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Technical Specification

KT PyeongChang 5G Special Interest Group (KT 5G-SIG); KT 5th Generation Radio Access; Physical Layer; Physical layer procedures (Release 1)

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Document History

Version	Date	Change
1.0	2016-02-17	First Draft Version
1.7	2016-07-13	Pre-final Version
1.8	2016-08-29	Apply CR for clarification and editorial correction
1.9	2016-09-19	CR on MCS and SR procedure approved Minor changes for technical/editorial correction

Contents

Foreword

This Technical Specification has been produced by the KT PyeongChang 5G Special Interest Group (KT 5G-SIG).

1 Scope

The present document specifies and establishes the characteristics of the physicals layer procedures in5G Radio Access (5G RA).

2 References

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

[1] TS 5G.201: "5G Radio Access (5G RA); Physical layer; General description".

[2] TS 5G.211: "5G Radio Access (5G RA); Physical channel and modulation".

[3] TS 5G.212: "5G Radio Access (5G RA); Multiplexing and channel coding".

[4] TS 5G.321: "5G Radio Access (5G RA); 5G Medium Access Control Protocol".

[5] TS 5G.331: "5G Radio Access (5G RA); 5G Radio Resource Control (5G-RRC) Protocol Specification".

3 Definitions, symbols, and abbreviations

3.1 Symbols

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

n_f	System frame number as defined in [2]
n_s	Slot number within a radio frame as defined in [2]
N_{cells}^{DL}	Number of configured cells
$N_{\mathrm{RB}}^{\mathrm{DL}}$	Downlink bandwidth configuration, expressed in units of $N_{\mathrm{sc}}^{\mathrm{RB}}$ as defined in [2]
$N_{\mathrm{RB}}^{\mathrm{UL}}$	Uplink bandwidth configuration, expressed in units of $N_{\mathrm{sc}}^{\mathrm{RB}}$ as defined in [2]
$N_{\mathrm{symb}}^{\mathrm{UL}}$	Number of SC-FDMA symbols in an uplink slot as defined in [2]
$N_{\mathrm{sc}}^{\mathrm{RB}}$	Resource block size in the frequency domain, expressed as a number of subcarriers as defined in [2]
T_s	Basic time unit as defined in [2]

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply.

ACK	Acknowledgement
BCH	Broadcast Channel
CCE	Control Channel Element
CIF	Carrier Indicator Field
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CSI	Channel State Information
DAI	Downlink Assignment Index
DCI	Downlink Control Information
DL	Downlink
DL-SCH	Downlink Shared Channel
DTX	Discontinuous Transmission
EPRE	Energy Per Resource Element

MCS	Modulation and Coding Scheme
NACK	Negative Acknowledgement
xPBCH	Physical Broadcast Channel
xPDCCH	Physical Downlink Control Channel
xPDSCH	Physical Downlink Shared Channel
PMI	Precoding Matrix Indicator
xPRACH	Physical Random Access Channel
PRB	Physical Resource Block
xPUCCH	Physical Uplink Control Channel
xPUSCH	Physical Uplink Shared Channel
PTI	Precoding Type Indicator
QoS	Quality of Service
RBG	Resource Block Group
RE	Resource Element
RI	Rank Indication
RPF	Repetition Factor
RS	Reference Signal
SIR	Signal-to-Interference Ratio
SINR	Signal to Interference plus Noise Ratio
SR	Scheduling Request
SRS	Sounding Reference Symbol
TA	Time alignment
TTI	Transmission Time Interval
UCI	Uplink Control Information
UE	User Equipment
UL	Uplink
UL-SCH	Uplink Shared Channel
VRB	Virtual Resource Block

4 Synchronisation 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. The following signals are transmitted in the downlink to facilitate cell search: the primary, secondary and extended synchronization signals. A UE may assume the antenna port for the primary/secondary/extended synchronization signals of a serving cell are quasi co-located

4.2 Timing synchronisation

4.2.1 Radio link monitoring

The downlink radio link quality of the primary cell shall be monitored by the UE for the purpose of indicating out-of-sync/in-sync status to higher layers.

In non-DRX mode operation, the physical layer in the UE shall assess the radio link quality, evaluated over the previous time period depending on the evaluation period in use, against thresholds (Q_{out} and Q_{in}).

