-PUSCH-AlphaSet$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - For  $j \in S_J$ , a set of  $\alpha_{b,f,c}(j)$  values are provided by a set of higher layer parameters  $alpha$  in  $P0-PUSCH-AlphaSet$  indicated by a respective set of higher layer parameters  $p0-PUSCH-AlphaSetId$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - If the UE is provided a higher layer parameter  $SRI-PUSCH-PowerControl$  and more than one values of  $p0-PUSCH-AlphaSetId$ , DCI format 0\_1 includes a SRI field and the UE obtains a mapping from higher layer parameter  $sri-PUSCH-PowerControlId$  in  $SRI-PUSCH-PowerControl$  between a set of values for the SRI field in DCI format 0\_1 [5, TS 38.212] and a set of indexes provided by higher layer parameter  $p0-PUSCH-AlphaSetId$  that map to a set of  $P0-PUSCH-AlphaSet$  values. If the PUSCH transmission is scheduled by a DCI format 0\_1, 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,  $j = 2$ , and the UE determines  $\alpha_{b,f,c}(j)$  from the first  $p0-pusch-alpha-set$  in  $p0-pusch-alpha-setconfig$ .
- $M_{RB,b,f,c}^{PUSCH}(i)$  is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for PUSCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and  $\mu$  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) index  $q_d$  for a DL BWP that is linked with UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
- If the UE is not provided higher layer parameter  $PUSCH-PathlossReferenceRS$  and before the UE is provided dedicated higher layer parameters, the UE calculates  $PL_{b,f,c}(q_d)$  using a RS resource from the SS/PBCH block index that the UE obtains higher layer parameter  $MasterInformationBlock$ .
- If the UE is configured with a number of RS resource indexes up to the value of higher layer parameter  $maxNrofPUSCH-PathlossReferenceRSs$  and a respective set of RS configurations for the number of RS resource indexes by higher layer parameter  $PUSCH-PathlossReferenceRS$ . The set of RS resource indexes can include one or both of a set of SS/PBCH block indexes, each provided by higher layer parameter  $ssb-$

*Index* when a value of a corresponding higher layer parameter *pusch-PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by higher layer parameter *csi-RS-Index* when a value of a corresponding higher layer parameter *pusch-PathlossReferenceRS-Id* maps to a CSI-RS resource index. The UE identifies a RS resource index in the set of RS resource indexes to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by higher layer parameter *pusch-PathlossReferenceRS-Id* in *PUSCH-PathlossReferenceRS*.

- If the PUSCH is an Msg3 PUSCH, the UE uses the same RS resource index as for a corresponding PRACH transmission.
- If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl* and more than one values of *PUSCH-PathlossReferenceRS-Id*, the UE obtains a mapping from higher layer parameter *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0\_1 and a set of *PUSCH-PathlossReferenceRS-Id* values. If the PUSCH transmission is scheduled by a DCI format 0\_1, DCI format 0\_1 includes a SRI field and the UE determines the RS resource  $q_d$  from the value of *pusch-pathlossreference-index* that is mapped to the SRI field value.
- If the PUSCH transmission is in response to a DCI format 0\_0 detection, and if the UE is provided a spatial setting by higher layer parameter *PUCCH-Spatialrelationinfo* for a PUCCH resource with a lowest index for UL BWP  $b$  of each carrier  $f$  and serving cell  $c$ , as described in Subclause 9.2.2, the UE uses the same RS resource index as for a PUCCH transmission.
- If the PUSCH transmission is scheduled by a DCI format 0\_0 and if the UE is not provided a spatial setting for a PUCCH transmission, or by a DCI format 0\_1 that does not include a SRI field, or if a higher layer parameter *SRI-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 transmission configured by higher layer parameter *ConfiguredGrantConfig*, if higher layer parameter *rrc-ConfiguredUplinkGrant* is included in *ConfiguredGrantConfig*, a RS resource index  $q_d$  is provided by a value of higher layer parameter *pathlossReferenceIndex* included in *rrc-ConfiguredUplinkGrant*.
- For a PUSCH transmission configured by higher layer parameter *ConfiguredGrantConfig* is not included in *ConfiguredGrantConfig* does not include higher layer parameter *pathlossReferenceIndex*, the UE determines the RS resource  $q_d$  from the value of *PUSCH-PathlossReferenceRS-Id* 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-PathlossReferenceRS-Id* value being equal to zero.

$PL_{b,f,c}(q_d)$   $PL_{f,c}(q_d) = \text{referenceSignalPower} - \text{higher layer filtered RSRP}$ , 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 provided by higher layer parameter *ss-PBCH-BlockPower*. For  $j > 0$ , *referenceSignalPower* is configured by either higher layer parameter *ss-PBCH-BlockPower* or, when periodic CSI-RS transmission is configured, by higher layer parameter *powerControlOffsetSS* providing an offset of the CSI-RS transmission power relative to the SS/PBCH block transmission power [6, TS 38.214].

- $\Delta_{\text{TF},b,f,c}(i) = 10 \log_{10} \left( \left( 2^{\text{BPRE} \cdot K_s} - 1 \right) \cdot \beta_{\text{offset}}^{\text{PUSCH}} \right)$  for  $K_s = 1.25$  and  $\Delta_{\text{TF},b,f,c}(i) = 0$  for  $K_s = 0$  where  $K_s$  is provided by higher layer parameter *deltaMCS* 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],  $\Delta_{\text{TF},b,f,c}(i) = 0$ .  $\text{BPRE}$  and  $\beta_{\text{offset}}^{\text{PUSCH}}$ , for each UL BWP  $b$  of each carrier  $f$  and each serving cell  $c$ , are computed as below.

- $\text{BPRE} = \sum_{r=0}^{C-1} K_r / N_{\text{RE}}$  for PUSCH with UL-SCH data and  $\text{BPRE} = O_{\text{CSI}} / N_{\text{RE}}$  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  $r$ ,  $O_{\text{CSI}}$  is the number of CSI part 1 bits including CRC bits, and  $N_{\text{RE}}$  is the number of resource elements determined as
 
$$N_{\text{RE}} = M_{\text{RB},b,f,c}^{\text{PUSCH}}(i) \cdot \sum_{j=0}^{N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)-1} N_{\text{sc,data}}^{\text{RB}}(i,j)$$
 , where  $N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)$  is the number of symbols for PUSCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$ ,  $N_{\text{sc,data}}^{\text{RB}}(i,j)$  is a number of subcarriers excluding DM-RS subcarriers in PUSCH symbol  $j$ ,  $0 \leq j < N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)$ , and  $C$ ,  $K_r$  are defined in [5, TS 38.212].
- $\beta_{\text{offset}}^{\text{PUSCH}} = 1$  when the PUSCH includes UL-SCH data and  $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{CSI},1}$ , 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 occasion  $i$ 
  - $\delta_{\text{PUSCH},b,f,c}(i_{\text{last}}, i, K_{\text{PUSCH}}, l)$  is a correction value, also referred to as a TPC command, and is included in a DCI format 0\_0 or DCI format 0\_1 that schedules the PUSCH transmission occasion  $i$ , after a last PUSCH transmission occasion  $i_{\text{last}}$ , on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  or jointly coded with other TPC commands in a DCI format 2\_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, as described in Subclause 11.3;
  - $l \in \{0, 1\}$  if the UE is configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates*, and  $l = 0$  if the UE is not configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates* or if the PUSCH is a Msg3 PUSCH.
    - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*, the value of  $l \in \{0, 1\}$  is provided to the UE by higher layer parameter *powerControlLoopToUse*
    - If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl*, the UE obtains a mapping between a set of values for the SRI field in DCI format 0\_1 and the  $l$  value(s) provided by higher layer parameter *sri-PUSCH-ClosedLoopIndex*. If the PUSCH transmission is scheduled by a DCI format 0\_1 and if DCI format 0\_1 includes a SRI field, the UE determines the  $l$  value that is mapped to the SRI field value
    - If the PUSCH transmission is scheduled by a DCI format 0\_0 or by a DCI format 0\_1 that does not include a SRI field, or if a higher layer parameter *SRI-PUSCH-PowerControl* is not provided to the UE,  $l = 0$
  - $\delta_{\text{PUSCH},b,f,c}(i_{\text{last}}, i, K_{\text{PUSCH}}, l) = 0$  dB if the UE does not detect, after a last PUSCH transmission occasion  $i_{\text{last}}$ , a DCI format providing a TPC command for PUSCH transmissions on 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 the TPC command is provided by DCI format 2\_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective  $\delta_{\text{PUSCH},b,f,c}$  accumulated values are given in Table 7.1.1-1.
  - If the PUSCH transmission is in response to a detection by the UE of a DCI format 0\_0 or DCI format 0\_1,  $K_{\text{PUSCH}}$  is a number of symbols for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  after a last symbol of a corresponding PDCCH and before a first symbol of the PUSCH transmission
  - If the PUSCH transmission is configured by higher layer parameter *ConfiguredGrantConfig*,  $K_{\text{PUSCH}}$  is a number of  $K_{\text{PUSCH},\text{min}}$  symbols equal to the product of a number of symbols per slot,  $N_{\text{sym}}^{\text{slot}}$ , and the minimum of the values provided by higher layer parameter  $k2$  and for UL BWP  $b$  of carrier  $f$  of serving cell  $c$

- If accumulation of TPC commands is enabled by higher layer parameter *tpc-Accumulation*, for accumulation of a TPC commands that the UE receives by DCI formats 2\_2 with CRC scrambled by a TPC-PUSCH-RNTI between a PUSCH transmission occasion  $i_{\text{last}}$  and a PUSCH transmission occasion  $i$ ,

$$\delta_{\text{PUSCH}, b, f, c}(i_{\text{last}}, i, K_{\text{PUSCH}}, l) = \delta_{\text{PUSCH}, b, f, c}(i_{\text{last}}, i, K_{\text{PUSCH}}, l) + \sum_{m=0}^{M-1} \delta_{\text{PUSCH}, b, f, c}(i_{\text{last}}, i, K_{\text{PUSCH}}(m), l)$$

where

- $i_{\text{last}}$  is a PUSCH transmission occasion immediately prior to PUSCH transmission occasion  $i$
- if the PUSCH transmission occasions  $i$  and  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  are in response to detection by the UE of DCI format(s) 0\_0 or DCI format(s) 0\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUSCH-RNTI that the UE receives corresponding PDCCHs
  - after a last symbol of a corresponding PDCCH for PUSCH transmission occasion  $i_{\text{last}}$ , and
  - before a last symbol of a corresponding PDCCH for PUSCH transmission occasion  $i$
- if the PUSCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is in response to detection by the UE of DCI format 0\_0 or DCI format 0\_1 and the PUSCH transmission occasion  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is configured by higher layer parameter *ConfiguredGrantConfig*,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUSCH-RNTI that the UE receives corresponding PDCCHs
  - after a number of  $K_{\text{PUSCH}, \text{min}}$  symbols before a first symbol for PUSCH transmission at occasion  $i_{\text{last}}$ , where  $K_{\text{PUSCH}, \text{min}}$  is equal to the product of a number of symbols per slot,  $N_{\text{slot}}^{\text{slot}}$ , and the minimum of the values provided by higher layer parameter  $k2$  and for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , and
  - before a last symbol of a corresponding PDCCH for PUSCH transmission occasion  $i$
- if the PUSCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is configured by higher layer parameter *ConfiguredGrantConfig* and the PUSCH transmission occasion  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is in response to detection by the UE of DCI format 0\_0 or DCI format 0\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUSCH-RNTI that the UE receives corresponding PDCCHs
  - after a last symbol of a corresponding PDCCH for PUSCH transmission occasion  $i_{\text{last}}$ , and
  - at or before a number of  $K_{\text{PUSCH}, \text{min}}$  symbols before a first symbol for PUSCH transmission occasion  $i$
- if the PUSCH transmission occasions  $i$  and  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  are configured by higher layer parameter *ConfiguredGrantConfig*,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUSCH-RNTI that the UE receives corresponding PDCCHs
  - after a number of  $K_{\text{PUSCH}, \text{min}}$  symbols before a first symbol for PUSCH transmission occasion  $i_{\text{last}}$ , and
  - at or before a number of  $K_{\text{PUSCH}, \text{min}}$  symbols before a first symbol for PUSCH transmission occasion  $i$

- $f_{b,f,c}(i,l) = f_{b,f,c}(i_{\text{last}},l) + \delta_{\text{PUSCH},b,f,c}(i_{\text{last}},i,K_{\text{PUSCH}},l)$  is the PUSCH power control adjustment state for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and PUSCH transmission occasion  $i$  if accumulation is enabled based on higher layer parameter *tpc-Accumulation*, where
  - If the UE has reached  $P_{\text{CMAX},f,c}(i)$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , the UE does not accumulate positive TPC commands for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - If UE has reached minimum power,  $P_{\text{CMIN},f,c}(i)$ , for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , the UE does not accumulate negative TPC commands for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - A UE resets accumulation for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ 
    - When  $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$  value is provided by higher layers;
    - When  $P_{\text{O\_UE\_PUSCH},b,f,c}(j)$  value is provided by higher layers and serving cell  $c$  is a secondary cell;
    - When  $\alpha_{f,b,c}(j)$  value is provided by higher layers;
  - If  $j > 1$ , the PUSCH transmission is scheduled by a DCI format 0\_1 that includes a SRI field, and the UE is provided higher layer parameter *SRI-PUSCH-PowerControl*, the UE determines the value of  $l$  from the value of  $j$  based on an indication by the SRI field for a *sri-PUSCH-PowerControlId* value associated with the *sri-P0-PUSCH-AlphaSetId* value corresponding to  $j$  and with the *sri-PUSCH-ClosedLoopIndex* value corresponding to  $l$
  - If  $j > 1$  and the PUSCH transmission is scheduled by a DCI format 0\_0 or by a DCI format 0\_1 that does not include a SRI field or the UE is not provided higher layer parameter *SRI-PUSCH-PowerControl*,  $l = 0$
  - If  $j = 1$ ,  $l$  is provided by the value of higher layer parameter *powerControlLoopToUse*
- $f_{b,f,c}(0,l) = 0$  is the first value after reset of accumulation.
- $f_{b,f,c}(i,l) = \delta_{\text{PUSCH},b,f,c}(i_{\text{last}},i,K_{\text{PUSCH}},l)$  is the PUSCH power control adjustment state for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and PUSCH transmission occasion  $i$  if accumulation is not enabled based on higher layer parameter *tpc-Accumulation*, where
  - If the PUSCH transmission is in response to a PDCCH decoding with DCI format 0\_0 or DCI format 0\_1, or the TPC command is provided by DCI format 2\_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective  $\delta_{\text{PUSCH},b,f,c}$  absolute values are given in Table 7.1.1-1.
  - $f_{b,f,c}(i,l) = f_{b,f,c}(i_{\text{last}},l)$  for a PUSCH transmission occasion  $i$ , where the UE does not detect a DCI format 0\_0 or DCI format 0\_1, or DCI format 2\_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, after an immediately previous PUSCH transmission occasion  $i_{\text{last}}$  on 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  $c$ 
  - $f_{b,f,c}(0,l) = \Delta P_{\text{rampup},b,f,c} + \delta_{\text{msg2},b,f,c}$ , where  $l = 0$  and
    - $\delta_{\text{msg2},b,f,c}$  is the TPC command indicated in the random access response grant of the random access response message corresponding to the random access preamble transmitted on UL BWP  $b$  of carrier  $f$  in the serving cell  $c$ , and

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

and  $\Delta P_{\text{rampuprequested},b,f,c}$  is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last random access preamble for carrier  $f$  in the serving cell  $c$ ,  $M_{\text{RB},b,f,c}^{\text{PUSCH}}(0)$  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  $\Delta_{\text{TF},b,f,c}(0)$  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  $\delta_{\text{PUSCH},b,f,c}$  values or  $\delta_{\text{SRS},b,f,c}$  values**

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

## 7.2 Physical uplink control channel

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

- When the procedures are applied for MCG, the term 'serving cell' in this subclause refers to serving cell belonging to the MCG.

When the procedures are applied for SCG, the term 'serving cell' in this subclause refers to serving cell belonging to the SCG. The term 'primary cell' in this subclause refers to the PSCell of the SCG. If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this subclause for both primary PUCCH group and secondary PUCCH group.

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

### 7.2.1 UE behaviour

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

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

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 PUCCH transmission occasion  $i$ .
- $P_{\text{O\_PUCCH},b,f,c}(q_u)$  is a parameter composed of the sum of a component  $P_{\text{O\_NOMINAL\_PUCCH}}$ , provided by higher layer parameter  $p0\text{-nominal}$  for carrier  $f$  of primary cell  $c$ , and a component  $P_{\text{O\_UE\_PUCCH}}(q_u)$  provided by higher layer parameter  $p0\text{-PUCCH-Value}$  in  $P0\text{-PUCCH}$  for UL BWP  $b$  of carrier  $f$  of primary cell  $c$ , where  $0 \leq q_u < Q_u$ .  $Q_u$  is a size for a set of  $P_{\text{O\_UE\_PUCCH}}$  values provided by higher layer parameter  $\text{maxNrofPUCCH-}P0\text{-PerSet}$ . The set of  $P_{\text{O\_UE\_PUCCH}}$  values is provided by higher layer parameter  $p0\text{-Set}$ .
- If the UE is provided higher layer parameter  $\text{PUCCH-SpatialRelationInfo}$ , the UE obtains a mapping, by an index provided by higher layer parameter  $p0\text{-PUCCH-Id}$ , between a set of  $\text{pucch-SpatialRelationInfoId}$  values and a set of  $p0\text{-PUCCH-Value}$  values. If the UE is provided more than one values for  $\text{pucch-SpatialRelationInfoId}$  and the UE receives an activation command [11, TS 38.321] indicating a value of  $\text{pucch-SpatialRelationInfoId}$ , the UE determines the  $p0\text{-PUCCH-Value}$  value through the link to a corresponding  $p0\text{-PUCCH-Id}$  index. The UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.
- If the UE is not provided higher layer parameter  $\text{PUCCH-SpatialRelationInfo}$ , the UE obtains the  $p0\text{-PUCCH-Value}$  value from the  $P0\text{-PUCCH}$  with  $p0\text{-PUCCH-Id}$  index 0 in  $p0\text{-Set}$ .
- $M_{\text{RB},b,f,c}^{\text{PUCCH}}(i)$  is the bandwidth of the PUCCH resource assignment expressed in number of resource blocks for PUCCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and  $\mu$  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) index  $q_d$  for a DL BWP that is linked with UL BWP  $b$  of carrier  $f$  of the primary cell  $c$ .
- If the UE is not provided higher layer parameter  $\text{pathlossReferenceRSs}$  and before the UE is provided dedicated higher layer parameters, the UE calculates  $PL_{b,f,c}(q_d)$  using a RS resource obtained from the SS/PBCH block index that the UE obtains higher layer parameter  $\text{MasterInformationBlock}$ .
- If the UE is provided a number of RS resource indexes, the UE calculates  $PL_{b,f,c}(q_d)$  using RS resource  $q_d$ , where  $0 \leq q_d < Q_d$ .  $Q_d$  is a size for a set of RS resources provided by higher layer parameter  $\text{maxNrofPUCCH-PathlossReferenceRSs}$ . The set of RS resources is provided by higher layer parameter  $\text{pathlossReferenceRSs}$ . The set of RS resources can include one or both of a set of SS/PBCH block indexes, each provided by higher layer parameter  $\text{ssb-Index}$  in  $\text{PUCCH-PathlossReferenceRS}$  when a value of a corresponding higher layer parameter  $\text{pucch-PathlossReferenceRS-Id}$  maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by higher layer parameter  $\text{csi-RS-Index}$  when a value of a corresponding higher layer parameter  $\text{pucch-PathlossReferenceRS-Id}$  maps to a CSI-RS resource index. The UE identifies a RS resource in the set of RS resources to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by higher layer parameter  $\text{pucch-PathlossReferenceRS-Id}$  in  $\text{PUCCH-PathlossReferenceRS}$ .
- If the UE is provided higher layer parameter  $\text{PUCCH-SpatialRelationInfo}$ , the UE obtains a mapping, by indexes provided by corresponding higher layer parameters  $\text{pucch-PathlossReferenceRS-Id}$ , between a set of  $\text{pucch-SpatialRelationInfoId}$  values and a set of  $\text{referencesignal}$  values provided by higher layer parameter  $\text{PUCCH-PathlossReferenceRS}$ . If the UE is provided more than one values for  $\text{pucch-SpatialRelationInfoId}$  and the UE receives an activation command [11, TS 38.321] indicating a value of  $\text{pucch-SpatialRelationInfoId}$ , the UE determines the  $\text{referencesignal}$  value in  $\text{PUCCH-PathlossReferenceRS}$  through the link to a corresponding  $\text{pucch-PathlossReferenceRS-Id}$  index. The UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.
- If higher layer parameter  $\text{pucch-SpatialRelationInfo}$  includes higher layer parameters  $\text{cell}$  and  $\text{bwp-Id}$ , the UE receives the RS with index  $q_d$  on the DL BWP provided by  $\text{bwp-Id}$  of the serving cell provided by  $\text{cell}$ .

- If the UE is not provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains the *referencesignal* value in *PUCCH-PathlossReferenceRS* from the *pucch-PathlossReferenceRS-Id* with index 0 in *PUCCH-PathlossReferenceRSs*.
- The parameter  $\Delta_{F\_PUCCH}(F)$  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.
- $\Delta_{TF,b,f,c}(i)$  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,  $\Delta_{TF,b,f,c}(i) = 10\log_{10}\left(\frac{N_{\text{ref}}^{\text{PUCCH}}}{N_{\text{ymb}}^{\text{PUCCH}}}\right)$

where

- $N_{\text{ymb}}^{\text{PUCCH}}$  is the number of PUCCH format 0 symbols or PUCCH format 1 symbols, provided by higher layer parameter *nrofSymbols* in *PUCCH-format0* or in *PUCCH-format1*, respectively
- $N_{\text{ref}}^{\text{PUCCH}} = 2$  for PUCCH format 0
- $N_{\text{ref}}^{\text{PUCCH}} = N_{\text{ymb}}^{\text{slot}}$  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,  $\Delta_{TF,b,f,c}(i) = 10\log_{10}\left(K_1 \cdot (n_{\text{HARQ-ACK}} + O_{\text{SR}} + O_{\text{CSI}}) / N_{\text{RE}}\right)$ , where
  - $K_1 = 6$
  - $n_{\text{HARQ-ACK}}$  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 *pdsch-HARQ-ACK-Codebook*,  $n_{\text{HARQ-ACK}} = 1$  if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise,  $n_{\text{HARQ-ACK}} = 0$ ;
  - $O_{\text{SR}}$  is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1;
  - $O_{\text{CSI}}$  is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2;
  - $N_{\text{RE}}$  is a number of resource elements determined as  $N_{\text{RE}} = M_{\text{RB},b,f,c}^{\text{PUCCH}}(i) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{ymb-UCL},b,f,c}^{\text{PUCCH}}(i)$ , where  $N_{\text{sc,ctrl}}^{\text{RB}}$  is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and  $N_{\text{ymb-UCL},b,f,c}^{\text{PUCCH}}(i)$  is a number of symbols excluding symbols used for DM-RS transmission, as defined in Subclause 9.2.5.2, for PUCCH transmission occasion  $i$  on 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,  $\Delta_{TF,b,f,c}(i) = 10\log_{10}\left(\left(2^{K_2 \cdot \text{BPRE}} - 1\right)\right)$ , where
  - $K_2 = 2.4$
  - $\text{BPRE} = (O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}) / N_{\text{RE}}$ ;
  - $O_{\text{ACK}}$  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 *pdsch-HARQ-ACK-Codebook*,  $O_{ACK} = 1$  if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise,  $O_{ACK} = 0$ ;

- $O_{SR}$  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  $N_{RE} = M_{RB,b,f,c}^{PUCCH}(i) \cdot N_{sc,ctrl}^{RB} \cdot N_{symb-UCI,b,f,c}^{PUCCH}(i)$ , where  $N_{sc,ctrl}^{RB}$  is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and  $N_{symb-UCI,b,f,c}^{PUCCH}(i)$  is a number of symbols excluding symbols used for DM-RS transmission, as defined in Subclause 9.2.5.2, for PUCCH transmission occasion  $i$  on 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 occasion  $i$ 
  - $\delta_{PUCCH,b,f,c}(i_{last}, i, K_{PUCCH}, l)$  is a correction value, also referred to as a TPC command, and is included in a 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 for PUCCH transmission occasion  $i$ , after a last PUCCH transmission occasion  $i_{last}$ , or jointly coded with other TPC commands in a DCI format 2\_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI [5, TS 36.212], as described in Subclause 11.3, where  $l \in \{0, 1\}$  if the UE is provided higher layer parameter *twoPUCCH-PC-AdjustmentStates* and  $l = 0$  if the UE is not provided higher layer parameter *twoPUCCH-PC-AdjustmentStates* or *PUCCH-SpatialRelationInfo*;
  - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by higher layer parameter *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of values for higher layer parameter *closedLoopIndex* that provide the  $l$  value(s). If the UE receives an activation command indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the value *closedLoopIndex* that provides the value of  $l$  through the link to a corresponding *p0-PUCCH-Id* index;
  - If the PUCCH transmission is in response to a detection by the UE of a DCI format 1\_0 or DCI format 1\_1,  $K_{PUCCH}$  is a number of symbols for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  after a last symbol of a corresponding PDCCH and before a first symbol of the PUCCH transmission;
  - If the PUCCH transmission is not in response to a detection by the UE of a DCI format 1\_0 or DCI format 1\_1,  $K_{PUCCH}$  is a number of  $K_{PUCCH,min}$  symbols equal to the product of a number of symbols per slot,  $N_{symb}^{slot}$ , and the minimum of the values provided by higher layer parameter  $k2$  and for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
  - The  $\delta_{PUCCH,b,f,c}$  dB values signalled 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.
  - $\delta_{PUCCH,b,f,c}(i_{last}, i, K_{PUCCH}, l) = 0$  dB if the UE does not detect after a last PUCCH transmission occasion  $i_{last}$  a DCI format providing a TPC command for PUCCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of the primary cell  $c$ .
  - If accumulation of TPC commands is enabled by higher layer parameter *tpc-Accumulation*, for accumulation of a TPC commands that the UE receives by DCI formats 2\_2 with CRC scrambled by a TPC-PUCCH-RNTI between a PUCCH transmission occasion  $i_{last}$  and a PUCCH transmission occasion  $i$ ,

$$\delta_{\text{PUCCH},b,f,c}(i_{\text{last}},i,K_{\text{PUCCH}},l) = \delta_{\text{PUCCH},b,f,c}(i_{\text{last}},i,K_{\text{PUCCH}},l) + \sum_{m=0}^{M-1} \delta_{\text{PUCCH},b,f,c}(i_{\text{last}},i,K_{\text{PUCCH}}(m),l)$$

where

- $i_{\text{last}}$  is a PUCCH transmission occasion immediately prior to PUCCH transmission occasion  $i$
- if the PUCCH transmission occasions  $i$  and  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  are in response to detection by the UE of DCI format(s) 1\_0 or DCI format(s) 1\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUCCH-RNTI that the UE receives corresponding PDCCHs
  - after a last symbol of a corresponding PDCCH for PUCCH transmission occasion  $i_{\text{last}}$ , and
  - before a last symbol of a corresponding PDCCH for PUCCH transmission occasion  $i$
- if the PUCCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is in response to detection by the UE of DCI format 1\_0 or DCI format 1\_1 and the PUCCH transmission occasion  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is not in response to detection by the UE of DCI format 1\_0 or DCI format 1\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUCCH-RNTI that the UE receives corresponding PDCCHs
  - after a number of  $K_{\text{PUCCH},\text{min}}$  symbols before a first symbol for PUCCH transmission occasion  $i_{\text{last}}$ , where  $K_{\text{PUCCH},\text{min}}$  is equal to the product of a number of symbols per slot,  $N_{\text{slot}}^{\text{slot}}$ , and the minimum of the values provided by higher layer parameter  $k2$  and for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , and
  - before a last symbol of a corresponding PDCCH for PUCCH transmission occasion  $i$
- if the PUCCH transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is not in response to detection by the UE of DCI format 1\_0 or DCI format 1\_1 and the PUCCH transmission occasion  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  is in response to a detection by the UE of DCI format 1\_0 or DCI format 1\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUCCH-RNTI that the UE receives corresponding PDCCHs
  - after a last symbol of a corresponding PDCCH for PUCCH transmission occasion  $i_{\text{last}}$ , and
  - at or before a number of  $K_{\text{PUCCH},\text{min}}$  symbols before a first symbol for PUCCH transmission occasion  $i$
- if the PUCCH transmission occasions  $i$  and  $i_{\text{last}}$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  are not in response to detection by the UE of DCI format 1\_0 or DCI format 1\_1,  $M$  is a number of DCI formats 2\_2 with CRC scrambled by a TPC-PUCCH-RNTI that the UE receives corresponding PDCCHs
  - after a number of  $K_{\text{PUCCH},\text{min}}$  symbols before a first symbol for PUCCH transmission occasion  $i_{\text{last}}$ , and
  - at or before a number of  $K_{\text{PUCCH},\text{min}}$  symbols before a first symbol for PUCCH transmission occasion  $i$
- $f_{b,f,c}(i,l) = f_{b,f,c}(i_{\text{last}},l) + \delta_{\text{PUCCH},b,f,c}(i_{\text{last}},i,K_{\text{PUCCH}},l)$  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 provided by higher layers,



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

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

- Else,

$$- g_{b,f,c}(0,l) = \Delta P_{\text{rampup},b,f,c} + \delta_{\text{msg } 2,b,f,c}, \text{ where}$$

$\delta_{\text{msg } 2,b,f,c}$  is the TPC command indicated in the random access response grant corresponding to the random access preamble transmitted on UL BWP  $b$  of carrier  $f$  in the serving cell  $c$  , and,

if the UE transmits PUCCH,

$$\Delta P_{\text{rampup},b,f,c} = \min \left[ \max \left( 0, P_{\text{CMAX},f,c} - (P_{\text{O\_PUCCH},b,f,c} + PL_{b,f,c}(q_d) + \Delta_{\text{F\_PUCCH}}(F) + \Delta_{\text{TF},b,f,c} + \delta_{\text{msg } 2,b,f,c}) \right), \Delta P_{\text{rampuprequested},b,f,c} \right]$$

;

otherwise,

$$\Delta P_{\text{rampup},b,f,c} = \min \left[ \max \left( 0, P_{\text{CMAX},f,c} - (P_{\text{O\_PUCCH},b,f,c} + PL_{b,f,c}(q_d)) \right), \Delta P_{\text{rampuprequested},b,f,c} \right] \text{ and } \Delta P_{\text{rampuprequested},b,f,c} \text{ is provided}$$

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  $f$  of primary cell  $c$  , and  $\Delta_{\text{F\_PUCCH}}(F)$  corresponds to PUCCH format 0 or PUCCH format 1.

- If the UE has reached  $P_{\text{CMAX},f,c}(i)$  for UL BWP  $b$  of carrier  $f$  of primary cell  $c$  , the UE does not accumulate positive TPC commands for UL BWP  $b$  of carrier  $f$  of primary cell  $c$  .
- If the UE has reached minimum power for UL BWP  $b$  of carrier  $f$  of primary cell  $c$  , the UE does not accumulate negative TPC commands for UL BWP  $b$  of carrier  $f$  of 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  $\delta_{\text{PUCCH},b,f,c}$  values**

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

## 7.3 Sounding reference signals

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

### 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 determines the SRS transmission power  $P_{\text{SRS},b,f,c}(i, q_s, l)$  in SRS transmission occasion  $i$  as

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

where,

- $P_{\text{CMAX},f,c}(i)$  is the configured UE transmit power defined in [8, TS 38.101-1] and [8-2, TS38.101-2] for carrier  $f$  of serving cell  $c$  in SRS transmission occasion  $i$ .
- $P_{\text{O\_SRS},b,f,c}(q_s)$  is provided by higher layer parameter  $p0$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and SRS resource set  $q_s$  provided by higher layer parameters *SRS-ResourceSet* and *SRS-ResourceSetId*.
- $M_{\text{SRS},b,f,c}(i)$  is the SRS bandwidth expressed in number of resource blocks for SRS transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and  $\mu$  is defined in [4, TS 38.211].
- $\alpha_{\text{SRS},b,f,c}(q_s)$  is provided by higher layer parameter *alpha* for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and SRS resource set  $q_s$ .
- $PL_{b,f,c}(q_d)$  is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) index  $q_d$  for a DL BWP that is linked with UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and SRS resource set  $q_s$  [6, TS 38.214]. The RS index  $q_d$  is provided by higher layer parameter *pathlossReferenceRS* associated with the SRS resource set  $q_s$  and is either a higher layer parameter *ssb-Index* providing a SS/PBCH block index or a higher layer parameter *csi-RS-Index* providing a CSI-RS resource index.
- If the UE is not provided higher layer parameter *pathlossReferenceRSs* and before the UE is provided dedicated higher layer parameters, the UE calculates  $PL_{b,f,c}(q_d)$  using a RS resource obtained from the SS/PBCH block index that the UE obtains higher layer parameter *MasterInformationBlock*.
- For the SRS power control adjustment state for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  and SRS transmission occasion  $i$ 
  - $h_{b,f,c}(i, l) = f_{b,f,c}(i, l)$ , where  $f_{b,f,c}(i, l)$  is the current PUSCH power control adjustment state as described in Subclause 7.1.1, if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions; or
  - $h_{b,f,c}(i) = h_{b,f,c}(i_{\text{last}}) + \delta_{\text{SRS},b,f,c}(i_{\text{last}}, i, K_{\text{SRS}})$  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-PowerControlAdjustmentStates* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions, and if accumulation is enabled based on the parameter *tpc-Accumulation* provided by higher layers, where  $\delta_{\text{SRS},b,f,c}(i_{\text{last}}, i, K_{\text{SRS}})$  is jointly coded with other TPC commands in a PDCCH with DCI format 2\_3, as described in Subclause 11.4, that is last received by the UE prior to the SRS transmission and accumulative values of  $\delta_{\text{SRS},b,f,c}(i_{\text{last}}, i, K_{\text{SRS}})$  are provided in Table 7.1.1-1, where
    - $i_{\text{last}}$  is a SRS transmission occasion immediately prior to SRS transmission occasion  $i$
    - if the SRS transmission is aperiodic,  $K_{\text{SRS}}$  is a number of symbols for UL BWP  $b$  of carrier  $f$  of serving cell  $c$  after a last symbol of a corresponding PDCCH and before a first symbol of the SRS transmission

- if the SRS transmission is semi-persistent or periodic,  $K_{\text{SRS}}$  is a number of  $K_{\text{SRS,min}}$  symbols equal to the product of a number of symbols per slot,  $N_{\text{slot}}^{\text{slot}}$ , and the minimum of the values provided by higher layer parameter  $k2$  and for UL BWP  $b$  of carrier  $f$  of serving cell  $c$
- for accumulation of a TPC commands that the UE receives by DCI formats 2\_3 between an aperiodic, semi-persistent, or periodic SRS transmission occasion  $i_{\text{last}}$  and an aperiodic, semi-persistent, or periodic SRS transmission occasion  $i$ ,

$$\delta_{\text{SRS},b,f,c}(i_{\text{last}},i,K_{\text{SRS}}) = \delta_{\text{SRS},b,f,c}(i_{\text{last}},i,K_{\text{SRS}}) + \sum_{m=0}^{M-1} \delta_{\text{SRS},b,f,c}(i_{\text{last}},i,K_{\text{SRS}}(m))$$

where

- $M$  is a number of DCI formats 2\_3 the UE receives corresponding PDCCHs
  - after a number of  $K_{\text{SRS,min}}$  symbols before a first symbol of SRS transmission occasion  $i_{\text{last}}$ , and
  - at or before a number of  $K_{\text{SRS,min}}$  symbols before a first symbol of SRS transmission occasion  $i$
- $\delta_{\text{SRS},b,f,c}(i_{\text{last}},i,K_{\text{SRS}}) = 0$  dB if the UE does not detect after a last SRS transmission a DCI format providing a TPC command for SRS transmissions on UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
- If the UE has reached  $P_{\text{CMax},f,c}(i)$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , the UE does not accumulate corresponding positive TPC commands.
- If UE has reached minimum power for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , the UE does not accumulate corresponding negative TPC commands.
- A UE resets accumulation for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ 
  - When  $P_{\text{O_SRS},b,f,c}(q_s)$  value is provided by higher layers;
  - When  $\alpha_{\text{SRS},b,f,c}(q_s)$  value is provided by higher layers.
- $h_{b,f,c}(0) = 0$  is the first value after reset of accumulation.
- If  $P_{\text{O_SRS},b,f,c}(q_s)$  value is provided by higher layers,
  - $h_{b,f,c}(0) = 0$
- Else,
  - $h_{b,f,c}(0) = \Delta P_{\text{rampup},b,f,c} + \delta_{\text{msg 2},b,f,c}$ , where

$\delta_{\text{msg 2},b,f,c}$  is the TPC command indicated in the random access response grant corresponding to the random access preamble transmitted on UL BWP  $b$  of carrier  $f$  of the serving cell  $c$ , and

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

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

- $h_{b,f,c}(i) = \delta_{\text{SRS},b,f,c}(i_{\text{last}}, i, K_{\text{PUSCH}})$  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-PowerControlAdjustmentStates* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions, and if accumulation is not enabled based on the higher layer parameter *tpc-Accumulation*, and the UE detects a DCI format 2\_3 for a SRS transmission occasion  $i$  that follows SRS transmission occasion  $i_{\text{last}}$ , where absolute values of  $\delta_{\text{SRS},b,f,c}(i_{\text{last}}, i, K_{\text{PUSCH}}, l)$  are provided in Table 7.1.1-1.
- $h_{b,f,c}(i) = h_{b,f,c}(i_{\text{last}})$  for a SRS transmission occasion  $i$  where the UE does not detect a DCI format 2\_3 after an immediately previous SRS transmission occasion  $i_{\text{last}}$  for UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .
- if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions, the update of the power control adjustment state for SRS transmission occasion  $i$  occurs at the beginning of each SRS resource in the SRS resource set  $q_s$ ; otherwise, the update of the power control adjustment state SRS transmission occasion  $i$  occurs at the beginning of the first transmitted SRS resource in the SRS resource set  $q_s$ .

## 7.4 Physical random access channel

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

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

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 occasion  $i$ ,  $P_{\text{PRACH,target},f,c}$  is the PRACH preamble target reception power *PREAMBLE\_RECEIVED\_TARGET\_POWER* provided by higher layers [11, TS 38.321] for the UL BWP  $b$  of carrier  $f$  of serving cell  $c$ , and  $PL_{b,f,c}$  is a pathloss for the UL BWP  $b$  of 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, or is in response to a detection of a PDCCH order by the UE that triggers a contention based random access procedure, *referenceSignalPower* is provided by *ss-PBCH-BlockPower*.

If the PRACH transmission from the UE is in response to a detection of a PDCCH order by the UE that triggers a non-contention based random access procedure and depending the DL RS that the DM-RS of the PDCCH order is quasi-collocated with as described in Subclause 10.1, *referenceSignalPower* is provided by *ss-PBCH-BlockPower* or, when the UE is configured resources for a periodic CSI-RS reception, *referenceSignalPower* is obtained by higher layer parameters *ss-PBCH-BlockPower* and *powerControlOffsetSS* where *powerControlOffsetSS* provides an offset of CSI-RS transmission power relative to SS/PBCH block transmission power [6, TS 38.214]. If *powerControlOffsetSS* is not provided to the UE, the UE assumes an offset of 0 dB.

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

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

## 7.5 Prioritizations for transmission power reductions

For single cell operation with two uplink carriers or for operation with carrier aggregation, if a total UE transmit power for a PUSCH or PUCCH or PRACH or SRS transmission in a respective transmission occasion  $i$  would exceed

$\hat{P}_{\text{CMAX}}(i)$ , where  $\hat{P}_{\text{CMAX}}(i)$  is the linear value of  $P_{\text{CMAX}}(i)$  in transmission occasion  $i$  as defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2], the UE allocates power to PUSCH/PUCCH/PRACH/SRS transmissions according to the

following priority order (in descending order) so that the total UE transmit power is smaller than or equal to  $\hat{P}_{\text{CMAX}}(i)$  in every symbol of transmission occasion  $i$ . When determining a total transmit power in a symbol of transmission occasion  $i$ , the UE does not include power for transmissions starting after the symbol of transmission occasion  $i$ . The total UE transmit power is defined as the sum of the linear values of UE transmit powers for PUSCH, PUCCH, PRACH, and SRS.

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

In case of same priority order and for operation with carrier aggregation, the UE prioritizes power allocation for transmissions on the primary cell of the MCG or the SCG over transmissions on a secondary cell and prioritizes power allocation for transmissions on the PCell over transmissions on the PSCell. In case of same priority order and for operation with two uplink carriers, the UE prioritizes power allocation for transmissions on the carrier where the UE is configured to transmit PUCCH.

## 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  $P_{\text{LTE}}$  for transmissions on the MCG by higher layer parameter  $p\text{-MaxEUTRA}$  and a maximum power  $P_{\text{NR}}$  for transmissions on the SCG by higher layer parameter  $p\text{-NR}$ . The UE determines a transmission power for the MCG as described in [13, TS 36.213] using  $P_{\text{LTE}}$  as the maximum transmission power. The UE determines transmission power for the SCG as described Subclauses 7.1 through 7.5 using  $P_{\text{NR}}$  as the maximum transmission power for  $P_{\text{CMAX}} \leq P_{\text{NR}}$ .

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  $P_{\text{LTE}}$ ,  $\hat{P}_{\text{NR}}$  is the linear value of  $P_{\text{NR}}$ , 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  $tdm\text{-PatternConfig-r15}$  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 any portion of slot  $i_2$  of the SCG,

the UE reduces transmission power in any portion of slot  $i_2$  of the SCG so that  $\hat{P}_{\text{MCG}}(i_1) + \hat{P}_{\text{SCG}}(i_2) \leq \hat{P}_{\text{Total}}^{\text{EN-DC}}$  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 *tdm-PatternConfig-r15* 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 occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$ . A Type 3 UE power headroom  $PH$  that is valid for SRS transmission occasion  $i$  on UL BWP  $b$  of carrier  $f$  of serving cell  $c$ .

A UE determines whether a power headroom report for an activated serving cell [11, TS38.321] is based on an actual transmission or a reference format by considering the downlink control information the UE received until and including the PDCCH monitoring occasion where the UE detects the first DCI format 0\_0 or DCI format 0\_1 scheduling an initial transmission of a transport block, as determined by the new data indicator field in DCI format 0\_0 or DCI format 0\_1, since a power headroom report was triggered.

If the UE is configured with a SCG,

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

If the UE is configured with a PUCCH-SCell,

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

### 7.7.1 Type 1 PH Report

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

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

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

If a UE is configured with multiple cells for PUSCH transmissions, where a subcarrier spacing configuration  $\mu_1$  on active UL BWP  $b_1$  of carrier  $f_1$  of serving cell  $c_1$  is smaller than a subcarrier spacing configuration  $\mu_2$  on active UL BWP  $b_2$  of carrier  $f_2$  of serving cell  $c_2$ , and if the UE provides a Type 1 power headroom report in a PUSCH transmission in a slot on UL BWP  $b_1$  that overlaps with multiple slots on UL BWP  $b_2$ , the UE provides a Type 1 power headroom report for the first slot of the multiple slots on UL BWP  $b_2$  that fully overlaps with the slot on UL BWP  $b_1$ .

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

- the second PUSCH transmission is in response to detection of a DCI format 0\_0 or a DCI format 0\_1 in a PDCCH received in a second PDCCH monitoring occasion, and
- the second PDCCH monitoring occasion is after a first PDCCH monitoring occasion where the UE detects a first DCI format 0\_0 or DCI format 0\_1 scheduling the first PUSCH transmission

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

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

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

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

## 7.7.2 Type 2 PH report

This subclause is reserved.