In DRX mode operation, the physical layer in the UE shall at least once every DRX period assess the radio link quality, evaluated over the previous time period depending on the length of the DRX cycle in use, against thresholds (Q_{out} and Q_{in}).

The physical layer in the UE shall in radio frames where the radio link quality is assessed indicate out-of-sync to higher layers when the radio link quality is worse than the threshold Q_{out}. When the radio link quality is better than the threshold Q_{in}, the physical layer in the UE shall in radio frames where the radio link quality is assessed indicate in-sync to higher layers.

4.2.2 Inter-cell synchronisation

No functionality is specified in this sub-clause.

4.2.3 Transmission timing adjustments

Upon reception of a timing advance command, the UE shall adjust its uplink transmission timing for xPUCCH/xPUSCH/SRS of primary cell. UL transmission timing for xPUCCH/xPUSCH/SRS of a secondary cell is the same as the primary cell.

In case of random access response, 11-bit timing advance command [4], T_A, indicates N_{TA} values by index values of T_A = 0, 1, 2, …, 1200, where an amount of the timing alignment is given by $N_{TA} = T_A$ is defined in TS 5G.211[2].

In other cases, 6-bit timing advanced command [4], T_A, indicates adjustment of the current N_{TA} value, $N_{TA,old}$, to the new value, $N_{TA,new}$, by index values of T_A = 0, 1, 2,…,63, where $N_{TA,new} = N_{TA,old} + (T_A\text{-}31)$. Here, adjustment of N_{TA} value by a positive or negative amount indicates advancing or delaying the uplink transmission timing by a given amount respectively.

For a timing advance command received on subframe *n*, the corresponding adjustment of the timing shall apply from the beginning of subframe *n+6*.

4.3 Timing for Secondary Cell Activation / Deactivation

Note: Once a secondary cell is added, it is always activated. No activation and deactivation command required

5 Beamforming procedures

5.1 Beam acquisition and tracking

The downlink transmitting beams are acquired from beam reference signals. Up to 8 antenna ports are supported for beam reference signal (BRS). A UE tracks downlink transmitting beams through the periodic BRS measurements. The BRS transmission period is configured by a 2 bit indicator in xPBCH. The BRS transmission period is the necessary time to sweep the whole downlink beams transmitted via BRS.

The following BRS transmission periods are supported:

- “00” Single slot (< 5ms) : supportable for maximum 7 downlink transmitting beams per antenna port
- “01” Single subframe (= 5m) : supportable for maximum 14 downlink transmitting beams per antenna port
- “10” Two subframe (= 10ms) : supportable for maximum 28 downlink transmitting beams per antenna port
- “11” Four subframe (= 20ms) : supportable for maximum 56 downlink transmitting beams per antenna port

UE maintains a candidate beam set of 4 BRS beams, where for each beam the UE records beam state information (BSI). BSI comprises beam index (BI) and beam reference signal received power (BRSRP).

UE reports BSI on PUCCH or PUSCH as indicated by 5G Node per clause 8.3. 5GNode may send BSI request in DL DCI, UL DCI, and RAR grant.

When reporting BSI on xPUCCH, UE reports BSI for a beam with the highest BRSRP in the candidate beam set.

When reporting BSI on xPUSCH, UE reports BSIs for $N \in \{1,2,4\}$ beams in the candidate beam set, where N is provided in the 2-bit BSI request from 5G Node. The BSI reports are sorted in decreasing order of BRSRP.

5.1.1 BRS management

There are two beam switch procedures, which are MAC-CE based beam switch procedure and DCI based beam switch procedure associated with BRS.

For the MAC-CE based beam switch procedure [4], 5G Node transmits a MAC-CE containing a BI to the UE.

The UE shall, upon receiving the MAC-CE, switch the serving beam at the UE to match the beam indicated by the MAC-CE. The beam swiching shall apply from the beginning of subframe $n+k_{beamswitch\text{-}delay\text{-}mac}$ where subframe n is used for HARQ-ACK transmission associated with the MAC-CE and $k_{beamswitch\text{-}delay\text{-}mac} = 14$. The UE shall assume that the 5G Node beam associated with xPDCCH, xPDSCH, CSI-RS, xPUCCH, xPUSCH, and xSRS is switched to the beam indicated by the MAC-CE from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}mac}$.