## 7.7.3 Type 3 PH Report

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

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

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

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

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

where  $q_s$  is a SRS resource set corresponding to  $\text{SRS-ResourceSetId} = 0$  and  $P_{\text{O\_SRS},b,f,c}(q_s)$ ,  $\alpha_{\text{SRS},f,c}(q_s)$ ,  $PL_{b,f,c}(q_d)$  and  $h_{b,f,c}(i)$  are defined in Subclause 7.3.1 with corresponding values obtained from  $\text{SRS-ResourceSetId} = 0$ .

$\tilde{P}_{\text{CMAX},f,c}(i)$  is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and  $\Delta T_C = 0$ dB. MPR, A-MPR, P-MPR and  $\Delta T_C$  are defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2].

## 8 Random access procedure

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

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

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

From the physical layer perspective, the L1 random access procedure 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,  $P_{PRACH,target}$ , a corresponding RA-RNTI, and a PRACH resource.

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

A UE is provided a number  $N$  of SS/PBCH blocks associated with one PRACH occasion and a number  $R$  of contention based preambles per SS/PBCH block by higher layer parameter *ssb-perRACH-OccasionAndCB-PreamblesPerSSB*. If  $N < 1$ , one SS/PBCH block is mapped to  $1/N$  consecutive PRACH occasions. If  $N \geq 1$ ,  $R$  contention based preambles with consecutive indexes associated with SS/PBCH block  $n$ ,  $0 \leq n \leq N-1$ , per PRACH occasion start from preamble index  $n \cdot 64/N$ . 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.

An association period, starting from frame 0, for mapping SS/PBCH blocks to PRACH occasions is the smallest value in the set determined by the PRACH configuration period according Table 8.1-1 such that  $N_{Tx}^{SSB}$  SS/PBCH blocks are mapped at least once to the PRACH occasions within the association period, where a UE obtains  $N_{Tx}^{SSB}$  from the value of higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* and/or in *ServingCellConfigCommon*.



If after an integer number of SS/PBCH blocks to PRACH occasions mapping cycles within the association period there is a set of PRACH occasions that are not mapped to  $N_{Tx}^{SSB}$  SS/PBCH blocks, no SS/PBCH blocks are mapped to the set of PRACH occasions. An association pattern period consists of one or more association periods and is determined so that a pattern between PRACH occasions and SS/PBCH blocks repeats at most every 160 msec. PRACH occasions not associated with SS/PBCH blocks after an integer number of association periods, if any, are not used for PRACH transmissions.

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

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

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

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

If a UE is provided higher layer parameter *tdd-UL-DL-ConfigurationCommon*, or is also provided higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, a PRACH occasion in a PRACH slot is valid if

- it is within UL symbols, or
- it does not precede a SS/PBCH block in the PRACH slot and starts at least  $N_{gap}$  symbols after a last downlink symbol and at least  $N_{gap}$  symbols after a last SS/PBCH block transmission symbol, where  $N_{gap}$  is provided in Table 8.2-2.

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

**Table 8.1-2:  $N_{gap}$  values for different preamble subcarrier spacing configurations  $\mu$**

Preamble subcarrier spacing	$N_{gap}$
1.25 kHz or 5 kHz	0
15 kHz or 30 kHz or 60 kHz or 120 kHz	2

If a random access procedure is initiated by a PDCCH order, the UE, if requested by higher layers, transmits a PRACH in the first available PRACH occasion 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  $N_{T,2} + \Delta_{BWPSwitching} + \Delta_{Delay}$  msec, where  $N_{T,2}$  is a time duration of  $N_2$  symbols corresponding to a PUSCH preparation time for PUSCH processing capability 1 [6, TS 38.214],  $\Delta_{BWPSwitching} = 0$  if the active UL BWP does not change and  $\Delta_{BWPSwitching}$  is defined in [10, TS 38.133] otherwise, and  $\Delta_{Delay} = 0.5$  msec for FR1 and  $\Delta_{Delay} = 0.25$  msec for FR2. For a PRACH transmission using 1.25 kHz or 5 kHz subcarrier spacing, the UE determines  $N_2$  assuming subcarrier spacing configuration  $\mu = 0$ .

For single cell operation or for operation with carrier aggregation in a same frequency band, a UE does not transmit PRACH and PUSCH/PUCCH/SRS in a same slot or when a gap between the first/last symbol of a PRACH

transmission in a first slot is separated by less than  $N$  symbols from the last/first symbol of a PUSCH/PUCCH/SRS transmission in a second slot where  $N = 2$  for  $\mu = 0$  or  $\mu = 1$ ,  $N = 4$  for  $\mu = 2$  or  $\mu = 3$ , and  $\mu$  is the subcarrier spacing configuration for the active UL BWP..

## 8.2 Random access response

In response to a PRACH transmission, a UE attempts to detect a DCI format 1\_0 with a CRC scrambled by a corresponding RA-RNTI during a window controlled by higher layers [11, TS 38.321]. The window starts at the first symbol of the earliest control resource set the UE is configured for Type1-PDCCH common search space, as defined in Subclause 10.1, that is at least  $\left\lceil \left( \Delta \cdot N_{\text{slot}}^{\text{subframe}, \mu} \cdot N_{\text{ymb}}^{\text{slot}} \right) / T_{\text{sf}} \right\rceil$  symbols after the last symbol of the preamble sequence transmission, where  $\Delta$  is defined in [10, TS 38.133] and  $\mu$  is the subcarrier spacing configuration for Type1-PDCCH common search space. The length of the window in number of slots, based on the subcarrier spacing for Type1-PDCCH common search space as defined in Subclause 10.1, is provided by higher layer parameter *ra-ResponseWindow*.

If a UE detects the DCI format 1\_0 with the CRC scrambled by 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 UE does not detect the DCI format 1\_0 with the CRC scrambled by the corresponding RA-RNTI within the window, or if the UE does not correctly receive the DL-SCH transport block in the PDSCH within the window, or 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. If requested by higher layers, the UE shall be ready to transmit a PRACH no later than  $N_{\text{T},1} + 0.75$  msec after the last symbol of the window, or the last symbol of the PDSCH reception, 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.

If a UE detects a DCI format 1\_0 with the CRC scrambled by the corresponding RA-RNTI and receives the corresponding PDSCH that includes the DL-SCH transport block, the UE may assume same DM-RS antenna port quasi co-location properties, as described in [6, 38.214], as for a SS/PBCH block or a CSI-RS resource the UE used for PRACH association as described in Subclause 8.1. If the UE attempts to detect the DCI format 1\_0 with CRC scrambled by the corresponding RA-RNTI in response to a PRACH transmission initiated by a PDCCH order that triggers non-contention based random access procedure, the UE may assume 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.

If the value of the frequency hopping flag is 0, the UE transmits Msg3 PUSCH without frequency hopping; otherwise, the UE transmits Msg3 PUSCH with frequency hopping.

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

If higher layer parameter *pusch-AllocationList* is provided by *pusch-ConfigCommon*, a value of the Msg3 PUSCH time resource allocation field indicates an entry to a table provided by *pusch-AllocationList*; otherwise a value of the Msg3 PUSCH time resource allocation field indicates an entry to default time resource allocation table [6, 38.214].

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  $\delta_{\text{msg } 2,b,f,c}$  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	14
Msg3 PUSCH time resource allocation	4
MCS	4
TPC command for Msg3 PUSCH	3
CSI request	1

**Table 8.2-2: TPC Command  $\delta_{msg\ 2,b,f,c}$  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 DCI format with CRC scrambled by a corresponding RA-RNTI or does not correctly receive 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-transformPrecoding* indicates to a UE whether or not the UE shall apply transform precoding, as described in [4, TS 38.211], for an Msg3 PUSCH transmission.

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

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

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

The subcarrier spacing for Msg3 PUSCH transmission is provided by higher layer parameter *SubcarrierSpacing* in *BWP-UplinkCommon*. A UE transmits PRACH and Msg3 PUSCH on a same uplink carrier of 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 higher layers.

A UE transmits an UL-SCH in an Msg3 PUSCH scheduled by a RAR grant in a corresponding RAR message using redundancy version number 0. Retransmissions, if any, of the UL-SCH in an Msg3 PUSCH are scheduled by a DCI format 0\_0 with CRC scrambled by a TC-RNTI provided in the corresponding RAR message [11, TS 38.321].

If in slot  $n$  a UE receives a PDSCH with a RAR message for a corresponding preamble transmission from the UE, the UE transmits a Msg3 PUSCH in slot  $n + k_2$ , where  $k_2$  is provided in [6, TS 38.214]. The UE may assume 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 is equal to  $N_{T,1} + N_{T,2} + 0.5$  msec.  $N_{T,1}$  is a time duration of  $N_1$  symbols corresponding to a PDSCH reception time for PDSCH processing capability 1 when additional PDSCH DM-RS is configured and,  $N_{T,2}$  is a time duration of  $N_2$  symbols corresponding to a PUSCH preparation time for PUSCH processing capability 1 [6, TS 38.214].

## 8.4 PDSCH with UE contention resolution identity

In response to an Msg3 PUSCH transmission when a UE has not been provided with a C-RNTI, the UE attempts to detect a DCI format 1\_0 with CRC scrambled by a corresponding TC-RNTI scheduling a PDSCH that includes a UE contention resolution identity [11, TS 38.321]. In response to the PDSCH reception with the UE contention resolution identity, the UE transmits HARQ-ACK information in a PUCCH. The PUCCH transmission is within a same initial active UL BWP as the Msg3 PUSCH transmission. A minimum time between the last symbol of the PDSCH reception and the first symbol of the corresponding HARQ-ACK information 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 overlaps with a PUSCH transmission, and the PUSCH and PUCCH transmissions fulfill the conditions in Subclause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in the PUSCH transmission and does not transmit the PUCCH.

If a UE multiplexes aperiodic CSI in a PUSCH and the UE would multiplex UCI in a PUCCH that overlaps with the PUSCH, the UE multiplexes the UCI in the PUSCH.

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

If a UE transmits multiple PUSCHs in a slot in response to detection by the UE of DCI format(s) 0\_0 or DCI format(s) 0\_1 on respective serving cells and the UE would multiplex UCI in one of the multiple PUSCHs and the UE does not multiplex aperiodic CSI in any of the multiple PUSCHs, the UE multiplexes the UCI in a PUSCH of the serving cell

with the smallest *ServCellIndex* subject to the conditions in Subclause 9.2.5 for UCI multiplexing being fulfilled. If the UE transmits more than one PUSCHs in the slot on the serving cell with the smallest *ServCellIndex* that fulfil the conditions in Subclause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in the PUSCH that the UE transmits first in the slot.

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

## 9.1 HARQ-ACK codebook determination

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

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

A UE 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 provided higher layer parameter *PDSCH-CodeBlockGroupTransmission* for a serving cell, the UE receives PDSCHs that include code block groups (CBGs) of a transport block and the UE is provided higher layer parameter *maxCodeBlockGroupsPerTransportBlock* indicating a maximum number  $N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}$  of CBGs for generating respective HARQ-ACK information bits for a transport block reception for the serving cell.

For a number of  $C$  code blocks (CBs) in a transport block, the UE determines a number of CBGs as

$N_{\text{HARQ-ACK}}^{\text{CBG/TB}} = \min(N_{\text{HARQ-ACK}}^{\text{CBG/TB,max}}, C)$ . Each of the first  $N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} = \text{mod}(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}})$  CBGs includes  $\lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rceil$  CBs,

where CBG  $n_{\text{CBG}}, 0 \leq n_{\text{CBG}} < N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}}$ , includes CBs  $n_{\text{CBG}} \cdot \lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rceil + n_{\text{CB}}, 0 \leq n_{\text{CB}} < \lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rceil$ , and each of the

last  $N_{\text{HARQ-ACK}}^{\text{CBG/TB,2}} = N_{\text{HARQ-ACK}}^{\text{CBG/TB}} - \text{mod}(C, N_{\text{HARQ-ACK}}^{\text{CBG/TB}})$  CBGs includes  $\lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rfloor$  CBs, where CBG

$n_{\text{CBG}}, N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} \leq n_{\text{CBG}} < N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} + N_{\text{HARQ-ACK}}^{\text{CBG/TB,2}}$ , includes CBs

$N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} \cdot \lceil C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rceil + (n_{\text{CBG}} - N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}}) \cdot \lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rfloor + n_{\text{CB}}, 0 \leq n_{\text{CB}} < \lfloor C / N_{\text{HARQ-ACK}}^{\text{CBG/TB}} \rfloor$ . The UE generates

$N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} + N_{\text{HARQ-ACK}}^{\text{CBG/TB,2}}$  HARQ-ACK information bits through a one-to-one mapping with the  $N_{\text{HARQ-ACK}}^{\text{CBG/TB,1}} + N_{\text{HARQ-ACK}}^{\text{CBG/TB,2}}$

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

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

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

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

$N_{\text{HARQ-ACK}}^{\text{CBG/TB}}$  CBGs, the UE generates a NACK value for each of the  $N_{\text{HARQ-ACK}}^{\text{CBG/TB}}$  CBGs.

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

If a UE receives a PDSCH that is scheduled by a PDCCH with DCI format 1\_0, or a SPS PDSCH, or the UE detects a SPS PDSCH release, and if the UE is configured with higher layer parameter *pdsch-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 or for the SPS PDSCH release, respectively, 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 *pdsch-HARQ-ACK-Codebook* = *semi-static*.

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

If the UE is provided higher layer parameter *pdsch-AggregationFactor*,  $N_{\text{PDSCH}}^{\text{repeat}}$  is a value of *pdsch-AggregationFactor*; otherwise,  $N_{\text{PDSCH}}^{\text{repeat}} = 1$ . The UE reports HARQ-ACK information only for a last slot of the  $N_{\text{PDSCH}}^{\text{repeat}}$  slots.

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 UL BWP
  - a) If the UE is configured to monitor PDCCH for DCI format 1\_0 and is not configured to monitor PDCCH for DCI format 1\_1 on serving cell  $c$ ,  $K_1$  is provided by the slot timing values {1, 2, 3, 4, 5, 6, 7, 8} for DCI format 1\_0;
  - b) If the UE is configured to monitor PDCCH for DCI format 1\_1 on serving cell  $c$ ,  $K_1$  is provided by higher layer parameter *dl-DataToUL-ACK* for DCI format 1\_1.
- b) when provided, on a set of row indexes of a table provided by higher layer parameter *PDSCH-TimeDomainResourceAllocation* 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 *tdd-UL-DL-ConfigurationCommon*, higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, and higher layer parameter *tdd-UL-DL-ConfigDedicated* as described in Subclause 11.1.

For the set of slot timing values  $K_1$ , the UE determines  $M_{A,c}$  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  $B = \emptyset$

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

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

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

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

Set  $R$  to the set of rows provided by *PDSCH-TimeDomainResourceAllocation*

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

Set  $r=0$  – index of row provided by *PDSCH-TimeDomainResourceAllocation*

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

$k = k + 1$ ;

else

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

if the UE is provided higher layer parameter *tdd-UL-DL-ConfigurationCommon*, or higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, or higher layer parameter *tdd-UL-DL-ConfigDedicated* and, for each slot from slot  $n - K_{1,k} - N_{\text{PDSCH}}^{\text{repeat}} + 1$  to slot  $n - K_{1,k}$ , at least one OFDM symbol of the PDSCH time resource derived by row  $r$  is configured as UL where  $K_{1,k}$  is the  $k$ -th slot timing value in set  $K_1$ ,

$R = R \setminus r$ ;

end if

$r = r + 1$ ;

end while

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

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

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

else

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

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

while  $R \neq \emptyset$

Set  $r=0$

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

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

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

$R = R \setminus r$ ;

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

```

    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 if

end while

For rows of *PDSCH-TimeDomainResourceAllocation* 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.

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

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

A UE determines  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O_{ACK}-1}^{ACK}$  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 information bit index

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

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

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

while  $m < M_c$

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



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

$j = j + 1$ ;

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

$j = j + 1$ ;

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

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

$j = j + 1$ ;

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

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

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

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

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

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

end if

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

end while

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

else

$\tilde{o}_j^{ACK}$  = HARQ-ACK information 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  $n_{\text{HARQ-ACK}} = \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}-1} \sum_{m=0}^{M_c-1} N_{m,c}^{\text{received}} + \sum_{c=0}^{N_{\text{cells}}^{\text{DL}}-1} \sum_{m=0}^{M_c-1} N_{m,c}^{\text{receivedCBG}}$

where

- $N_{m,c}^{\text{received}}$  is the number of transport blocks the UE receives in PDSCH reception occasion  $m$  for serving cell  $c$  if higher layer parameters *harq-ACK-SpatialBundlingPUCCH* and *PDSCH-CodeBlockGroupTransmission* are not provided, or the number of transport blocks the UE receives in PDSCH reception occasion  $m$  for serving cell  $c$  if higher layer parameter *PDSCH-CodeBlockGroupTransmission* is provided and the PDSCH reception is in response to a DCI format 1\_0 detection, or the number of PDSCH receptions if higher layer parameter *harq-ACK-SpatialBundlingPUCCH* is provided or SPS PDSCH release in PDSCH reception occasion  $m$  for serving cell  $c$  and the UE reports corresponding HARQ-ACK information in the PUCCH.
- $N_{m,c}^{\text{receivedCBG}}$  is the number of CBGs the UE receives in a PDSCH reception occasion  $m$  for serving cell  $c$  if higher layer parameter *PDSCH-CodeBlockGroupTransmission* is provided and the PDSCH reception is in response to a DCI format 1\_1 detection 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 information in a PUSCH transmission that is not scheduled by a DCI format or is scheduled by DCI format 0\_0, then

- if the UE has not received any PDSCH or SPS PDSCH release that the UE transmits corresponding HARQ-ACK information in the PUSCH, based on a value of a respective PDSCH-to-HARQ feedback timing field in a DCI format scheduling the PDSCH reception or the SPS PDSCH release, in any of the  $M_c$  occasions for PDSCH reception by DCI format 1\_0 or DCI format 1\_1 or SPS PDSCH on any serving cell  $c$ , as described in Subclause 9.1.2.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission;
- else the UE generates the HARQ-ACK codebook as described in Subclause 9.1.2.1 except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

A UE sets to NACK value in the HARQ-ACK codebook any HARQ-ACK information corresponding to PDSCH reception or SPS PDSCH release scheduled by DCI format 1\_0 or DCI format 1\_1 that the UE detects in a PDCCH monitoring occasion that is after a PDCCH monitoring occasion where the UE detects a DCI format 0\_0 or a DCI format 0\_1 scheduling the PUSCH transmission.

If a UE multiplexes HARQ-ACK information in a PUSCH transmission that is scheduled by DCI format 0\_1, the UE generates the HARQ-ACK codebook as described in Subclause 9.1.2.1 when a value of the DAI field in DCI format 0\_1 is  $V_{\text{T-DAI},m}^{\text{UL}} = 1$  except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

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

### 9.1.3 Type-2 HARQ-ACK codebook determination

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

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

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

- maximum and minimum PDSCH-to-HARQ\_feedback timing values provided by union 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-DataToUL-ACK* for DCI format 1\_1
- a set of slot offsets  $K_0$  [6, TS 38.214] determined by higher layer parameter *PDSCH-TimeDomainResourceAllocation*, when provided, and by higher layer parameter *pdsch-AggregationFactor*, when provided.

The set of PDCCH monitoring occasions is defined as the union of PDCCH monitoring occasions across active DL BWPs of configured serving cells, ordered in ascending order of start time of the search space set associated with a PDCCH monitoring occasion. The cardinality of the set of PDCCH monitoring occasions defines a total number  $M$  of PDCCH monitoring occasions.

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

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

If the UE transmits HARQ-ACK information in a PUCCH in slot  $n$  and for any PUCCH format, the UE determines the  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O_{ACK}-1}^{ACK}$ , 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  $V_s = \emptyset$

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

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

while  $m < M$

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

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

$c = c + 1$ ;

else

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

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

$j = j + 1$

end if

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

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

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

else

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

end if

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

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

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

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

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

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

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

else

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

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

end if

end if

$$c = c + 1$$

end if

end while

$$m = m + 1$$

end while

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

$$j = j + 1$$

end if

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

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

else

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

end if

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

Set  $c = 0$

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

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

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

$$o_{O^{ACK}-1}^{ACK} = \text{HARQ-ACK information bit associated with the SPS PDSCH reception}$$

end if

$$c = c + 1;$$

end while

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

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

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

where

- if  $N_{\text{cells}}^{\text{DL}} = 1$ ,  $V_{\text{DAI},m_{\text{last}}}^{\text{DL}}$  is the value of the counter DAI in the last DCI format 1\_0 or DCI format 1\_1 scheduling PDSCH reception or indicating SPS PDSCH release for any serving cell  $c$  that the UE detects within the  $M$  PDCCH monitoring occasions.
- if  $N_{\text{cells}}^{\text{DL}} > 1$

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

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

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

- $N_{cells}^{DL}$  is used for the determination of a first HARQ-ACK sub-codebook for SPS PDSCH releases, SPS PDSCH receptions, and for TB-based PDSCH receptions scheduled by DCI formats 1\_0 on the  $N_{cells}^{DL,CBG}$  serving cells and by DCI formats 1\_0 and DCI formats 1\_1 on the  $N_{cells}^{DL,TB}$  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  $N_{HARQ-ACK,max}^{CBG/TB,max}$  HARQ-ACK information bits, where  $N_{HARQ-ACK,max}^{CBG/TB,max}$  is the maximum value of  $N_{TB,c}^{DL} \cdot N_{HARQ-ACK,c}^{CBG/TB,max}$  across all  $N_{cells}^{DL,CBG}$  serving cells and  $N_{TB,c}^{DL}$  is the value of higher

layer parameter  $maxNrofCodeWordsScheduledByDCI$  for serving cell  $c$ . If for a serving cell  $c$  it is

$N_{TB,c}^{DL} \cdot N_{HARQ-ACK,c}^{CBG/TB,max} < N_{HARQ-ACK,max}^{CBG/TB,max}$ , the UE generates NACK for the last  $N_{HARQ-ACK,max}^{CBG/TB,max} - N_{TB,c}^{DL} \cdot N_{HARQ-ACK,c}^{CBG/TB,max}$  HARQ-ACK information bits for serving cell  $c$ ;

- The pseudo-code operation when higher layer parameter  $harq-ACK-SpatialBundlingPUCCH$  is provided is not applicable;
- The counter DAI value and the total DAI value apply separately for each HARQ-ACK sub-codebook;
- The UE generates the HARQ-ACK codebook by appending the second HARQ-ACK sub-codebook to the first HARQ-ACK sub-codebook.

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

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

where

- if  $N_{cells}^{DL} = 1$ ,  $V_{DAI,m_{last}}^{DL}$  is the value of the counter DAI in the last DCI format 1\_1 scheduling CBG-based PDSCH reception for any serving cell  $c$  that the UE detects within the  $M$  PDCCH monitoring occasions.
- if  $N_{cells}^{DL} > 1$ ,  $V_{C-DAI,m_{last}}^{DL}$  is the value of the total DAI in the last DCI format 1\_1 scheduling CBG-based PDSCH reception for any serving cell  $c$  that the UE detects within the  $M$  PDCCH monitoring occasions
- $V_{DAI,m_{last}}^{DL} = 0$  if the UE does not detect any DCI format 1\_1 scheduling CBG-based PDSCH reception for any serving cell  $c$  in any of the  $M$  PDCCH monitoring occasions.
- $U_{DAI,c}^{CBG}$  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  $c$ .  $U_{DAI,c}^{CBG} = 0$  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.
- $N_{m,c}^{receivedCBG}$  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-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

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

- For  $0 \leq m < M-1$ ,  $V_{T-DAI,m}^{DL} = \emptyset$  and for  $m = M-1$ ,  $V_{T-DAI,m}^{DL}$  is replaced by  $V_{T-DAI,m}^{UL}$  where  $V_{T-DAI,m}^{UL}$  is the value of the DAI field in DCI format 0\_1 according to Table 9.1.3-2
- For the case of first and second HARQ-ACK sub-codebooks, DCI format 0\_1 includes a first DAI field corresponding to the first HARQ-ACK sub-codebook and a second DAI field corresponding to the second HARQ-ACK sub-codebook
- *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.

A UE does not multiplex in a PUSCH transmission HARQ-ACK information that is in response to PDSCH reception or SPS PDSCH release scheduled by DCI format 1\_0 or DCI format 1\_1 that the UE detects in a PDCCH monitoring occasion that is after a PDCCH monitoring occasion where the UE detects a DCI format 0\_0 or a DCI format 0\_1 scheduling the PUSCH transmission.

If a UE is scheduled for a PUSCH transmission by DCI format 0\_1 with  $V_{T-DAI}^{UL} = 4$  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 information, SR, and CSI. UCI bits include HARQ-ACK information bits, if any, SR information bit, if any, and CSI bits, if any. The HARQ-ACK information bits correspond to a HARQ-ACK codebook as described in Subclause 9.1.

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

### 9.2.1 PUCCH Resource Sets

If a UE does not have dedicated PUCCH resource configuration, provided by higher layer parameter *PUCCH-ResourceSet* in *PUCCH-Config*, a PUCCH resource set is provided by higher layer parameter *pucch-ResourceCommon* in *SystemInformationBlockType1* through an index to a row of Table 9.2.1-1 for transmission of HARQ-ACK information on PUCCH in an initial active UL BWP of  $N_{\text{BWP}}^{\text{size}}$  PRBs provided by *SystemInformationBlockType1*. The



PUCCH resource set is provided by higher layer parameter *PUCCH-Resource-Common* and includes sixteen resources, each corresponding to a PUCCH format, a first symbol, a duration, a PRB offset  $RB_{BWP}^{\text{offset}}$ , and a cyclic shift index set for a PUCCH transmission. The UE transmits a PUCCH using frequency hopping. The UE transmits 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.

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

$$r_{\text{PUCCH}} = \left\lfloor \frac{2 \cdot n_{\text{CCE},0}}{N_{\text{CCE},0}} \right\rfloor + 2 \cdot \Delta_{\text{PRI}}, \text{ where } N_{\text{CCE},0} \text{ is a number of CCEs in a control resource set of a PDCCH reception}$$

conveying the DCI format 1\_0, as described in Subclause 10.1,  $n_{\text{CCE},0}$  is the index of a first CCE for the PDCCH reception, and  $\Delta_{\text{PRI}}$  is a value of the PUCCH resource indicator field in the DCI format 1\_0 or DCI format 1\_1.

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

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

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

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

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

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

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

A PUCCH resource includes the following parameters:

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

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

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

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

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

A UE can be configured up to four sets of PUCCH resources by higher layer parameter *PUCCH-ResourceSet*. A PUCCH resource set is associated with a PUCCH resource set index provided by higher layer parameter *pucch-ResourceSetId*, with a set of PUCCH resource indexes provided by higher layer parameter *resourceList* that provides a set of *pucch-ResourceId* used in the PUCCH resource set, and with a maximum number of UCI information bits the UE can transmit using a PUCCH resource in the PUCCH resource set provided by higher layer parameter *maxPayloadMinus1*. For the first PUCCH resource set, the maximum number of UCI information bits is fixed to two. For the PUCCH resource set with the largest index, other than the first one, the maximum number of UCI information bits is 1706. A maximum number of PUCCH resource indexes for a set of PUCCH resources is provided by higher layer parameter *maxNrofPUCCH-ResourcesPerSet*. The maximum number of PUCCH resources in the first PUCCH resource set is 32 and the maximum number of PUCCH resources in the other sets of PUCCH resources is 8.

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

- a first set of PUCCH resources with *pucch-ResourceSetId* = 0 if  $N_{\text{UCI}} \leq 2$  including 1 or 2 HARQ-ACK information bits and a positive or negative SR on one SR transmission occasion if transmission of HARQ-ACK information and SR occurs simultaneously, or
- a second set of PUCCH resources with *pucch-ResourceSetId* = 1, if provided by higher layers, if  $2 < N_{\text{UCI}} \leq N_2$  where  $N_2$  is provided by higher layer parameter *maxPayloadMinus1* for the PUCCH resource set with *pucch-ResourceSetId* = 1, or
- a third set of PUCCH resources with *pucch-ResourceSetId* = 2, if provided by higher layers, if  $N_2 < N_{\text{UCI}} \leq N_3$  where  $N_3$  is provided by higher layer parameter *maxPayloadMinus1* for the PUCCH resource set with *pucch-ResourceSetId* = 2, or

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

### 9.2.2 PUCCH Formats for UCI transmission

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

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

A spatial setting for a PUCCH transmission is provided by higher layer parameter *PUCCH-Spatialrelationinfo* if the UE is configured with a single value for higher layer parameter *pucch-SpatialrelationinfoId*; otherwise, the spatial setting is provided by higher layer parameter *PUCCH-SpatialRelationInfo* from a set of multiple values provided by respective higher layer parameters *pucch-SpatialRelationInfoId* [11, TS 38.321]. The UE applies corresponding actions in [10, TS 38.321] and a corresponding setting for a spatial domain filter to transmit PUCCH 3 msec after the slot where the UE transmits HARQ-ACK information corresponding to a PDSCH reception providing the *PUCCH-SpatialRelationInfo*.

- If *PUCCH-Spatialrelationinfo* provides higher layer parameter *ssb-Index*, the UE transmits the PUCCH using a same spatial domain filter as for a reception of a SS/PBCH block with index provided by *ssb-Index*; else if *PUCCH-Spatialrelationinfo* provides higher layer parameter *csi-RS-Index*, the UE transmits the PUCCH using a same spatial domain filter as for a reception of a CSI-RS with resource index provided by *csi-RS-Index*; else *PUCCH-Spatialrelationinfo* provides higher layer parameter *srs*, and the UE transmits the PUCCH with a same spatial domain filter used as for a transmission of a SRS with resource index provided by *srs*.

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

Use of  $\pi/2$ -PQSK, instead of QPSK, for a PUCCH transmission using PUCCH format 3 or 4 is indicated by higher layer parameter *pi2PQSK*.

### 9.2.3 UE procedure for reporting HARQ-ACK

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

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

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

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

With reference to slots for PUCCH transmissions, if the UE detects a DCI format 1\_0 or a DCI format 1\_1 scheduling a PDSCH reception in slot  $n$  or if the UE detects a DCI format 1\_0 indicating a SPS PDSCH release through a PDCCH reception in slot  $n$ , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot  $n+k$ , where  $k$  is a number of slots and is indicated by the PDSCH-to-HARQ-timing-indicator field in the DCI format, if present, or provided by higher layer parameter *dl-DataToUL-ACK*. If the PDSCH subcarrier spacing is equal to or larger than the PUCCH subcarrier spacing,  $k=0$  corresponds to the slot of the PUCCH transmission that overlaps with the slot of the PDSCH transmission. If the PDSCH subcarrier spacing is smaller than the PUCCH subcarrier spacing,  $k=0$  corresponds to the slot of the PUCCH transmission that ends at a same time as the slot of the PDSCH reception or of the PDCCH reception in case of SPS PDSCH release.

HARQ-ACK information 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'	1 <sup>st</sup> value provided by <i>dl-DataToUL-ACK</i>
'001'	2 <sup>nd</sup> value provided by <i>dl-DataToUL-ACK</i>
'010'	3 <sup>rd</sup> value provided by <i>dl-DataToUL-ACK</i>
'011'	4 <sup>th</sup> value provided by <i>dl-DataToUL-ACK</i>
'100'	5 <sup>th</sup> value provided by <i>dl-DataToUL-ACK</i>
'101'	6 <sup>th</sup> value provided by <i>dl-DataToUL-ACK</i>
'110'	7 <sup>th</sup> value provided by <i>dl-DataToUL-ACK</i>
'111'	8 <sup>th</sup> value provided by <i>dl-DataToUL-ACK</i>

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

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

For the first set of PUCCH resources and when the size  $R_{\text{PUCCH}}$  of higher layer parameter *resourceList* is larger than eight, when a UE provides HARQ-ACK information in a PUCCH transmission in response to detecting a last DCI format 1\_0 or DCI format 1\_1, the UE determines a PUCCH resource with index  $r_{\text{PUCCH}}$ ,  $0 \leq r_{\text{PUCCH}} \leq R_{\text{PUCCH}} - 1$ , as

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

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

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

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

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

If a UE transmits HARQ-ACK information using PUCCH format 0, the UE determines values  $m_0$  and  $m_{\text{CS}}$  for computing a value of cyclic shift  $\alpha$  [4, TS 38.211] where  $m_0$  is provided by higher layer parameter *initialCyclicShift* of *PUCCH-format0*, and  $m_{\text{CS}}$  is determined from the value of one HARQ-ACK information bit or from the values of two HARQ-ACK information bits as in Table 9.2.3-3 and Table 9.2.3-4, respectively.

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

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

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

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

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

If a UE transmits  $O_{\text{ACK}}$  HARQ-ACK information bits and  $O_{\text{CRC}}$  bits using PUCCH format 2 or PUCCH format 3 in a PUCCH resource that includes  $M_{\text{RB}}^{\text{PUCCH}}$  PRBs, the UE determines a number of PRBs  $M_{\text{RB,min}}^{\text{PUCCH}}$  for the PUCCH transmission to be the minimum number of PRBs, that is smaller than or equal to a number of PRBs  $M_{\text{RB}}^{\text{PUCCH}}$  provided respectively by higher layer parameter *nrofPRBs* of *PUCCH-format2* or *nrofPRBs* of *PUCCH-format3* and starts from the first PRB from the number of PRBs, that results to  $(O_{\text{ACK}} + O_{\text{CRC}}) \leq M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$  and, if  $M_{\text{RB}}^{\text{PUCCH}} > 1$ ,  $(O_{\text{ACK}} + O_{\text{CRC}}) > (M_{\text{RB,min}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ , where  $N_{\text{sc,ctrl}}^{\text{RB}}$ ,  $N_{\text{symb-UCI}}^{\text{PUCCH}}$ ,  $Q_m$ , and  $r$  are defined in Subclause 9.2.5.2. If  $(O_{\text{ACK}} + O_{\text{CRC}}) > (M_{\text{RB}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ , the UE transmits the PUCCH over  $M_{\text{RB}}^{\text{PUCCH}}$  PRBs.

## 9.2.4 UE procedure for reporting SR

A UE is configured by higher layer parameter *SchedulingRequestResourceConfig* 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 or slots and an offset  $SR_{\text{OFFSET}}$  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  $n_{\text{s,f}}^{\mu}$  [4, TS 38.211] in a frame with number  $n_f$  if  $(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{\text{s,f}}^{\mu} - SR_{\text{OFFSET}}) \bmod SR_{\text{PERIODICITY}} = 0$ .

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

If  $SR_{\text{PERIODICITY}}$  is smaller than one slot, the UE determines a SR transmission occasion in a PUCCH to start in a symbol with index  $l$  [4, TS 38.211] if  $(l - l_0 \bmod SR_{\text{PERIODICITY}}) \bmod SR_{\text{PERIODICITY}} = 0$  where  $l_0$  is the value of 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 obtaining  $m_0$  as described for HARQ-ACK information transmission in Subclause 9.2.3 and by setting  $m_{\text{cs}} = 0$ . For a positive SR transmission using PUCCH format 1, the UE transmits the PUCCH as described in [4, TS 38.211] by setting  $b(0) = 0$ .

## 9.2.5 UE procedure for reporting multiple UCI types

A UE multiplexes HARQ-ACK/SR and periodic/semi-persistent CSI in a same PUCCH if the UE is provided higher layer parameter *simultaneousHARQ-ACK-CSI*; otherwise, the UE drops the periodic/semi-persistent CSI report(s) and includes only HARQ-ACK/SR in the PUCCH.

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

- if the UE is not provided higher layer parameter *multi-CSI-PUCCH-ResourceList*, the UE determines a first resource corresponding to a CSI report with the highest priority [6, TS38.214]. If the first resource includes PUCCH format 2, and if there are remaining resources that do not overlap with the first resource, the UE determines a CSI report with the highest priority, among the CSI reports with corresponding resources from the remaining resources, and a corresponding second resource as an additional resource for CSI reporting

- if the UE is provided higher layer parameter *multi-CSI-PUCCH-ResourceList*, the UE multiplexes CSI reports with overlapping resources in a resource from the resources provided by *multi-CSI-PUCCH-ResourceList*, as described in Subclause 9.2.5.2

If a UE would transmit multiple overlapping PUCCHs without repetitions in a slot or overlapping PUCCH(s) without repetitions and PUSCH(s) in a slot and, when applicable as described in Subclauses 9.2.5.1 and 9.2.5.2, the UE is configured to multiplex different UCI types in one PUCCH, and one of the multiple overlapping PUCCHs or PUSCHs is in response to a DCI format detection by the UE, the UE multiplexes all corresponding UCI types if the following conditions are met.

If one of the PUCCHs or PUSCHs is in response to a DCI format detection by the UE, the UE expects that the first symbol of the earliest PUCCH or PUSCH, among the overlapping PUCCHs and PUSCHs in the slot, is not before symbol  $N_1^+ + d_{1,1} + d_{1,2}$  after a last symbol of any corresponding PDSCH or SPS PDSCH release and is not before symbol  $N_2^+ + d_{2,1}$  after a last symbol of any corresponding PDCCH where  $N_1^+$  is obtained by adding one symbol to a number of symbols  $N_1$  corresponding to a PDSCH reception time for the UE PDSCH processing capability,  $N_2^+$  is obtained by adding one symbol to a number of symbols  $N_2$  corresponding to a PUSCH preparation time for the UE PUSCH processing capability, where  $N_1$ ,  $N_2$ ,  $d_{1,1}$ ,  $d_{1,2}$ , and  $d_{2,1}$  are defined in [6, TS 38.214]. A UE does not expect a PUCCH or a PUSCH that is in response to a DCI format detection to overlap with any other PUCCH or PUSCH that does not satisfy the above  $N_1^+ + d_{1,1} + d_{1,2}$  and  $N_2^+ + d_{2,1}$  timing conditions.

If a UE would transmit multiple PUCCHs in a slot that include HARQ-ACK/SR and CSI and PUCCHs with HARQ-ACK satisfies the above  $N_1^+ + d_{1,1} + d_{1,2}$  and  $N_2^+ + d_{2,1}$  timing conditions and does not overlap with any other PUCCH or PUSCH that does not satisfy the above  $N_1^+ + d_{1,1} + d_{1,2}$  and  $N_2^+ + d_{2,1}$  timing conditions, the UE multiplexes HARQ-ACK/SR and CSI and determines corresponding PUCCH(s) for transmission in the slot according to the following pseudo-code.

Set  $Q$  to the set of resources for transmission of corresponding PUCCHs in a slot where

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

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

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

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

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

Set  $o=0$  - counter of overlapped resources

while  $j < \ell(Q) - 1$

if any of resources  $\{Q(j-o), Q(j-o+1), \dots, Q(j)\}$  overlaps with resource  $Q(j+1)$

$o = o + 1$

$j = j + 1$

else

if  $o > 0$

multiplex UCI for resources  $\{Q(j-o), Q(j-o+1), \dots, Q(j)\}$  in a single resource as described in Subclauses 9.2.5.1 and 9.2.5.2

set the index of the single resource to  $j$

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

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

$o = 0$

$\text{order}(Q)$  % function that re-orders resources in current set  $Q$

else

$j = j + 1$

end if

end if

end while

The function  $\text{order}(Q)$  performs the following pseudo-code

{

$k = 0$

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

$l = 0$

while  $l < \ell(Q) - 1 - k$

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

temp =  $Q(l)$

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

$Q(l+1) = \text{temp}$

end if

$l = l + 1$

end while