For the DCI based beam switch procedure, 5G Node requests a BSI report via DCI and the *beam_switch_indication* field is set to 1 in the same DCI. The UE shall, upon receiving such a DCI, switch the serving beam at the UE to match the beam indicated by the first BI reported by the UE in the BSI report corresponding to this BSI request. The beam swiching shall apply from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}dic}$ where subframe n is used for sending the BSI report and $k_{beam\text{-}switch\text{-}delay\text{-}dci} = 11$.

If *beam_switch_indication* field=0 in the DCI the UE is not required to switch the serving beam at the UE.

For any given subframe, if there is a conflict in selecting the serving beam at the UE, the serving beam is chosen that is associated with the most recently received subframe containing the MAC-CE (for MAC-CE based procedure) or the DCI (for DCI based procedure). A UE is not expected to receive multiple requests for beam switching in the same subframe.

5.2 Beam refinement

BRRS is triggered by DCI. A UE can also request BRRS using SR [4]. To request the serving 5G Node to transmit BRRS, the UE transmits the scheduling request preamble where the higher layer configured preamble resource $\{u, v, f'$, and $N_{SR}\}$ is dedicated for beam refinement reference signal initiation request.

The time and frequency resources that can be used by the UE to report Beam Refinement Information (BRI), which consists of BRRS Resource Index (BRRS-RI) and BRRS reference power (BRRS-RP), are controlled by the 5G Node.

A UE can be configured with 4 Beam Refinement (BR) processes by higher layers. A 2-bit resource allocation field and a 2 bit process indication field in the DCI are described in Table 5.2-1 and Table 5.2-2, respectively.

Table 5.2-1: BRRS resource allocation field for xPDCCH with DL or UL DCI

Value of BRRS resource allocation field	**Description**	
	Subframe type allocation	Symbol type allocation
'00'	5 symbols in slot 0	13^{th} symbol
'01'	5 symbols in slot 1	14^{th} symbol
'10'	10 symbols	13 & 14^{th} symbols
'11'	Reserved	Reserved

Table 5.2-2: BRRS process indication field for xPDCCH with DL or UL DCI

Value of BRRS process indication field	**Description**
'00'	The first BR process configured by the higher layers
'01'	The second BR process configured by the higher layers
'10'	The third BR process configured by the higher layers
'11'	The fourth BR process configured by the higher layers

A BR process comprises of up to eight BRRS resources, a resource allocation type and a VCID, and is configured via RRC signalling. A BRRS resource comprises of a set of antenna ports to be measured.

Table 5.2-3: BR process configuration

	Description	Bit length
BRRS resource ID 0, BRRS resource ID 1, …, BRRS resource ID 7	Antenna Ports to be measured for each BRRS resource (up to 8 ports) (8 bit bitmap for ports 600 to 607).	8*8=64bits
Resource allocation type	0 : subframe type allocation 1 : symbol type allocation	1 bits
VCID	Virtual cell ID	9 bits

A BRRS transmission can span 1, 2, 5 or 10 OFDM symbols, and is associated with a BRRS resource allocation, BRRS process indication, and a BR process configuration as in Table 5.2-1, 5.2.-2 and 5.2.-3. A BRI reported by the UE corresponds to one BR process that is associated with up to eight BRRS resources. The UE shall assume that BRRS mapped to the BRRS resource ID 0 in each BRRS process is transmitted by the serving beam.

5.2.1 BRRS management

There are two beam switch procedures, which are MAC-CE based beam switch procedure and DCI based beam switch procedure associated with BRRS.

For the MAC-CE based beam switch procedure [4], 5G Node transmits a MAC-CE containing a BRRS resource ID and the associated BR process ID to the UE.

The UE shall, upon receiving the MAC-CE, switch the serving beam at the UE to match the beam indicated by the MAC-CE. The beam swiching shall apply from the beginning of subframe $n+k_{beamswitch\text{-}delay\text{-}mac}$ where subframe n is used for HARQ-ACK transmission associated with the MAC-CE and $k_{beamswitch\text{-}delay\text{-}mac} = 14$. The UE shall assume that the 5G Node beam associated with xPDCCH, xPDSCH, CSI-RS, xPUCCH, xPUSCH, and xSRS is switched to the beam indicated by the MAC-CE from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}mac}$.