```

    k = k + 1
end while
}

```

For each PUCCH resource in the set  $Q$  that satisfies the aforementioned  $N_1^+ + d_{1,1} + d_{1,2}$  and  $N_2^+ + d_{2,1}$  timing conditions

- the UE transmits a PUCCH using the resource if the resource does not overlap with a PUSCH, or if the resource is associated with repetitions of a PUCCH over multiple slots
- the UE multiplexes HARQ-ACK information and/or CSI in a PUSCH if the resource overlaps with the PUSCH, as described in Subclause 9.3, and does not transmit SR. In case the resource overlaps with multiple PUSCHs, the PUSCH for multiplexing HARQ-ACK information and/or CSI is selected as described in Subclause 9.

Subclauses 9.2.5.1 and 9.2.5.2 assume the following

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

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

In the following, a UE is configured to transmit  $K$  PUCCHs for respective  $K$  SRs in a slot, as determined by a set of higher layer parameters *schedulingRequestResourceId*, with transmission occasions that would overlap with a transmission of HARQ-ACK information from the UE in the slot or with periodic/semi persistent CSI transmission from the UE in the slot.

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

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

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

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

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

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

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

If the UE would transmit positive SR in a resource using PUCCH format 1 and at most two HARQ-ACK information bits in a resource using PUCCH format 1 in a slot, the UE transmits a PUCCH in the PUCCH resource using PUCCH format 1 for SR transmission as described in Subclause 9.2.4. If a UE would transmit negative SR in a resource using

PUCCH format 1 and at most two HARQ-ACK information bits in a resource using PUCCH format 1 in a slot, the UE transmits a PUCCH in the resource using PUCCH format 1 for HARQ-ACK information as described in Subclause 9.2.3.

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

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

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

If a UE transmits  $O_{\text{ACK}}$  HARQ-ACK information bits,  $O_{\text{SR}} = \lceil \log_2(K+1) \rceil$  SR bits, and  $O_{\text{CRC}}$  CRC bits using PUCCH format 2 or PUCCH format 3 in a PUCCH resource that includes  $M_{\text{RB}}^{\text{PUCCH}}$  PRBs, the UE determines a number of PRBs  $M_{\text{RB,min}}^{\text{PUCCH}}$  for the PUCCH transmission to be the minimum number of PRBs, that is smaller than or equal to a number of PRBs provided respectively by higher layer parameter *nrofPRBs* in *PUCCH-format2* or *nrofPRBs* in *PUCCH-format3* and starts from the first PRB from the number of PRBs, that results to

$$(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) \leq M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r \text{ and, if } M_{\text{RB}}^{\text{PUCCH}} > 1,$$

$$(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) > (M_{\text{RB,min}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r, \text{ where } N_{\text{sc,ctrl}}^{\text{RB}}, N_{\text{symb-UCI}}^{\text{PUCCH}}, Q_m, \text{ and } r \text{ are defined in}$$

Subclause 9.2.5.2. If  $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CRC}}) > (M_{\text{RB}}^{\text{PUCCH}} - 1) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ , the UE transmits the PUCCH over the  $M_{\text{RB}}^{\text{PUCCH}}$  PRBs.

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

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

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

A UE is configured by higher layer parameter *maxCodeRate* a code rate for transmission of HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in PUCCH format 2, PUCCH format 3, or PUCCH format 4.

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

If a UE transmits periodic/semi-persistent CSI reports that include Part 2 CSI reports, the UE determines a PUCCH resource and a number of PRBs in the PUCCH resource assuming that each of the periodic/semi-persistent CSI reports indicates rank 1. Let  $N_{\text{UCI}} = O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}}$  be a total number of UCI bits and  $O_{\text{CRC}}$  be a total number of CRC bits a UE transmits in a PUCCH, where

- $O_{ACK}$  is a total number of HARQ-ACK bits, if any
- $O_{SR} = 0$  if there is no scheduling request bit; otherwise,  $O_{SR} = \lceil \log_2(K+1) \rceil$  as described in Subclause 9.2.5.1
- $O_{CSI} = \sum_{n=1}^{N_{CSI}^{total}} (O_{CSI-part1,n} + O_{CSI-part2,n})$ ,  $O_{CSI-part1,n}$  is a number of Part 1 CSI report bits for CSI report with priority level  $n$ ,  $O_{CSI-part2,n}$  is a number of Part 2 CSI report bits, if any, for CSI report with priority level  $n$  [6, TS 38.214], and  $N_{CSI}^{total}$  is a number of periodic/semi-persistent CSI reports
- $O_{CRC} = O_{CRC,CSI-part1} + O_{CRC,CSI-part2}$ ,  $O_{CRC,CSI-part1}$  is a number of CRC bits, if any, for encoding HARQ-ACK/SR and Part 1 of a CSI report, and  $O_{CRC,CSI-part2}$  is a number of CRC bits, if any, for encoding Part 2 of the CSI report

In the following

- $r$  is a code rate given by higher layer parameter *maxCodeRate* as in Table 9.2.5.2-1.
- $M_{RB}^{PUCCH}$  is a number of PRBs for PUCCH format 2, or PUCCH format 3, or PUCCH format 4, respectively, where  $M_{RB}^{PUCCH}$  is provided by higher layer parameter *nrofPRBs* in *PUCCH-format2* for PUCCH format 2 or by higher layer parameter *nrofPRBs* in *PUCCH-format3* for PUCCH format 3, and  $M_{RB}^{PUCCH} = 1$  for PUCCH format 4
- $N_{sc,ctrl}^{RB} = N_{sc}^{RB} - 4$  for PUCCH format 2,  $N_{sc,ctrl}^{RB} = N_{sc}^{RB}$  for PUCCH format 3, and  $N_{sc,ctrl}^{RB} = N_{sc}^{RB} / N_{SF}^{PUCCH,4}$  for PUCCH format 4, where  $N_{sc}^{RB}$  is a number of subcarriers per resource block [4, TS 38.211]
- $N_{symb-UCI}^{PUCCH}$  is equal to a number of PUCCH symbols  $N_{symb}^{PUCCH,2}$  for PUCCH format 2 provided by higher layer parameter *nrofSymbols* in *PUCCH-format2*. For PUCCH format 3 or for PUCCH format 4,  $N_{symb-UCI}^{PUCCH}$  is equal to a number of PUCCH symbols  $N_{symb}^{PUCCH,3}$  for PUCCH format 3 or equal to a number of PUCCH symbols  $N_{symb}^{PUCCH,4}$  for PUCCH format 4 provided by higher layer parameter *nrofSymbols* in *PUCCH-format3* or *nrofSymbols* in *PUCCH-format4*, respectively, after excluding a number of symbols used for DM-RS transmission for PUCCH format 3 or for PUCCH format 4, respectively [4, TS 38.211]
- $Q_m = 1$  if pi/2-BPSK is the modulation scheme and  $Q_m = 2$  if QPSK is the modulation scheme as indicated by higher layer parameter *pi2BPSK* for PUCCH format 3 or PUCCH format 4. For PUCCH format 2,  $Q_m = 2$

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

- if the UE is provided by higher layer parameter *pucch-CSI-ResourceList* or by higher layer parameter *multi-CSI-PUCCH-ResourceList* with  $J \leq 2$  PUCCH resources, for PUCCH format 2 and/or PUCCH format 3 and/or PUCCH format 4, as described in Subclause 9.2.1, where the resources are indexed according to an ascending order for the product of a number of corresponding REs, modulation order  $Q_m$ , and configured code rate  $r$ ;
- if  $(O_{ACK} + O_{SR} + O_{CSI} + O_{CRC}) \leq M_{RB,0}^{PUCCH} \cdot N_{sc,ctrl}^{RB} \cdot N_{symb-UCI,0}^{PUCCH} \cdot Q_m \cdot r$ , the UE uses PUCCH format 2 resource 0, or the PUCCH format 3 resource 0, or the PUCCH format 4 resource 0;
- else if  $(O_{ACK} + O_{SR} + O_{CSI} + O_{CRC}) > M_{RB,j}^{PUCCH} \cdot N_{sc,ctrl}^{RB} \cdot N_{symb-UCI,j}^{PUCCH} \cdot Q_m \cdot r$  and  $(O_{ACK} + O_{SR} + O_{CSI} + O_{CRC}) \leq M_{RB,j+1}^{PUCCH} \cdot N_{sc,ctrl}^{RB} \cdot N_{symb-UCI,j+1}^{PUCCH} \cdot Q_m \cdot r$ ,  $0 \leq j < J-1$ , the UE transmits a PUCCH conveying HARQ-ACK/SR and periodic/semi-persistent CSI report(s) in a respective PUCCH where the UE uses the PUCCH format 2 resource  $j+1$ , or the PUCCH format 3 resource  $j+1$ , or the PUCCH format 4 resource;

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

If a UE has HARQ-ACK/SR and wideband or sub-band CSI reports to transmit and the UE determines a PUCCH resource with PUCCH format 2, or the UE has HARQ-ACK/SR and wideband CSI reports [6, TS38.214] to transmit and the UE determines a PUCCH resource with PUCCH format 3 or PUCCH format 4, where

- the UE determines the PUCCH resource using the PUCCH resource indicator field [5, TS 38.212] in a last DCI format 1\_0 or DCI format 1\_1, from DCI formats 1\_0 or DCI formats 1\_1 that have a value of a PDSCH-to-HARQ\_feedback timing indicator field indicating a same slot for the PUCCH transmission, from a PUCCH resource set provided to the UE for HARQ-ACK transmission, and
- the UE determines the PUCCH resource set as described in Subclause 9.2.1 and Subclause 9.2.3 for  $N_{\text{UCI}}$  UCI bits

and

- if  $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI-part1}} + O_{\text{CRC,CSI-part1}}) \leq M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$ , the UE transmits the HARQ-ACK/SR and periodic/semi-persistent CSI reports bits by selecting the minimum number  $M_{\text{RB,min}}^{\text{PUCCH}}$  of the  $M_{\text{RB}}^{\text{PUCCH}}$  PRBs satisfying  $(O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI-part1}} + O_{\text{CRC,CSI-part1}}) \leq M_{\text{RB,min}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} \cdot Q_m \cdot r$  as described in Subclauses 9.2.3 and 9.2.5.1;
- else, the UE selects  $N_{\text{CSI}}^{\text{reported}}$  CSI report(s) for transmission together with HARQ-ACK/SR in ascending priority order, where the value of  $N_{\text{CSI}}^{\text{reported}}$  satisfies

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

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

number of CRC bits corresponding to  $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}} O_{\text{CSI-part1},n}$  UCI bits, and  $O_{\text{CRC,CSI-part1},N+1}$  is a number of CRC bits corresponding to  $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI}}^{\text{reported}}+1} O_{\text{CSI-part1},n}$  UCI bits.

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

- the UE determines the PUCCH resource using the PUCCH resource indicator field [5, TS 38.212] in a last DCI format 1\_0 or DCI format 1\_1, from DCI formats 1\_0 or DCI formats 1\_1 that have a value of a PDSCH-to-HARQ\_feedback timing indicator field indicating a same slot for the PUCCH transmission, from a PUCCH resource set provided to the UE for HARQ-ACK transmission, and
- the UE determines the PUCCH resource set as described in Subclause 9.2.1 and Subclause 9.2.3 for  $N_{\text{UCI}}$  UCI bits

and

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

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

$$\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}} O_{\text{CSI-part2},n} + O_{\text{CRC,CSI-part2},N} \leq \left( M_{\text{RB}}^{\text{PUCCH}} \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCI}}^{\text{PUCCH}} - \left[ \left( O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI}}^{\text{total}}} O_{\text{CSI-part1},n} + O_{\text{CRC,CSI-part1}} \right) / (\mathcal{Q}_m \cdot r) \right] \right) \cdot \mathcal{Q}_m \cdot r$$

and

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

,

the UE selects the first  $N_{\text{CSI-part2}}^{\text{reported}}$  CSI part 2 report priority level(s), according to [6, TS 38.214], for transmission

together with the HARQ-ACK/SR and  $N_{\text{CSI}}^{\text{total}}$  CSI part 1 reports, where  $O_{\text{CSI-part1},n}$  is the number of CSI part 1 report bits for the  $n_{\text{th}}$  CSI report and  $O_{\text{CSI-part2},n}$  is the number of CSI part 2 report bits for the  $n_{\text{th}}$  CSI report priority level,  $O_{\text{CRC,CSI-part2},N}$  is a number of CRC bits corresponding to  $\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}} O_{\text{CSI-part2},n}$ , and

$O_{\text{CRC,CSI-part2},N+1}$  is a number of CRC bits corresponding to  $\sum_{n=1}^{N_{\text{CSI-part2}}^{\text{reported}}+1} O_{\text{CSI-part2},n}$ ;

- else, the UE drops all CSI part 2 reports and selects  $N_{\text{CSI-part1}}^{\text{reported}}$  CSI part 1 report(s), in ascending priority order, for transmission together with the HARQ-ACK/SR bits where the value of  $N_{\text{CSI-part1}}^{\text{reported}}$  satisfies

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

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

$O_{\text{CRC,CSI-part1},N}$  is a number of CRC bits corresponding to  $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}} O_{\text{CSI-part1},n}$  UCI bits, and

$O_{\text{CRC,CSI-part1},N+1}$  is a number of CRC bits corresponding to  $O_{\text{ACK}} + O_{\text{SR}} + \sum_{n=1}^{N_{\text{CSI-part1}}^{\text{reported}}+1} O_{\text{CSI-part1},n}$  UCI bits.

**Table 9.2.5.2-1: Code rate  $r$  corresponding to higher layer parameter *maxCodeRate***

<i>maxCodeRate</i>	Code rate $r$
0	0.08
1	0.15
2	0.25
3	0.35
4	0.45
5	0.60
6	0.80
7	Reserved

## 9.2.6 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 *nrofSlots*.

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 *nrofSymbols* in *PUCCH-format1*, *nrofSymbols* in *PUCCH-format3*, or *nrofSymbols* in *PUCCH-format4*, in each of the  $N_{\text{PUCCH}}^{\text{repeat}}$  slots;
- a PUCCH transmission has a same first symbol, as provided by higher layer parameter *startingSymbolIndex* in *PUCCH-format1*, *startingSymbolIndex* in *PUCCH-format3*, or *startingSymbolIndex* in *PUCCH-format4*, in each of the  $N_{\text{PUCCH}}^{\text{repeat}}$  slots;
- the UE is configured by higher layer parameter *interslotFrequencyHopping* whether or not to perform frequency hopping for PUCCH transmissions in different slots.
  - If the UE is configured to perform frequency hopping for PUCCH transmissions 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* for the corresponding PUCCH format, the UE does not transmit the PUCCH in the slot.

If a UE is provided higher layer parameter *tdd-UL-DL-ConfigurationCommon*, or is additionally provided higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, or is additionally provided higher layer parameter *tdd-UL-DL-ConfigDedicated* 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 *tdd-UL-DL-ConfigurationCommon* or higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, the UE determines the  $N_{\text{PUCCH}}^{\text{repeat}}$  slots for a PUCCH transmission as the  $N_{\text{PUCCH}}^{\text{repeat}}$  consecutive slots starting from a slot indicated to the UE as described in Subclause 9.2.3.

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

### 9.3 UCI reporting in physical uplink shared channel

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

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

Offset values are defined for a UE to determine a number of resources for multiplexing HARQ-ACK information and for multiplexing CSI 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  $\beta_{\text{offset}}$  indicator field, schedules the PUSCH transmission from the UE, the UE applies the  $\beta_{\text{offset}}^{\text{HARQ-ACK}}$ ,  $\beta_{\text{offset}}^{\text{CSI-1}}$ , and  $\beta_{\text{offset}}^{\text{CSI-2}}$  values that are configured by higher layers for the corresponding HARQ-ACK information and/or CSI part 1 and CSI part 2 payloads.

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

CSI part 1 and CSI part 2 offsets  $\beta_{\text{offset}}^{\text{CSI-1}}$  and  $\beta_{\text{offset}}^{\text{CSI-2}}$ , respectively, is configured to values according to Table 9.3-2. Higher layer parameters  $\beta_{\text{OffsetCSI-Part1-Index1}}$  and  $\beta_{\text{OffsetCSI-Part2-Index1}}$  respectively provide indexes  $I_{\text{offset},0}^{\text{CSI-1}}$  and  $I_{\text{offset},0}^{\text{CSI-2}}$  for the UE to use if the UE multiplexes up to 11 bits for CSI part 1 or CSI part 2 in the PUSCH. Higher layer parameters  $\beta_{\text{OffsetCSI-Part1-Index2}}$  and  $\beta_{\text{OffsetCSI-Part2-Index2}}$  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  $\beta_{\text{offset}}$  indicator field, as configured by higher layer parameter  $\text{uci-OnPUSCH}$ , the UE is provided by each of higher layer parameters {  $\beta_{\text{OffsetACK-Index1}}$ ,  $\beta_{\text{OffsetACK-Index2}}$ ,  $\beta_{\text{OffsetACK-Index3}}$  } a set of four  $I_{\text{offset}}^{\text{HARQ-ACK}}$  indexes, by each of higher layer parameters {  $\beta_{\text{OffsetCSI-Part1-Index1}}$ ,  $\beta_{\text{OffsetCSI-Part1-Index2}}$  } a set of four  $I_{\text{offset}}^{\text{CSI-1}}$  indexes and by each of higher layer parameters {  $\beta_{\text{OffsetCSI-Part2-Index1}}$ ,  $\beta_{\text{OffsetCSI-Part2-Index2}}$  } a set of four  $I_{\text{offset}}^{\text{CSI-2}}$  indexes from Table 9.3-1 and 9.3-2, respectively, for multiplexing HARQ-ACK information, CSI part 1, and CSI part 2, respectively, in the PUSCH transmission. The  $\beta_{\text{offset}}$  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  $\beta_{\text{offset}}$  values for HARQ-ACK information and the index signalled by higher layers**

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



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

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

**Table 9.3-3: Mapping of beta\_offset indicator values to offset indexes**

beta_offset indicator	$(I_{\text{offset},0}^{\text{HARQ-ACK}} \text{ or } I_{\text{offset},1}^{\text{HARQ-ACK}} \text{ or } I_{\text{offset},2}^{\text{HARQ-ACK}})$ , $(I_{\text{offset},0}^{\text{CSI-1}} \text{ or } I_{\text{offset},0}^{\text{CSI-2}})$ , $(I_{\text{offset},1}^{\text{CSI-1}} \text{ or } I_{\text{offset},1}^{\text{CSI-2}})$
'00'	1 <sup>st</sup> offset index provided by higher layers
'01'	2 <sup>nd</sup> offset index provided by higher layers
'10'	3 <sup>rd</sup> offset index provided by higher layers
'11'	4 <sup>th</sup> 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 monitors a set of PDCCH candidates in one or more control resource sets on the active DL BWP on each activated serving cell configured with PDCCH monitoring according to corresponding search space sets where monitoring implies decoding each PDCCH candidate according to the monitored DCI formats.

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

For monitoring of a PDCCH candidate in a slot

- If the UE has received *ssb-PositionsInBurst* in *SystemInformationBlockType1* and has not received *ssb-PositionsInBurst* in *ServingCellConfigCommon* for a serving cell and if the UE does not monitor PDCCH candidates in a Type0-PDCCH common search space and at least one RE for a PDCCH candidate overlaps with respective at least one RE corresponding to a SS/PBCH block index provided by *ssb-PositionsInBurst* in *SystemInformationBlockType1*, the UE is not required to monitor the PDCCH candidate.
- If a UE has received *ssb-PositionsInBurst* in *ServingCellConfigCommon* for a serving cell and if the UE does not monitor PDCCH candidates in a Type0-PDCCH common search space and at least one RE for a PDCCH candidate overlaps with respective at least one RE corresponding to a SS/PBCH block index provided by *ssb-PositionsInBurst* in *ServingCellConfigCommon*, the UE is not required to monitor the PDCCH candidate.
- If the UE monitors the PDCCH candidate for a Type0-PDCCH common search space on the serving cell according to the procedure described in Subclause 13, the UE may assume that no SS/PBCH block is transmitted in REs used for monitoring the PDCCH candidate on the serving cell.
- If at least one RE of a PDCCH candidate on the serving cell overlaps with at least one RE of *lte-CRS-ToMatchAround*, the UE is not required to monitor the PDCCH candidate.

If a UE indicates in *UE-NR-Capability* a carrier aggregation capability larger than 4 serving cells, the UE includes in *UE-NR-Capability* an indication for a maximum number of PDCCH candidates the UE can monitor per slot when the UE is configured for carrier aggregation operation over more than 4 cells. When the UE is configured for carrier aggregation operation over more than 4 cells, the UE 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 space sets. A search space set can be a common search space set or a UE-specific search space set. A UE monitors PDCCH candidates in one or more of the following search spaces sets

- a Type0-PDCCH common search space set configured by *searchSpaceZero* in *MasterInformationBlock* or by *searchSpaceSIB1* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on a primary cell;
- a Type0A-PDCCH common search space set configured by *searchSpace-OSI* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a SI-RNTI on a primary cell;
- a Type1-PDCCH common search space set configured by *ra-SearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a RA-RNTI, or a TC-RNTI on a primary cell;
- a Type2-PDCCH common search space set configured by *pagingSearchSpace* in *PDCCH-ConfigCommon* for a DCI format with CRC scrambled by a P-RNTI on a primary cell;
- a Type3-PDCCH common search space set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = common* for DCI formats with CRC scrambled by INT-RNTI, or SFI-RNTI, or TPC-PUSCH-RNTI, or TPC-PUCCH-RNTI, or TPC-SRS-RNTI and, only for the primary cell, C-RNTI, or CS-RNTI(s); and
- a UE-specific search space set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = ue-Specific* for DCI formats with CRC scrambled by C-RNTI, or CS-RNTI(s).

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

If a UE is not provided by dedicated higher layer signaling a control resource set for Type0A-PDCCH common search space or for Type2-PDCCH common search space, the corresponding control resource set is same as the control resource set for Type0-PDCCH common search space. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level for Type0A-PDCCH common search space or for Type2-PDCCH common search space 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 *ra-ControlResourceSet* and a configuration for a search space by higher layer parameter *ra-SearchSpace*. If higher layer parameter *ra-ControlResourceSet* 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 *searchSpaceOtherSystemInformation* for Type0A-PDCCH common search space set, the association between PDCCH monitoring occasions for Type0A-PDCCH common search space set and the SS/PBCH block index are same as the association of PDCCH monitoring occasions for Type0-PDCCH common search space set as described in Subclause 13. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level are given in Table 10.1-1.

If a UE is not provided higher layer parameter *pagingSearchSpace* for Type2-PDCCH common search space set, the association between PDCCH monitoring occasions for Type2-PDCCH common search space set and the SS/PBCH block index are same as the association of PDCCH monitoring occasions for Type0-PDCCH common search space set as described in Subclause 13. The CCE aggregation levels and the number of PDCCH candidates per CCE aggregation level are given in Table 10.1-1.

The UE may assume that the DM-RS antenna port associated with PDCCH receptions in the control resource set configured by *pdccch-ConfigSIB1* in *MasterInformationBlock* and for corresponding PDSCH receptions, and the corresponding SS/PBCH block are quasi co-located with respect to average gain, QCL-TypeA, and QCL-TypeD properties, when applicable [6, TS 38.214]. The value for the DM-RS scrambling sequence initialization is the cell ID. A subcarrier spacing is provided by higher layer parameter *subCarrierSpacingCommon* in *MasterInformationBlock*.

For single cell operation or for operation with carrier aggregation in a same frequency band, a UE is not expected to monitor a PDCCH for Type0/0A/2/3-PDCCH common search space if the SS/PBCH block or the CSI-RS the UE selects for PRACH association, as described in Subclause 8.1, does not have same QCL-TypeD [6, TS 38.214] with a DM-RS for monitoring the PDCCH for Type0/0A/2/3-PDCCH common search space.

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

If a UE is provided one or more search space sets by corresponding one or more higher layer parameters *searchSpaceZero*, *searchSpaceSIB1*, *searchSpaceOtherSystemInformation*, *pagingSearchSpace*, *ra-SearchSpace*, and the UE is provided with a C-RNTI or a CS-RNTI, the UE monitors PDCCH candidates for DCI format 0\_0 and DCI format 1\_0 with the C-RNTI or the CS-RNTI in the one or more search space sets.

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

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

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

- a control resource set index  $p$ ,  $0 \leq p < 12$ , by higher layer parameter *controlResourceSetId*;
- a DM-RS scrambling sequence initialization value by higher layer parameter *pdccch-DMRS-ScramblingID*;
- a precoder granularity for a number of REGs in the frequency domain where the UE can assume use of a same DM-RS precoder by higher layer parameter *precoderGranularity*;
- a number of consecutive symbols provided by higher layer parameter *duration*;
- a set of resource blocks provided by higher layer parameter *frequencyDomainResources*;
- CCE-to-REG mapping parameters provided by higher layer parameter *cce-REG-MappingType*;
- an antenna port quasi co-location, from a set of antenna port quasi co-locations provided by higher layer parameter *TCI-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\_1 transmitted by a PDCCH in control resource set  $p$ , by higher layer parameter *TCI-PresentInDCI*.

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

For each control resource set in a DL BWP of a serving cell, a respective higher layer parameter *frequencyDomainResources* provides a bitmap. The bits of the bitmap have a one-to-one mapping with non-overlapping groups of 6 PRBs, in ascending order of the PRB index in the DL BWP bandwidth of  $N_{RB}^{BWP}$  PRBs with starting position  $N_{BWP}^{start}$  where the first PRB of the first group of 6 PRBs has index  $6 \cdot \lceil N_{BWP}^{start} / 6 \rceil$ . A group of 6 PRBs is allocated to a control resource set if a corresponding bit value in the bitmap is 1; else, if a corresponding bit value in the bitmap is 0, the group of 6 PRBs is not allocated to the control resource set.

If a UE has received initial configuration of more than one TCI states by higher layer parameter *TCI-StatesPDCCH* but has not received a MAC CE activation command for one of the TCI states, the UE assumes that the DM-RS antenna port associated with PDCCH reception is quasi co-located with the SS/PBCH block the UE identified during the initial access procedure.

If the UE has received a MAC CE activation command for one of the TCI states, the UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.

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

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

- a search space set index  $s$ ,  $0 \leq s < 40$ , by higher layer parameter *searchSpaceId*;
- an association between the search space set  $s$  and a control resource set  $p$  by higher layer parameter *controlResourceSetId*;
- a PDCCH monitoring periodicity of  $k_{p,s}$  slots and a PDCCH monitoring offset of  $o_{p,s}$  slots, by higher layer parameter *monitoringSlotPeriodicityAndOffset*;
- a PDCCH monitoring pattern within a slot, indicating first symbol(s) of the control resource set within a slot for PDCCH monitoring, by higher layer parameter *monitoringSymbolsWithinSlot*;
- a number of PDCCH candidates  $M_{p,s}^{(L)}$  per CCE aggregation level  $L$  by higher layer parameters *aggregationLevel1*, *aggregationLevel2*, *aggregationLevel4*, *aggregationLevel8*, and *aggregationLevel16*, for CCE aggregation level 1, CCE aggregation level 2, CCE aggregation level 4, CCE aggregation level 8, and CCE aggregation level 16, respectively;
- an indication that search space set  $s$  is either a common search space set or a UE-specific search space set by higher layer parameter *searchSpaceType*;
- if search space set  $s$  is a common search space set,
  - an indication by higher layer parameter *dci-Format0-0-AndFormat1-0* to monitor PDCCH candidates for DCI format 0\_0 and DCI format 1\_0 with CRC scrambled by a C-RNTI or a CS-RNTI (if configured), RA-RNTI, TC-RNTI, P-RNTI, SI-RNTI;
  - an indication by higher layer parameter *dci-Format2-0* to monitor one or two PDCCH candidates for DCI format 2\_0 and a corresponding CCE aggregation level;
  - an indication by higher layer parameter *dci-Format2-1* to monitor PDCCH candidates for DCI format 2\_1;
  - an indication by higher layer parameter *dci-Format2-2* to monitor PDCCH candidates for DCI format 2\_2;
  - an indication by higher layer parameter *dci-Format2-3* to monitor PDCCH candidates for DCI format 2\_3;
- if search space set  $s$  is a UE-specific search space set, an indication by higher layer parameter *dci-Formats* to monitor PDCCH candidate either for DCI format 0\_0 and DCI format 1\_0, or for DCI format 0\_1 and DCI format 1\_1.

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

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

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

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

A UE determines a PDCCH monitoring occasion from the PDCCH monitoring periodicity, the PDCCH monitoring offset, and the PDCCH monitoring pattern within a slot. For search space set  $s$  in control resource set  $p$ , the UE

determines that a PDCCH monitoring occasion(s) exists in a slot with number  $n_{s,f}^{\mu}$  [4, TS 38.211] in a frame with number  $n_f$  if  $(n_f \cdot N_{\text{slot}}^{\text{frame},\mu} + n_{s,f}^{\mu} - o_{p,s}) \bmod k_{p,s} = 0$ . If the UE is provided higher layer parameter *duration*, the UE monitors PDCCH for search space set  $s$  in control resource set  $p$  for  $T_{p,s}$  consecutive slots, starting from slot  $n_{s,f}^{\mu}$ , and does not monitor PDCCH for search space set  $s$  in control resource set  $p$  for the next  $k_{p,s} - T_{p,s}$  consecutive slots.

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

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

For a DL BWP of a serving cell on which a UE monitors PDCCH candidates in a UE-specific search space, if the UE is not configured with a carrier indicator field, the UE monitors the PDCCH candidates without carrier indicator field. For a serving cell on which a UE monitors PDCCH candidates in a UE-specific search space, if a UE is configured with a carrier indicator field, the UE monitors the PDCCH candidates with carrier indicator field.

A UE 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 monitors PDCCH candidates at least for the same serving cell.

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

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

where

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

for a UE-specific search space,  $Y_{p,n_{s,f}^{\mu}} = (A_p \cdot Y_{p,n_{s,f}^{\mu}-1}) \bmod D$ ,  $Y_{p,-1} = n_{\text{RNTI}} \neq 0$ ,  $A_0 = 39827$  for  $p \bmod 3 = 0$ ,  $A_1 = 39829$  for  $p \bmod 3 = 1$ ,  $A_2 = 39839$  for  $p \bmod 3 = 2$ , and  $D = 65537$ ;

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

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

$m_{s,n_{CI}} = 0, \dots, M_{p,s,n_{CI}}^{(L)} - 1$ , 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  $n_{\text{RNTI}}$  is defined in [5, TS 38.212] and in [6, TS 38.214].

A UE that is configured for operation with carrier aggregation, and indicates support of search space sharing through higher layer parameter *searchSpaceSharingCA-UL*, and has a PDCCH candidate with CCE aggregation level  $L$  in

control resource set  $p$  for a DCI format 0\_1 having a first size and associated with serving cell  $n_{CI,2}$ , can receive a corresponding PDCCH through a PDCCH candidate with CCE aggregation level  $L$  in control resource set  $p$  for a DCI format 0\_1 having a second size and associated with serving cell  $n_{CI,1}$  if the first size and the second size are same. A UE that is configured for operation with carrier aggregation, and indicates support of search space sharing through higher layer parameter *searchSpaceSharingCA-DL*, and has a PDCCH candidate with CCE aggregation level  $L$  in control resource set  $p$  for a DCI format 1\_1 having a first size and associated with serving cell  $n_{CI,2}$ , can receive a corresponding PDCCH through a PDCCH candidate with CCE aggregation level  $L$  in control resource set  $p$  for a DCI format 1\_1 having a second size and associated with serving cell  $n_{CI,1}$  if the first size and the second size are same.

A PDCCH candidate with index  $m_{s_j, n_{CI}}$  for a search space set  $s_j$  using a set of CCEs in a control resource set  $p$  for serving cell  $n_{CI}$  is not counted as a monitored PDCCH candidate if there is a PDCCH candidate with index  $m_{s_i, n_{CI}}$  for a search space set  $s_i < s_j$  in the control resource set  $p$  for serving cell  $n_{CI}$  using a same set of CCEs, have identical scrambling, and the corresponding DCI formats for the PDCCH candidates have a same size; otherwise, the PDCCH candidate with index  $m_{s_j, n_{CI}}$  is counted as a monitored PDCCH candidate.

Table 10.1-2 provides the maximum number of monitored PDCCH candidates,  $M_{PDCCH}^{\max, \text{slot}, \mu}$ , for subcarrier spacing configuration  $\mu$  for a UE per slot for operation with a single serving cell.

**Table 10.1-2: Maximum number  $M_{PDCCH}^{\max, \text{slot}, \mu}$  of monitored PDCCH candidates per slot for subcarrier spacing configuration  $\mu \in \{0, 1, 2, 3\}$  for a single serving cell**

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

Table 10.1-3 provides the maximum number of non-overlapped CCEs,  $C_{PDCCH}^{\max, \text{slot}, \mu}$ , for subcarrier spacing configuration  $\mu$  that a UE is expected to monitor per slot for operation with a single serving cell.

CCEs are non-overlapped if they correspond to

- different control resource set indexes, or
- different first symbols for the reception of the respective PDCCH candidates.

**Table 10.1-3: Maximum number  $C_{PDCCH}^{\max, \text{slot}, \mu}$  of non-overlapped CCEs per slot for subcarrier spacing configuration  $\mu \in \{0, 1, 2, 3\}$  for a single serving cell**

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

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

If a UE is capable for operation with carrier aggregation with more than 4 downlink cells, and the UE indicates through *pdccch-BlindDetectionCA* a capability to monitor PDCCH candidates for  $N_{\text{cells}}^{\text{cap}} \geq 4$  downlink cells, and the UE is configured with  $N_{\text{cells}}^{\text{DL},\mu}$  with subcarrier spacing configuration  $\mu$ , and for scheduling on a same cell, the UE is expected

to be able to monitor a total of  $M_{\text{PDCCH}}^{\text{total},\mu} = \min \left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} / \sum_{\mu=0}^3 N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\}$  PDCCH

candidates for DCI formats with different size and/or different corresponding DM-RS scrambling sequences per slot over the  $N_{\text{cells}}^{\text{DL},\mu}$  cells with subcarrier spacing configuration  $\mu$ , and a total of

$$C_{\text{PDCCH}}^{\text{total},\mu} = \min \left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} / \sum_{\mu=0}^3 N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\} \text{ non-overlapped CCEs per slot over the } N_{\text{cells}}^{\text{DL},\mu}$$

cells with subcarrier spacing configuration  $\mu$ . The maximum number of PDCCH candidates for DCI formats with different size and/or different corresponding DM-RS scrambling sequences and the maximum number of non-overlapped CCEs per slot and per cell of the  $N_{\text{cells}}^{\text{DL},\mu}$  cells are  $M_{\text{PDCCH}}^{\text{max,slot},\mu}$  and  $C_{\text{PDCCH}}^{\text{max,slot},\mu}$ , respectively.

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

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

For same cell scheduling, a UE does not expect a number of PDCCH candidates for DCI formats with different size and/or different corresponding DM-RS scrambling sequences, and a number of corresponding non-overlapped CCEs per slot on a secondary cell to be larger than the corresponding numbers that the UE is capable of monitoring on the secondary cell per slot.

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

Denote by  $M_{P_{\text{css}}(i), S_{\text{css}}(i)}^{(L), \text{monitor}}$  a number of monitored PDCCH candidates,  $0 \leq i < I_{\text{css}}$ , from the  $M_{P_{\text{css}}(i), S_{\text{css}}(i)}^{(L)}$  PDCCH candidates for common search space set  $S_{\text{css}}(i)$  in corresponding control resource set  $P_{\text{css}}(i)$  and by  $M_{P_{\text{uss}}(j), S_{\text{uss}}(j)}^{(L), \text{monitor}}$  a number of monitored PDCCH candidates,  $0 \leq j < J_{\text{uss}}$ , from the  $M_{P_{\text{uss}}(j), S_{\text{uss}}(j)}^{(L)}$  PDCCH candidates for UE-specific search space set  $S_{\text{uss}}(j)$  in corresponding control resource set  $P_{\text{uss}}(j)$ .

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

The UE allocates monitored PDCCH candidates to UE-specific search space sets of the primary cell with subcarrier spacing configuration  $\mu$  in slot  $n$  according to the following pseudocode. A UE is not expected to monitor PDCCH in a UE-specific search space set without monitored PDCCH candidates.

Denote by  $V_{\text{CCE}}(S_{\text{uss}}(j))$  the set of non-overlapping CCEs for search space set  $S_{\text{uss}}(j)$  and by  $\ell(V_{\text{CCE}}(S_{\text{uss}}(j)))$  the cardinality of  $V_{\text{CCE}}(S_{\text{uss}}(j))$  where the non-overlapping CCEs for search space set  $S_{\text{uss}}(j)$  are determined considering



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

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

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

Set  $j = 0$

while  $\sum_L M_{P_{\text{uss}}(j), S_{\text{uss}}(j)}^{(L), \text{monitor}} \leq M_{\text{PDCCH}}^{\text{uss}}$  AND  $\mathcal{C}(V_{\text{CCE}}(S_{\text{uss}}(j))) \leq C_{\text{PDCCH}}^{\text{uss}}$

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

$$M_{\text{PDCCH}}^{\text{uss}} = M_{\text{PDCCH}}^{\text{uss}} - \sum_L M_{P_{\text{uss}}(j), S_{\text{uss}}(j)}^{(L), \text{monitor}};$$

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

$j = j + 1$ ;

end while

A UE configured with a bandwidth part indicator in DCI formats 0\_1 or 1\_1 determines, in case of an active DL BWP or of an active UL BWP change, the DCI information applicable to the new active DL BWP or UL BWP, respectively, as described in Subclause 12.

For unpaired spectrum operation, if a UE is not configured for PUSCH/PUCCH transmission on serving cell  $c_2$ , the UE 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  $c_2$ .

If a UE is provided higher layer parameters *resourceblocks* and *symbolsInResourceBlock* in *RateMatchPattern*, or if the UE is additionally provided higher layer parameter *periodicityAndPattern* in *RateMatchPattern*, the UE can determine a set of RBs in symbols of a slot that are not available for PDSCH reception as described in [6, TS 38.214]. If a PDCCH candidate in a slot is mapped to one or more subcarriers that overlap with subcarriers of any RB in the set of RBs in symbols of the slot, the UE is not expected to monitor the PDCCH candidate.

## 10.2 PDCCH validation for DL SPS and UL grant Type 2

A UE validates, for scheduling activation or scheduling release, a DL SPS assignment PDCCH or configured UL grant Type 2 PDCCH if

- the CRC parity bits of a corresponding DCI format are scrambled with a CS-RNTI provided by higher layer parameter *cs-RNTI*, and
- the new data indicator field for the enabled transport block is set to '0'.

Validation of the DCI format is achieved if all fields for the DCI format are set according to Table 10.2-1 or Table 10.2-2.

If validation is achieved, the UE considers the information in the DCI format as a valid activation or valid release of DL SPS or configured UL grant Type 2. If validation is not achieved, the UE considers the DCI format as having been detected with a non-matching CRC.

**Table 10.2-1: Special fields for DL SPS and UL grant Type 2 scheduling activation PDCCH validation**

	DCI format 0_0/0_1	DCI format 1_0	DCI format 1_1
HARQ process number	set to all '0's	set to all '0's	set to all '0's
Redundancy version	set to '00'	set to '00'	For the enabled transport block: set to '00'

**Table 10.2-2: Special fields for DL SPS and UL grant Type 2 scheduling release PDCCH validation**

	DCI format 0_0	DCI format 1_0
HARQ process number	set to all '0's	set to all '0's
Redundancy version	set to '00'	set to '00'
Modulation and coding scheme	set to all '1's	set to all '1's
Resource block assignment	set to all '1's	set to all '1's

A UE with capability 1 [6, TS 36.214] is expected to be able to provide HARQ-ACK information in response to a DL SPS scheduling release after  $N$  symbols from the last symbol of a PDCCH providing the DL SPS scheduling release where, for the subcarrier spacing of the PDCCH reception,  $N = 10$  for 15 kHz,  $N = 12$  for 30 kHz,  $N = 22$  for 60 kHz, and  $N = 25$  for 120 kHz.

## 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 *tdd-UL-DL-ConfigurationCommon* and the UE is not provided higher layer parameter *tdd-UL-DL-ConfigurationCommon2*, the UE sets the slot format per slot over a number of slots as indicated by higher layer parameter *tdd-UL-DL-ConfigurationCommon*.

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

- A reference subcarrier spacing  $\mu_{\text{ref}}$  by higher layer parameter *referenceSubcarrierSpacing*
- A slot configuration period of  $P$  msec by higher layer parameter *dl-UL-TransmissionPeriodicity*
- A number of slots  $d_{\text{slots}}$  with only downlink symbols by higher layer parameter *nrofDownlinkSlots*
- A number of downlink symbols  $d_{\text{sym}}$  by higher layer parameter *nrofDownlinkSymbols*
- A number of slots  $u_{\text{slots}}$  with only uplink symbols by higher layer parameter *nrofUplinkSlots*
- A number of uplink symbols  $u_{\text{sym}}$  by higher layer parameter *nrofUplinkSymbols*

A value  $P = 0.625$  msec is valid only for  $\mu_{\text{ref}} = 3$ . A value  $P = 1.25$  msec is valid only for  $\mu_{\text{ref}} = 2$  or  $\mu_{\text{ref}} = 3$ . A value  $P = 2.5$  msec is valid only for  $\mu_{\text{ref}} = 1$ , or  $\mu_{\text{ref}} = 2$ , or  $\mu_{\text{ref}} = 3$ .

A slot configuration period of  $P$  msec includes  $S = P \cdot 2^{\mu_{\text{ref}}}$  slots with  $\mu_{\text{ref}}$  subcarrier spacing. From the  $S$  slots, a first  $d_{\text{slots}}$  slots include only downlink symbols and a last  $u_{\text{slots}}$  slots include only uplink symbols. The  $d_{\text{sym}}$  symbols after the first  $d_{\text{slots}}$  slots are downlink symbols. The  $u_{\text{sym}}$  symbols before the last  $u_{\text{slots}}$  slots are uplink symbols. The remaining  $(S - d_{\text{slots}} - u_{\text{slots}}) \cdot N_{\text{symb}}^{\text{slot}} - d_{\text{sym}} - u_{\text{sym}}$  are flexible symbols.

The first symbol every  $20/P$  periods is a first symbol in an even frame.

A UE expects that the reference subcarrier spacing  $\mu_{\text{ref}}$  is smaller than or equal to the subcarrier spacing  $\mu$  for any of the configured DL BWP or UL BWP.

If the UE is provided higher layer parameters *tdd-UL-DL-ConfigurationCommon* and *tdd-UL-DL-ConfigurationCommon2*, the UE sets the slot format per slot over a first number of slots as indicated by higher layer parameter *tdd-UL-DL-ConfigurationCommon* and the UE sets the slot format per slot over a second number of slots as indicated by *tdd-UL-DL-ConfigurationCommon2*.

The higher layer parameter *tdd-UL-DL-ConfigurationCommon2* provides

- A reference subcarrier spacing  $\mu_{\text{ref},2}$  by higher layer parameter *referenceSubcarrierSpacing*;
- A slot configuration period of  $P_2$  msec by higher layer parameter *dl-UL-TransmissionPeriodicity*;
- A number of slots  $d_{\text{slots},2}$  with only downlink symbols by higher layer parameter *nrofDownlinkSlots*;
- A number of downlink symbols  $d_{\text{sym},2}$  by higher layer parameter *nrofDownlinkSymbols*;
- A number of slots  $u_{\text{slots},2}$  with only uplink symbols by higher layer parameter *nrofUplinkSlots*;
- A number of uplink symbols  $u_{\text{sym},2}$  by higher layer parameter *nrofUplinkSymbols*.

A UE expects  $\mu_{\text{ref},2} = \mu_{\text{ref}}$ .

A value  $P_2 = 0.625$  msec is valid only for  $\mu_{\text{ref},2} = 3$ . A value  $P_2 = 1.25$  msec is valid only for  $\mu_{\text{ref},2} = 2$  or  $\mu_{\text{ref},2} = 3$ . A value  $P_2 = 2.5$  msec is valid only for  $\mu_{\text{ref},2} = 1$ , or  $\mu_{\text{ref},2} = 2$ , or  $\mu_{\text{ref},2} = 3$ .

A slot configuration period of  $P + P_2$  slots includes first  $S = P \cdot 2^{\mu_{\text{ref}}}$  slots and second  $S_2 = P_2 \cdot 2^{\mu_{\text{ref}}}$  slots. From the  $S_2$  slots, a first  $d_{\text{slots},2}$  slots include only downlink symbols and a last  $u_{\text{slots},2}$  include only uplink symbols. The  $d_{\text{sym},2}$  symbols after the first  $d_{\text{slots},2}$  slots are downlink symbols. The  $u_{\text{sym},2}$  symbols before the last  $u_{\text{slots},2}$  slots are uplink symbols. The remaining  $(S_2 - d_{\text{slots},2} - u_{\text{slots},2}) \cdot N_{\text{symb}}^{\text{slot}} - d_{\text{sym},2} - u_{\text{sym},2}$  are flexible symbols.

A UE expects that  $P + P_2$  divides 20 msec.

The first symbol every  $20/(P + P_2)$  periods is a first symbol in an even frame.

If the UE is additionally provided higher layer parameter *tdd-UL-DL-ConfigDedicated*, the parameter *tdd-UL-DL-ConfigDedicated* overrides only flexible symbols per slot over the number of slots as provided by *tdd-UL-DL-ConfigurationCommon* or *tdd-UL-DL-ConfigurationCommon2*.

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

- A set of slot configurations by higher layer parameter *slotSpecificConfigurationsToAddModList*;
- For each slot configuration from the set of slot configurations
  - A slot index for a slot provided by higher layer parameter *slotIndex*;

- A set of symbols for a slot by higher layer parameter *symbols* where
  - if *symbols* = *allDownlink*, all symbols in the slot are downlink;
  - if *symbols* = *allUplink*, all symbols in the slot are uplink;
  - if *symbols* = *explicit* and higher layer parameter *nrofDownlinkSymbols* provides a number of downlink first symbols in the slot and higher layer parameter *nrofUplinkSymbols* provides a number of uplink last symbols in the slot. If *nrofDownlinkSymbols* is not provided, there are no downlink first symbols in the slot and if *nrofUplinkSymbols* is not provided, there are no uplink last symbols in the slot. The remaining symbols in the slot are flexible.

For each slot having a corresponding index provided by higher layer parameter *slotIndex*, the UE applies a format provided by the corresponding higher layer parameter *symbols*. The UE does not expect *tdd-UL-DL-ConfigDedicated* to indicate as uplink or as downlink a symbol that *tdd-UL-DL-ConfigurationCommon* or, when provided, *tdd-UL-DL-ConfigurationCommon2* indicates as a downlink or as an uplink symbol, respectively.

For each slot configuration provided by *tdd-UL-DL-ConfigDedicated*, a reference subcarrier spacing is the reference subcarrier spacing  $\mu_{\text{ref}}$  provided by *tdd-UL-DL-ConfigurationCommon*.

A slot configuration period and a number of downlink symbols, uplink symbols, and flexible symbols in each slot of the slot configuration period are determined from higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2* and *tdd-UL-DL-ConfigDedicated* and are common to each configured BWP.

A UE considers symbols in a slot indicated as downlink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated* to be available for receptions and considers symbols in a slot indicated as uplink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or by *tdd-UL-DL-ConfigDedicated* to be available for transmissions.

If a UE is not configured to monitor PDCCH for DCI format 2-0, for a set of symbols of a slot that are indicated as flexible by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to a UE, or when *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, and *tdd-UL-DL-ConfigDedicated* are not provided to the UE.

- The UE receives PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1.
- The UE transmits PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3.
- If 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 receives the PDCCH, the PDSCH, or the CSI-RS if
  - the UE does not detect a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 that indicates to the UE to transmit a PUSCH, a PUCCH, a PRACH, or a SRS in the set of symbols of the slot, or
  - the UE detects a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 that indicates to the UE to transmit a PUSCH, a PUCCH, a PRACH, or a SRS in the set of symbols of the slot and a number of symbols between a last symbol of a control resource set where the UE detects the DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 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].

Otherwise, the UE does not receive the PDCCH, or the PDSCH, or the CSI-RS 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 transmits 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 1\_0, DCI format 1\_1, or DCI format 0\_1 that indicates to the UE to receive PDSCH or CSI-RS in the set of symbols in the slot, or

- the UE detects a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1 that indicates to the UE to receive PDSCH or CSI-RS in the set of symbols in the slot and a number of symbols between a last symbol of a control resource set where the UE detects the DCI format 1\_0 or DCI format 1\_1 and a first symbol in the set of symbols is smaller than the PUSCH preparation time  $N_2$  for the corresponding PUSCH timing capability.

Otherwise, the UE does not transmit the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in the set of symbols of the slot.

A PUSCH preparation time  $N_2$  throughout Subclause 11.1 is defined with respect to the subcarrier spacing of the PDCCH providing the corresponding DCI format.

For a set of symbols of a slot that are indicated to a UE as uplink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to the UE, the UE does not receive PDCCH, PDSCH, or CSI-RS in the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE as downlink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to the UE, the UE does not transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE as flexible by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to the UE, the UE does not expect to receive both dedicated higher layer parameters configuring transmission from the UE in the set of symbols of the slot and dedicated higher layer parameters configuring reception by the UE in the set of symbols of the slot.

For a set of symbols of a slot that are indicated to a UE by higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon*, when provided to the UE, for reception of SS/PBCH blocks, the UE does not transmit PUSCH, PUCCH, PRACH in the slot if a transmission would overlap with any symbol from the set of symbols and the UE does not transmit SRS in the set of symbols of the slot. The UE does not expect the set of symbols of the slot to be indicated as uplink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to the UE.

For a set of symbols of a slot corresponding to a valid PRACH occasion and  $N_{\text{gap}}$  symbols before the valid PRACH occasion, as described in Subclause 8.1, the UE does not receive PDCCH for Type1-PDCCH common search space, PDSCH, or CSI-RS in the slot if a reception would overlap with any symbol from the set of symbols. The UE does not expect the set of symbols of the slot to be indicated as downlink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*.

For a set of symbols of a slot indicated to a UE by higher layer parameters *pdccch-ConfigSIB1* in *MasterInformationBlock* for a control resource set for Type0-PDCCH common search space, the UE does not expect the set of symbols to be indicated as uplink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*.

If a UE is scheduled by a DCI format 1\_1 to receive PDSCH over multiple slots, and if higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to the UE, indicate that, for a slot from the multiple slots, at least one symbol from a set of symbols where the UE is scheduled PDSCH reception in the slot is an uplink symbol, the UE does not receive the PDSCH in the slot.

If a UE is scheduled by a DCI format 0\_1 to transmit PUSCH over multiple slots, and if higher layer parameter *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to a UE, indicates that, for a slot from the multiple slots, at least one symbol from a set of symbols where the UE is scheduled PUSCH transmission in the slot is a downlink symbol, the UE does not transmit the PUSCH in the slot.

### 11.1.1 UE procedure for determining slot format

This subclause applies for a serving cell that is included in a set of serving cells configured to a UE by higher layer parameters *slotFormatCombToAddModList* and *slotFormatCombToReleaseList*.

If a UE is configured by higher layers with parameter *SlotFormatIndicator*, the UE is provided with a SFI-RNTI by higher layer parameter *sfi-RNTI* and with a payload size of DCI format 2\_0 by higher layer parameter *dci-PayloadSize*.

The UE is also provided in one or more serving cells with a configuration for a search space set  $s$  and a corresponding control resource set  $p$  for monitoring  $M_{p,s}^{(L_{\text{SFI}})}$  PDCCH candidates for DCI format 2\_0 with a CCE aggregation level of  $L_{\text{SFI}}$  CCEs as described in Subclause 10.1. The  $M_{p,s}^{(L_{\text{SFI}})}$  PDCCH candidates are the first  $M_{p,s}^{(L_{\text{SFI}})}$  PDCCH candidates for CCE aggregation level  $L_{\text{SFI}}$  for search space set  $s$  in control resource set  $p$ .

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

- an identity of the serving cell by higher layer parameter *servingCellId*
- a location of a SFI-index field in DCI format 2\_0 by higher layer parameter *positionInDCI*
- a set of slot format combinations by higher layer parameter *slotFormatCombinations*, where each slot format combination in the set of slot format combinations includes
  - one or more slot formats indicated by a respective higher layer parameter *slotFormats* for the slot format combination, and
  - a mapping for the slot format combination provided by *slotFormats* to a corresponding SFI-index field value in DCI format 2\_0 provided by higher layer parameter *slotFormatCombinationId*
- for unpaired spectrum operation, a reference subcarrier spacing  $\mu_{\text{SFI}}$  by higher layer parameter *subcarrierSpacing* and, when a supplementary UL carrier is configured for the serving cell, a reference subcarrier spacing  $\mu_{\text{SFI,SUL}}$  by higher layer parameter *subcarrierSpacing2* for the supplementary UL carrier
- for paired spectrum operation, a reference subcarrier spacing  $\mu_{\text{SFI,DL}}$  for a DL BWP by higher layer parameter *subcarrierSpacing* and a reference subcarrier spacing  $\mu_{\text{SFI,UL}}$  for an UL BWP by higher layer parameter *subcarrierSpacing2*

A SFI-index field value in a DCI format 2\_0 indicates to a UE a slot format for each slot in a number of slots for each DL BWP or each UL BWP starting from a slot where the UE detects the DCI format 2\_0. The number of slots is equal to or larger than a PDCCH monitoring periodicity for DCI format 2\_0. The SFI-index field includes

$\log_2(\text{maxSFIindex})$  bits where maxSFIindex is the maximum value of the values provided by corresponding higher layer parameters *slotFormatCombinationId*. A slot format is identified by a corresponding format index as provided in Table 11.1.1-1 where 'D' denotes a downlink symbol, 'U' denotes an uplink symbol, and 'F' denotes a flexible symbol.

If a PDCCH monitoring periodicity for DCI format 2\_0, provided to a UE for the search space set  $s$  by higher layer parameter *monitoringSlotPeriodicityAndOffset*, is smaller than a duration of a slot format combination the UE obtains at a PDCCH monitoring occasion for DCI format 2\_0 by a corresponding SFI-index field value, and the UE detects more than one DCI formats 2\_0 indicating a slot format for a slot, the UE expects each of the more than one DCI formats 2\_0 to indicate a same format for the slot.

A UE does not expect to be configured to monitor PDCCH for DCI format 2\_0 on a second serving cell that uses larger subcarrier spacing than the serving cell.

Table 11.1.1-1: Slot formats for normal cyclic prefix

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	F	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	F	U	U	U	U	U	U	U	U	U	U
37	D	F	F	U	U	U	U	U	U	U	U	U	U	U
38	D	D	F	F	U	U	U	U	U	U	U	U	U	U
39	D	D	D	F	F	U	U	U	U	U	U	U	U	U
40	D	F	F	F	U	U	U	U	U	U	U	U	U	U
41	D	D	F	F	F	U	U	U	U	U	U	U	U	U
42	D	D	D	F	F	F	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	F	F	F	F	U
44	D	D	D	D	D	D	F	F	F	F	F	F	U	U
45	D	D	D	D	D	D	F	F	U	U	U	U	U	U
46	D	D	D	D	D	F	U	D	D	D	D	D	F	U
47	D	D	F	U	U	U	U	D	D	F	U	U	U	U
48	D	F	U	U	U	U	U	D	F	U	U	U	U	U
49	D	D	D	D	F	F	U	D	D	D	D	F	F	U
50	D	D	F	F	U	U	U	D	D	F	F	U	U	U
51	D	F	F	U	U	U	U	D	F	F	U	U	U	U
52	D	F	F	F	F	F	U	D	F	F	F	F	F	U
53	D	D	F	F	F	F	U	D	D	F	F	F	F	U
54	F	F	F	F	F	F	F	D	D	D	D	D	D	D
55	D	D	F	F	F	U	U	U	D	D	D	D	D	D
56 – 254	Reserved													
255	UE determines the slot format for the slot based on <i>tdd-UL-DL-ConfigurationCommon</i> , <i>tdd-UL-DL-ConfigurationCommon2</i> , or <i>tdd-UL-DL-ConfigDedicated</i> and, if any, on detected DCI formats													

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

For paired spectrum operation for a UE on a serving cell, the SFI-index field in DCI format 2\_0 indicates a combination of slot formats that includes a combination of slot formats for a reference DL BWP and a combination of slot formats for a reference UL BWP of the serving cell. The UE is provided by higher layer parameter *subcarrierSpacing* a reference subcarrier spacing configuration of  $\mu_{\text{SFI, DL}}$  for the combination of slot formats indicated by the SFI-index field value in DCI format 2\_0 for the reference DL BWP of the serving cell. The UE is provided by higher layer parameter *subcarrierSpacing2* a reference subcarrier spacing configuration of  $\mu_{\text{SFI, UL}}$  for the combination of slot formats indicated by the SFI-index field value in DCI format 2\_0 for the reference UL BWP of the serving cell. If  $\mu_{\text{SFI, DL}} \geq \mu_{\text{SFI, UL}}$  and for each  $2^{(\mu_{\text{SFI, DL}} - \mu_{\text{SFI, UL}})} + 1$  values provided by a value of higher layer parameter *slotFormats*, where the value of *slotFormats* is determined by a value of *slotFormatCombinationId* in *slotFormatCombination* and the value of *slotFormatCombinationId* is set by the value of the SFI-index field value in DCI format 2\_0, the first  $2^{(\mu_{\text{SFI, DL}} - \mu_{\text{SFI, UL}})}$  values for the combination of slot formats are applicable to the reference DL BWP and the next value is applicable to the reference UL BWP. If  $\mu_{\text{SFI, DL}} < \mu_{\text{SFI, UL}}$  and for each  $2^{(\mu_{\text{SFI, UL}} - \mu_{\text{SFI, DL}})} + 1$  values provided by higher layer parameter *slotFormats*, the first value for the combination of slot formats is applicable to the reference DL BWP and the next  $2^{(\mu_{\text{SFI, UL}} - \mu_{\text{SFI, DL}})}$  values are applicable to the reference UL BWP.

The UE is provided with a reference subcarrier spacing configuration of  $\mu_{\text{SFI, DL}}$  so that for an active DL BWP with subcarrier spacing configuration of  $\mu_{\text{DL}}$ , it is  $\mu_{\text{DL}} \geq \mu_{\text{SFI, DL}}$ . The UE is provided with a reference subcarrier spacing configuration of  $\mu_{\text{SFI, UL}}$  so that for an active UL BWP with subcarrier spacing configuration of  $\mu_{\text{UL}}$ , it is  $\mu_{\text{UL}} \geq \mu_{\text{SFI, UL}}$ . Each slot format for a combination of slot formats indicated by the SFI-index field value in DCI format 2\_0 for the reference DL BWP, by indicating a value for *slotFormatCombinationId* that is mapped to a value of *slotFormats* in *slotFormatCombination*, is applicable to  $2^{(\mu_{\text{DL}} - \mu_{\text{SFI, DL}})}$  consecutive slots for the active DL BWP where the first slot starts at a same time as a first slot in the reference DL BWP and each downlink or flexible symbol for the reference subcarrier spacing configuration of  $\mu_{\text{SFI, DL}}$  corresponds to  $2^{(\mu_{\text{DL}} - \mu_{\text{SFI, DL}})}$  consecutive downlink or flexible symbols for the subcarrier spacing configuration  $\mu_{\text{DL}}$ . Each slot format for the combination of slot formats for the reference UL BWP is applicable to  $2^{(\mu_{\text{UL}} - \mu_{\text{SFI, UL}})}$  consecutive slots for the active UL BWP where the first slot starts at a same time as a first slot in the reference UL BWP and each uplink or flexible symbol for the reference subcarrier spacing configuration of  $\mu_{\text{SFI, UL}}$  corresponds to  $2^{(\mu_{\text{UL}} - \mu_{\text{SFI, UL}})}$  consecutive uplink or flexible symbols for the subcarrier spacing configuration  $\mu_{\text{UL}}$ .

For unpaired spectrum operation with a second UL carrier for a UE on a serving cell, the SFI-index field value in DCI format 2\_0 indicates a combination of slot formats that includes a combination of slot formats for a reference first UL carrier of the serving cell and a combination of slot formats for a reference second UL carrier of the serving cell. The UE is provided by higher layer parameter *subcarrierSpacing* a reference subcarrier spacing configuration of  $\mu_{\text{SFI}}$  for the combination of slot formats indicated by the SFI-index field in DCI format 2\_0 for the reference first UL carrier of the serving cell. The UE is provided by higher layer parameter *subcarrierSpacing2* a reference subcarrier spacing configuration of  $\mu_{\text{SFI, SUL}}$  for the combination of slot formats indicated by the SFI-index field value in DCI format 2\_0 for the reference second UL carrier of the serving cell. For each  $2^{(\mu_{\text{SFI}} - \mu_{\text{SFI, SUL}})} + 1$  values of higher layer parameter *slotFormats*, the first  $2^{(\mu_{\text{SFI}} - \mu_{\text{SFI, SUL}})}$  values for the combination of slot formats are applicable to the reference first UL carrier and the next value is applicable to the reference second UL carrier.



The UE expects to be provided with a reference subcarrier spacing configuration of  $\mu_{\text{SFI,SUL}}$  so that for an active UL BWP in the second UL carrier with subcarrier spacing configuration of  $\mu_{\text{SUL}}$ , it is  $\mu_{\text{SUL}} \geq \mu_{\text{SFI,SUL}}$ . Each slot format for a combination of slot formats indicated by the SFI-index field in DCI format 2\_0 for the reference first UL carrier is applicable to  $2^{(\mu - \mu_{\text{SFI}})}$  consecutive slots for the active DL BWP and 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  $2^{(\mu_{\text{SUL}} - \mu_{\text{SFI,SUL}})}$  consecutive slots for the active UL BWP in the second UL carrier where the first slot starts at a same time as a first slot in the reference second UL carrier.

If a BWP in the serving cell is configured with  $\mu = 2$  and with extended CP, the UE expects  $\mu_{\text{SFI}} = 0$ ,  $\mu_{\text{SFI}} = 1$ , or  $\mu_{\text{SFI}} = 2$ . A format for a slot with extended CP is determined from a format for a slot with normal CP. A UE determines an extended CP symbol to be a downlink/uplink/flexible symbol if the overlapping normal CP symbols that are downlink/uplink/flexible symbols, respectively. A UE determines an extended CP symbol to be a flexible symbol if one of the overlapping normal CP symbols is flexible. A UE determines an extended CP symbol to be a flexible symbol if the pair of the overlapping normal CP symbols includes a downlink and an uplink symbol.

A reference subcarrier spacing configurations of  $\mu_{\text{SFI}}$ , or  $\mu_{\text{SFI,DL}}$ , or  $\mu_{\text{SFI,UL}}$ , or  $\mu_{\text{SFI,SUL}}$  is either 0, or 1, or 2 for frequency range 1 and is either 2 or 3 for frequency range 2.

For a set of symbols of a slot, a UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols of the slot as uplink and to detect a DCI format 1\_0, a DCI format 1\_1, or DCI format 0\_1 indicating to the UE to receive PDSCH or CSI-RS in the set of symbols of the slot.

For a set of symbols of a slot, a UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols in the slot as downlink and to detect a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot.

For a set of symbols of a slot that are indicated as downlink/uplink by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, or *tdd-UL-DL-ConfigDedicated*, when provided to a UE, the UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols of the slot as uplink/downlink, respectively, or as flexible.

For a set of symbols of a slot indicated to a UE by higher layer parameter *ssb-PositionsInBurst* in *SystemInformationBlockType1* or *ssb-PositionsInBurst* in *ServingCellConfigCommon* for reception of SS/PBCH blocks, the UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols of the slot as uplink.

For a set of symbols of a slot indicated to a UE by higher layer parameter *prach-ConfigurationIndex* in *RACH-ConfigCommon* for PRACH transmissions, the UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols of the slot as downlink.

For a set of symbols of a slot indicated to a UE by higher layer parameters *pdccch-ConfigSIB1* in *MasterInformationBlock* for a control resource set for Type0-PDCCH common search space, the UE does not expect to detect a DCI format 2\_0 with an SFI-index field value indicating the set of symbols of the slot as uplink.

For a set of symbols of a slot indicated to a UE as flexible by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, and *tdd-UL-DL-ConfigDedicated*, when provided to the UE, or when higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, and *tdd-UL-DL-ConfigDedicated* are not provided to the UE, and if the UE detects a DCI format 2\_0 providing a format for the slot using a slot format value other than 255

- If one or more symbols from the set of symbols are symbols in a control resource set configured to the UE for PDCCH monitoring, the UE receives PDCCH in the control resource set only if an SFI-index field value in DCI format 2\_0 indicates that the one or more symbols are downlink symbols.
- If an SFI-index field value in DCI format 2\_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1 indicating to the UE to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE receives PDSCH or CSI-RS in the set of symbols of the slot.
- If an SFI-index field value in DCI format 2\_0 indicates the set of symbols of the slot as flexible and the UE detects a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to

the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot the UE transmits the PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot.

- If an SFI-index field value in DCI format 2\_0 indicates the set of symbols of the slot as flexible, and the UE does not detect a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1 indicating to the UE to receive PDSCH or CSI-RS, or the UE does not detect a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to the UE to transmit PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot, the UE does not transmit or receive in the set of symbols of the slot.
- If the UE is configured by higher layers to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE receives the PDSCH or the CSI-RS in the set of symbols of the slot only if an SFI-index field value in DCI format 2\_0 indicates the set of symbols of the slot as downlink.
- If the UE is configured by higher layers to transmit PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE transmits the PUCCH, or the PUSCH, or the PRACH in the slot only if an SFI-index field value in DCI format 2\_0 indicates the set of symbols of the slot as uplink.
- If the UE is configured by higher layers to transmit periodic SRS in the set of symbols of the slot, the UE transmits the periodic SRS only in a subset of symbols from the set of symbols of the slot indicated as uplink symbols by an SFI-index field value in DCI format 2\_0.
- A UE does not expect to detect an SFI-index field value in DCI format 2\_0 indicating the set of symbols of the slot as downlink and also detect a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to the UE to transmit SRS, PUSCH, PUCCH, or PRACH, in one or more symbols from the set of symbols of the slot.
- A UE does not expect to detect an SFI-index field value in DCI format 2\_0 indicating the set of symbols of the slot as downlink if the set of symbols of the slot includes symbols corresponding to a first repetition of a PUSCH transmission activated by an UL Type 2 grant PDCCH as described in Subclause 10.2.
- A UE does not expect to detect an SFI-index field value in DCI format 2\_0 indicating the set of symbols of the slot as uplink and also detect a DCI format 1\_0 or DCI format 1\_1 or DCI format 0\_1 indicating to the UE to receive PDSCH or CSI-RS in one or more symbols from the set of symbols of the slot.

If a UE is configured by higher layers to receive a CSI-RS or a PDSCH in a set of symbols of a slot and the UE detects a DCI format 2\_0 with a slot format value other than 255 that indicates a slot format with a subset of symbols from the set of symbols as uplink or flexible, or the UE detects a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to the UE to transmit PUSCH, PUCCH, SRS, or PRACH in at least one symbol in the set of the symbols, the UE cancels the CSI-RS reception in the set of symbols of the slot or cancels the PDSCH reception in the slot.

If a UE is configured by higher layers to transmit periodic SRS, or PUCCH, or PUSCH, or PRACH in a set of symbols of a slot and the UE detects a DCI format 2\_0 with a slot format value other than 255 that indicates a slot format with a subset of symbols from the set of symbols as downlink or flexible, or the UE detects a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1 indicating to the UE to receive CSI-RS or PDSCH in at least one symbol in the set of symbols, then

- the UE does not expect to cancel the transmission in symbols from the subset of symbols that occur, relative to a last symbol of a control resource set where the UE detects the DCI format 2\_0, 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 PUCCH, or PUSCH, or PRACH transmission in the remaining symbols of the slot and cancels the periodic SRS transmission in the subset of symbols of the slot.

A PUSCH preparation time  $N_2$  throughout Subclause 11.1.1 is defined with respect to the subcarrier spacing of the PDCCH providing DCI format 2\_0.

A UE assumes that flexible symbols in a control resource set configured to the UE for PDCCH monitoring are downlink symbols if the UE does not detect an SFI-index field value in DCI format 2\_0 indicating the set of symbols of the slot as flexible or uplink and the UE does not detect a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3 indicating to the UE to transmit SRS, PUSCH, PUCCH, or PRACH in the set of symbols.

For a set of symbols of a slot that are indicated as flexible by higher layer parameters *tdd-UL-DL-ConfigurationCommon*, *tdd-UL-DL-ConfigurationCommon2*, and *tdd-UL-DL-ConfigDedicated*, when provided to a

UE, or when higher layer parameters *tdd-UL-DL-ConfigurationCommon*, or *tdd-UL-DL-ConfigurationCommon2*, and *tdd-UL-DL-ConfigDedicated* are not provided to the UE, and if the UE does not detect a DCI format 2\_0 providing a slot format for the slot.

- The UE receives PDSCH or CSI-RS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 1\_0, DCI format 1\_1, or DCI format 0\_1.
- The UE transmits PUSCH, PUCCH, PRACH, or SRS in the set of symbols of the slot if the UE receives a corresponding indication by a DCI format 0\_0, DCI format 0\_1, DCI format 1\_0, DCI format 1\_1, or DCI format 2\_3.
- The UE receives PDCCH as described in Subclause 11.1.
- If the UE is configured by higher layers to receive PDSCH or CSI-RS in the set of symbols of the slot, the UE does not receive the PDSCH or the CSI-RS in the set of symbols of the slot.
- If the UE is configured by higher layers to transmit periodic SRS, or PUCCH, or PUSCH, or PRACH in the set of symbols of the slot, the UE
  - does not transmit the PUCCH, or the PUSCH, or the PRACH in the slot and does not transmit the SRS in symbols from the set of symbols in the slot, if any, starting from a symbol that is a number of symbols equal to the PUSCH preparation time  $N_2$  for the corresponding PUSCH timing capability after a last symbol of a control resource set where the UE is configured to monitor PDCCH for DCI format 2\_0;
  - is not expected to cancel the transmission of the periodic SRS, or the PUCCH, or the PUSCH, or the PRACH in symbols from the set of symbols in the slot, if any, starting before a symbol that is a number of symbols equal to the PUSCH preparation time  $N_2$  for the corresponding PUSCH timing capability after a last symbol of a control resource set where the UE is configured to monitor PDCCH for DCI format 2\_0.

## 11.2 Interrupted transmission indication

If a UE is provided higher layer parameter *DownlinkPreemption*, the UE is configured with an INT-RNTI provided by higher layer parameter *int-RNTI* for monitoring PDCCH conveying DCI format 2\_1 [5, TS 38.212]. The UE is additionally configured with:

- a set of serving cells by higher layer parameter *INT-ConfigurationPerServingCell* that includes a set of serving cell indexes provided by corresponding higher layer parameters *servingCellId* and a corresponding set of locations for fields in in DCI format 2\_1 by higher layer parameter *positionInDCI*;
- an information payload size for DCI format 2\_1 by higher layer parameter *dci-PayloadSize*;
- an indication granularity for time-frequency resources by higher layer parameter *timeFrequencySet*.

If a UE detects a DCI format 2\_1 for a serving cell from the configured set of serving cells, the UE may assume that no transmission to the UE is present in PRBs and in symbols, 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  $B_{\text{INT}}$  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  $N_{\text{slot}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$  symbols prior to the first symbol of the control resource set in the slot where  $T_{\text{INT}}$  is the PDCCH monitoring periodicity provided by the value of higher layer parameter *monitoringSlotPeriodicityAndOffset*, as described in Subclause 10.1,  $N_{\text{slot}}^{\text{slot}}$  is the number of symbols per slot,  $\mu$  is the subcarrier spacing configuration for a serving cell with mapping to a respective field in the DCI format 2\_1,  $\mu_{\text{INT}}$  is the subcarrier spacing configuration of the DL BWP where the UE receives the PDCCH conveying the DCI format 2\_1. If the UE is configured with higher layer parameters *tdd-UL-DL-ConfigurationCommon* or *tdd-UL-DL-ConfigurationCommon2*, symbols indicated as uplink by *tdd-UL-DL-ConfigurationCommon* or *tdd-UL-DL-ConfigurationCommon2* are excluded from the last  $N_{\text{slot}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$  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  $N_{\text{INT}}$ .

The UE does not expect to be provided values of  $\mu$ ,  $\mu_{\text{INT}}$ , and  $T_{\text{INT}}$  resulting to a value of  $N_{\text{slot}}^{\text{slot}} \cdot T_{\text{INT}} \cdot 2^{\mu - \mu_{\text{INT}}}$  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 *timeFrequencySet*.

If the value of *timeFrequencySet* is 0, 14 bits of a field in DCI format 2\_1 have a one-to-one mapping with 14 groups of consecutive symbols from the set of symbols where each of the first  $N_{\text{INT}} - \lfloor N_{\text{INT}}/14 \rfloor \cdot 14$  symbol groups includes  $\lceil N_{\text{INT}}/14 \rceil$  symbols, each of the last  $14 - N_{\text{INT}} + \lfloor N_{\text{INT}}/14 \rfloor \cdot 14$  symbol groups includes  $\lfloor N_{\text{INT}}/14 \rfloor$  symbols, a bit value of 0 indicates transmission to the UE in the corresponding symbol group and a bit value of 1 indicates no transmission to the UE in the corresponding symbol group.

If the value of *timeFrequencySet* is 1, 7 pairs of bits of a field in the DCI format 2\_1 have a one-to-one mapping with 7 groups of consecutive symbols where each of the first  $N_{\text{INT}} - \lfloor N_{\text{INT}}/7 \rfloor \cdot 7$  symbol groups includes  $\lceil N_{\text{INT}}/7 \rceil$  symbols, each of the last  $7 - N_{\text{INT}} + \lfloor N_{\text{INT}}/7 \rfloor \cdot 7$  symbol groups includes  $\lfloor N_{\text{INT}}/7 \rfloor$  symbols, a first bit in a pair of bits for a symbol group is applicable to the subset of first  $\lceil B_{\text{INT}}/2 \rceil$  PRBs from the set of  $B_{\text{INT}}$  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  $B_{\text{INT}}$  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

A UE can be provided with

- a TPC-PUCCH-RNTI for a DCI format 2\_2 by higher layer parameter *tpc-PUCCH-RNTI*
- A field in DCI format 2\_2 is a TPC command of 2 bits mapping to  $\delta_{\text{PUCCH}, b, f, c}$  values as described in Subclause 7.2.1
- an index for a location in DCI format 2\_2 of a first bit for a TPC command field for the PCell, or the SpCell for EN-DC operation, or for a carrier of the PCell by higher layer parameter *tpc-IndexPCell*
- an index for a location in DCI format 2\_2 of a first bit for a TPC command field for the PSCell or for a carrier for the PSCell by higher layer parameter *tpc-IndexPUCCH-Scell*
- a mapping for the PUCCH power control adjustment state  $l \in \{0, 1\}$ , by a corresponding  $\{0, 1\}$  value of a closed loop index field that is appended to the TPC command field for the PCell, or for a carrier of the PCell, or for the PSCell, or for a carrier of the PSCell, in DCI format 2\_2 if the UE indicates a capability to support two PUCCH power control adjustment states by higher layer parameter *twoDifferentTPC-Loop-PUCCH*, and if the UE is configured for two PUCCH power control adjustment states by higher layer parameter *twoPUCCH-PC-AdjustmentStates*.

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

For PUSCH transmissions on an uplink carrier or on a second uplink carrier of a serving cell, a UE can be provided with

- a TPC-PUSCH-RNTI for a DCI format 2\_2 by higher layer parameter *tpc-PUSCH-RNTI*
- A field in DCI format 2\_2 is a TPC command of 2 bits mapping to  $\delta_{\text{PUSCH}, b, f, c}$  values as described in Subclause 7.1.1
- an index for a location in DCI format 2\_2 of a first bit for a TPC command field for the uplink carrier of the serving cell by higher layer parameter *tpc-Index*
- an index for a location in DCI format 2\_2 of a first bit for a TPC command field for the second uplink carrier of the serving cell by higher layer parameter *tpc-IndexSUL*

- an index of the serving cell by higher layer parameter *targetCell*. If higher layer parameter *targetCell* is not provided, the serving cell is the cell of the PDCCH reception for DCI format 2\_2
- a mapping for the PUSCH power control adjustment state  $l \in \{0, 1\}$ , by a corresponding  $\{0, 1\}$  value of a closed loop index field that is appended to the TPC command field for the uplink carrier or for the second uplink carrier of the serving cell in DCI format 2\_2 if the UE indicates a capability to support two PUSCH power control adjustment states, by higher layer parameter *twoDifferentTPC-Loop-PUSCH*, and if the UE is configured for two PUSCH power control adjustment states by higher layer parameter *twoPUSCH-PC-AdjustmentStates*.

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

## 11.4 SRS switching

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

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

- a TPC-SRS-RNTI for a DCI format 2\_3 provided by higher layer parameter *srs-TPC-RNTI*
- an index of a serving cell where the UE interrupts transmission in order to transmit SRS on one or more other serving cells by higher layer parameter *srs-SwitchFromServCellIndex*
- a DCI format 2\_3 field configuration type by higher layer parameter *typeA* or higher layer parameter *typeB*
  - for higher layer parameter *typeA*, an index for a set of serving cells is provided by higher layer parameter *cc-SetIndex*, indexes of serving cells in the set of serving cells are provided by higher layer parameter *cc-IndexInOneCC-Set*, and a DCI format 2\_3 field includes a TPC command for each serving cell from the set of serving cells and can also include a SRS request for SRS transmission on the set of serving cells
  - for higher layer parameter *typeB*, DCI format 2\_3 field includes a TPC command for a serving cell index and can also include a SRS request for SRS transmission on the serving cell - a mapping between a serving cell index for SRS transmission and a DCI format 2\_3 field is provided by higher layer parameter *srs-CellToSFI*
- an indication for a serving cell for whether or not a field in DCI format 2\_3 includes a SRS request by higher layer parameter *fieldTypeFormat2-3* where a value of 0/1 indicates absence/presence of the SRS request – a mapping for a 2 bit SRS request to SRS resource sets is as provided in [6, TS 38.214]
- an index for a location in DCI format 2\_3 of a first bit for a field by higher layer parameter *startingBitOfFormat2-3*

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## 12 Bandwidth part operation

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

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

A UE configured for operation in bandwidth parts (BWPs) of a serving cell, is configured by higher layers for the serving cell a set of at most four bandwidth parts (BWPs) for receptions by the UE (DL BWP set) in a DL bandwidth by parameter *BWP-Downlink* and a set of at most four BWPs for transmissions by the UE (UL BWP set) in an UL bandwidth by parameter *BWP-Uplink* 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 or on a

secondary cell, a UE is provided an initial active UL BWP by higher layer parameter *initialuplinkBWP*. If the UE is configured with a supplementary carrier, the UE can be provided an initial UL BWP on the supplementary carrier by higher layer parameter *initialUplinkBWP* in *supplementaryUplink*.

If a UE has dedicated BWP configuration, the UE can be provided by higher layer parameter *firstActiveDownlinkBWP-Id* a first active DL BWP for receptions and by higher layer parameter *firstActiveUplinkBWP-Id* a first active UL BWP for transmissions on the primary cell.

For each DL BWP or UL BWP in a set of DL BWPs or UL BWPs, respectively, the UE is 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 *subcarrierSpacing*;
- a cyclic prefix provided by higher layer parameter *cyclicPrefix*;
- a first PRB and a number of contiguous PRBs indicated by higher layer parameter *locationAndBandwidth* that is interpreted as RIV according to [4, TS 38.214], setting  $N_{\text{BWP}}^{\text{size}}=275$ , and the first PRB is a PRB offset relative to the PRB indicated by higher layer parameters *offsetToCarrier* and *subcarrierSpacing*;
- an index in the set of DL BWPs or UL BWPs by respective higher layer parameter *bwp-Id*;
- a set of BWP-common and a set of BWP-dedicated parameters by higher layer parameters *bwp-Common* and *bwp-Dedicated* [12, TS 38.331]

For unpaired spectrum operation, a DL BWP from the set of configured DL BWPs with index provided by higher layer parameter *bwp-Id* for the DL BWP is linked with an UL BWP from the set of configured UL BWPs with index provided by higher layer parameter *bwp-Id* for the UL BWP when the DL BWP index and the UL BWP index are equal. For unpaired spectrum operation, a UE does not expect to receive a configuration where the center frequency for a DL BWP is different than the center frequency for an UL BWP when the *bwp-Id* of the DL BWP is equal to the *bwp-Id* 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 does not expect 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 prepends zeros to the information field until its size is the one required for the interpretation of the information field for the UL BWP or DL BWP prior to interpreting the DCI format 0\_1 or DCI format 1\_1 information fields, respectively;
  - if the size of the information field is larger than the one required for the DCI format 0\_1 or DCI format 1\_1 interpretation for the UL BWP or DL BWP that is indicated by the bandwidth part indicator, respectively, the UE uses a number of least significant bits of DCI format 0\_1 or DCI format 1\_1 equal to the one required for the UL BWP or DL BWP indicated by bandwidth part indicator prior to interpreting the DCI format 0\_1 or DCI format 1\_1 information fields, respectively;

- set the active UL BWP or DL BWP to the UL BWP or DL BWP indicated by the bandwidth part indicator in the DCI format 0\_1 or DCI format 1\_1, respectively.

A UE expects to detect a DCI format 0\_1 indicating active UL BWP change, or a DCI format 1\_1 indicating active DL BWP change, only if a corresponding PDCCH is received within the first 3 symbols of a slot.

For the primary cell, a UE can be provided by higher layer parameter *defaultDownlinkBWP-Id* a default DL BWP among the configured DL BWPs. If a UE is not provided a default DL BWP by higher layer parameter *defaultDownlinkBWP-Id*, the default DL BWP is the initial active DL BWP.

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

If a UE is configured by higher layer parameter *bwp-InactivityTimer* a timer value for the primary cell [11, TS 38.321] and the timer is running, the UE increments the timer every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the UE does not detect a DCI format for PDSCH reception on the primary cell for paired spectrum operation or if the UE does not detect a DCI format for PDSCH reception or a DCI format for PUSCH transmission on the primary cell for unpaired spectrum operation during the interval [11, TS 38.321].

If a UE is configured by higher layer parameter *BWP-InactivityTimer* a timer value for a secondary cell [11, TS 38.321] and the timer is running, the UE increments the timer every interval of 1 millisecond for frequency range 1 or every 0.5 milliseconds for frequency range 2 if the UE does not detect a DCI format for PDSCH reception on the secondary cell for paired spectrum operation or if the UE does not detect a DCI format for PDSCH reception or a DCI format for PUSCH transmission on the secondary cell for unpaired spectrum operation during the interval. The UE may deactivate the secondary cell when the timer expires.

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

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

A UE does not expect to monitor PDCCH when the UE performs RRM measurements [10, TS 38.133] over a bandwidth that is not within the active DL BWP for the UE.

## 13 UE procedure for monitoring Type0-PDCCH common search space

If during cell search a UE determines that a control resource set for Type0-PDCCH common search space is present, as described in Subclause 4.1, the UE determines a number of consecutive resource blocks and a number of consecutive symbols for the control resource set of the Type0-PDCCH common search space from the four most significant bits of *pdccch-ConfigSIB1* as described in Tables 13-1 through 13-10 and determines PDCCH monitoring occasions from the four least significant bits of *pdccch-ConfigSIB1*, included in *MasterInformationBlock*, as described in Tables 13-11 through 13-15.  $SFN_C$  and  $n_C$  are the SFN and slot index within a frame of the control resource set based on subcarrier spacing of the control resource set and  $SFN_{SSB,i}$  and  $n_{SSB,i}$  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  $SFN_{SSB,i}$  and slot  $n_{SSB,i}$ .

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  $k_{SSB} = 0$  or  $k_{SSB} > 0$  [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  $n_0 = (O \cdot 2^\mu + \lfloor i \cdot M \rfloor) \bmod N_{\text{slot}}^{\text{frame}, \mu}$  located in a frame with system frame number (SFN)  $\text{SFN}_C$  satisfying  $\text{SFN}_C \bmod 2 = 0$  if  $\lfloor (O \cdot 2^\mu + \lfloor i \cdot M \rfloor) / N_{\text{slot}}^{\text{frame}, \mu} \rfloor \bmod 2 = 0$  or in a frame with SFN satisfying  $\text{SFN}_C \bmod 2 = 1$  if  $\lfloor (O \cdot 2^\mu + \lfloor i \cdot M \rfloor) / N_{\text{slot}}^{\text{frame}, \mu} \rfloor \bmod 2 = 1$ .  $M$  and  $O$  are provided by Tables 13-11 and 13-12, and  $\mu \in \{0, 1, 2, 3\}$  based on the subcarrier spacing for PDCCH receptions in the control resource set [4, TS 38.211]. The index for the first symbol of the control resource set in slot  $n_C$  is the first symbol index provided by Tables 13-11 and 13-12.

For the SS/PBCH block and control resource set multiplexing patterns 2 and 3, a UE monitors PDCCH in the Type0-PDCCH common search space over one slot with Type0-PDCCH common search space periodicity equal to the periodicity of SS/PBCH block. For the SS/PBCH block and control resource set multiplexing patterns 2 and 3, if the active DL BWP is the initial DL BWP, the UE is expected to be able to perform radio link monitoring, as described in Subclause 5, and measurements for radio resource management [10, TS 38.133] using a SS/PBCH block that provides a control resource set for Type0-PDCCH common search space. For a SS/PBCH block with index  $i$ , the UE determines the slot index  $n_C$  and  $\text{SFN}_C$  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 for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz**

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{sym}^{CORESET}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	2
2	1	24	2	4
3	1	24	3	0
4	1	24	3	2
5	1	24	3	4
6	1	48	1	12
7	1	48	1	16
8	1	48	2	12
9	1	48	2	16
10	1	48	3	12
11	1	48	3	16
12	1	96	1	38
13	1	96	2	38
14	1	96	3	38
15	Reserved			

Table 13-2: Set of resource blocks and slot symbols of control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {15, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{symb}^{CORESET}$	Offset (RBs)
Index				
0	1	24	2	5
1	1	24	2	6
2	1	24	2	7
3	1	24	2	8
4	1	24	3	5
5	1	24	3	6
6	1	24	3	7
7	1	24	3	8
8	1	48	1	18
9	1	48	1	20
10	1	48	2	18
11	1	48	2	20
12	1	48	3	18
13	1	48	3	20
14	Reserved			
15	Reserved			

**Table 13-3: Set of resource blocks and slot symbols of control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 15} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz**

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{symbol}^{CORESET}$	Offset (RBs)
0	1	48	1	2
1	1	48	1	6
2	1	48	2	2
3	1	48	2	6
4	1	48	3	2
5	1	48	3	6
6	1	96	1	28
7	1	96	2	28
8	1	96	3	28
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

**Table 13-4: Set of resource blocks and slot symbols of control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 30} kHz for frequency bands with minimum channel bandwidth 5 MHz or 10 MHz**

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{symbol}^{CORESET}$	Offset (RBs)
0	1	24	2	0
1	1	24	2	1
2	1	24	2	2
3	1	24	2	3
4	1	24	2	4
5	1	24	3	0
6	1	24	3	1
7	1	24	3	2
8	1	24	3	3
9	1	24	3	4
10	1	48	1	12
11	1	48	1	14
12	1	48	1	16
13	1	48	2	12
14	1	48	2	14
15	1	48	2	16

**Table 13-5: Set of resource blocks and slot symbols of control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 15} kHz for frequency bands with minimum channel bandwidth 40MHz**

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{sym}^{CORESET}$	Offset (RBs)
0	1	48	1	4
1	1	48	2	4
2	1	48	3	4
3	1	96	1	0
4	1	96	1	56
5	1	96	2	0
6	1	96	2	56
7	1	96	3	0
8	1	96	3	56
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

**Table 13-6: Set of resource blocks and slot symbols of control resource set for Type0-PDCCH search space when {SS/PBCH block, PDCCH} subcarrier spacing is {30, 30} kHz for frequency bands with minimum channel bandwidth 40MHz**

Index	SS/PBCH block and control resource set multiplexing pattern	Number of RBs $N_{RB}^{CORESET}$	Number of Symbols $N_{sym}^{CORESET}$	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 $N_{sym}^{CORESET}$	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 $N_{sym}^{CORESET}$	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 $N_{sym}^{CORESET}$	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 $N_{sym}^{CORESET}$	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	48	1	-41 if condition A -42 if condition B
7	2	48	1	49
8	Reserved			
9	Reserved			
10	Reserved			
11	Reserved			
12	Reserved			
13	Reserved			
14	Reserved			
15	Reserved			

**Table 13-11: Parameters for PDCCH monitoring occasions for Type0-PDCCH common search space - SS/PBCH block and control resource set multiplexing pattern 1 and frequency range 1**

Index	$O$	Number of search space sets per slot	$M$	First symbol index
0	0	1	1	0
1	0	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
2	2	1	1	0
3	2	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
4	5	1	1	0
5	5	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
6	7	1	1	0
7	7	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
8	0	1	2	0
9	5	1	2	0
10	0	1	1	1
11	0	1	1	2
12	2	1	1	1
13	2	1	1	2
14	5	1	1	1
15	5	1	1	2

**Table 13-12: Parameters for PDCCH monitoring occasions for Type0-PDCCH common search space - SS/PBCH block and control resource set multiplexing pattern 1 and frequency range 2**

Index	$O$	Number of search space sets per slot	$M$	First symbol index
0	0	1	1	0
1	0	2	1/2	{0, if $i$ is even}, {7, if $i$ is odd}
2	2.5	1	1	0
3	2.5	2	1/2	{0, if $i$ is even}, {7, if $i$ is odd}
4	5	1	1	0
5	5	2	1/2	{0, if $i$ is even}, {7, if $i$ is odd}
6	0	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
7	2.5	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
8	5	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
9	7.5	1	1	0
10	7.5	2	1/2	{0, if $i$ is even}, {7, if $i$ is odd}
11	7.5	2	1/2	{0, if $i$ is even}, { $N_{\text{symb}}^{\text{CORESET}}$ , if $i$ is odd}
12	0	1	2	0
13	5	1	2	0
14	Reserved			
15	Reserved			

**Table 13-13: PDCCH monitoring occasions for Type0-PDCCH common search space - SS/PBCH block and control resource set multiplexing pattern 2 and {SS/PBCH block, PDCCH} subcarrier spacing {120, 60} kHz**

Index	PDCCH monitoring occasions (SFN and slot number)	First symbol index ( $k = 0, 1, \dots, 15$ )
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 ( $k = 0, 1, \dots, 7$ )
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 ( $k = 0, 1, \dots, 15$ )
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  $24 \leq k_{SSB} \leq 29$  for FR1 or for  $12 \leq k_{SSB} \leq 13$  for FR2, the UE may determine the nearest (in the corresponding frequency direction) global synchronization channel number (GSCN) of a second SS/PBCH block having a control resource set for an associated Type0-PDCCH common search space as  $N_{GSCN}^{Reference} + N_{GSCN}^{Offset} \cdot N_{GSCN}^{Reference}$  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 the UE detects the second SS/PBCH block and the second SS/PBCH block does not provide a control resource set for Type0-PDCCH common search space, as described in Subclause 4.1, the UE may ignore the information related to GSCN of SS/PBCH block locations for performing cell search.

If a UE detects a SS/PBCH block and determines that a control resource set for Type0-PDCCH common search space is not present, and for  $k_{SSB} = 31$  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*.

If a UE does not detect any SS/PBCH block providing a control resource set for Type0-PDCCH common search space, as described in Subclause 4.1, within a time period determined by the UE, the UE may ignore the information related to GSCN of SS/PBCH locations in performing cell search.

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

$k_{SSB}$	<i>RMSI-PDCCH-Config</i>	$N_{GSCN}^{Offset}$
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**

$k_{SSB}$	<i>RMSI-PDCCH-Config</i>	$N_{GSCN}^{Offset}$
12	0, 1, ..., 255	1, 2, ..., 256
13	0, 1, ..., 255	-1, -2, ..., -256
14	0, 1, ..., 255	Reserved, Reserved, ..., Reserved

## Annex A:

### Change history

Date	TSG #	TSG Doc.	CR	Rev	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
2018-06	RAN#80	RP-181172	0002	1	CR to TS 38.213 capturing the RAN1#92bis and RAN1#93 meeting agreements and aligning higher layer parameters with TS 38.331	15.2.0