For the DCI based beam switch procedure, 5G Node requests a BRI report via DCI and the *beam_switch_indication* field is set to 1 in the same DCI. The UE shall, upon receiving such a DCI, switch the serving beam at the UE to match the beam indicated by the first BRRS-RI reported by the UE in the BRI report corresponding to this BRI request. . The beam swiching shall apply from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}dic}$ where subframe n is used for sending the BRI report and $k_{beam\text{-}switch\text{-}delay\text{-}dci} = 11$.

If *beam_switch_indication* field=0 in the DCI the UE is not required to switch the serving beam at the UE.

For any given subframe, if there is a conflict in selecting the serving beam at the UE, the serving beam is chosen that is associated with the most recently received subframe containing the MAC-CE (for MAC-CE based procedure) or the DCI (for DCI based procedure). A UE is not expected to receive multiple requests for beam switching in the same subframe.

5.3 Beam Recovery

If a UE detects the current serving beam is misaligned [4] and has BSIs for beam recovery, the UE shall perform beam recovery process.

In the UL synchronized UE case, the UE transmits scheduling request by scheduling request preamble where the preamble resource $\{u, v, f'$ and $N_{SR}\}$ is dedicated for beam recovery as configured by higher layers. Upon the reception of this request, 5G Node may initiate BSI reporting procedure as described in section 8.3.

In UL asynchronized UE case, the UE transmits random access preamble for contention based random access. If the UE is scheduled by RAR triggering BSI reporting, the UE reports N BSIs in Msg3 as UCI multiplexing in [3].

6 Power control

6.1 Uplink power control

Uplink power control controls the transmit power of the different uplink physical channels.

6.1.1 Physical uplink shared channel

6.1.1.1 UE behaviour

The setting of the UE Transmit power $P_{\text{PUSCH}}(i)$ for the physical uplink shared channel (xPUSCH) transmission in subframe i is defined by

$$P_{\text{PUSCH}}(i) = \min\{P_{\text{CMAX}}, 10\log_{10}(M_{\text{PUSCH}}(i)) + P_{\text{O\_PUSCH}}(j) + \alpha(j)\cdot PL + \Delta_{\text{TF}}(i) + f(i)\} \quad \text{[dBm]}$$

where,

- All parameters are separately defined per serving cell, unless otherwise stated
- P_{CMAX} is the configured UE transmitted power defined in [FFS]
- $M_{\text{PUSCH}}(i)$ is the bandwidth of the xPUSCH resource assignment expressed in number of resource blocks valid for subframe *i*.
- $P_{\text{O\_PUSCH}}(j)$ is a parameter composed of the sum of a cell specific nominal component $P_{\text{O\_NOMINAL\_PUSCH}}$ provided from higher layers and a UE specific component $P_{\text{O\_UE\_PUSCH}}$ provided by higher layers.
    - For PUSCH (re)transmissions corresponding to a dynamic scheduled grant then *j=1* and for PUSCH (re)transmissions corresponding to the random access response grant then *j=2*. $P_{\text{O\_UE\_PUSCH}}(2) = 0$ and $P_{\text{O\_NOMINAL\_PUSCH}}(2) = P_{\text{O\_PRE}} + \Delta_{PREAMBLE\_Msg3}$, where the parameter PREAMBLE_INITIAL_RECEIVED_TARGET_POWER [8] ($P_{\text{O\_PRE}}$) and $\Delta_{PREAMBLE\_Msg3}$ are signalled from higher layers.
    - For *j=1*, $\alpha(j) \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$. For *j*=2, $\alpha(j) = 1$.
    - The pair of values used for $P_{\text{O\_PUSCH}}(1)$ and α is indicated by the DCI scheduling the PUSCH, wherein the pair of values is selected from a set of pairs of values configured by higher layers.
- *PL* is the downlink beamformed pathloss estimate calculated in the UE in dB:
    - *PL* is derived from the B-RSRP measurement by the UE, using the BRS reference signal corresponding to the serving BRS beam index
    - *PL* = (referenceBeamSignalPower – higher layer filtered B-RSRP), where referenceBeamSignalPower is provided by higher layers and the higher layer filter configuration is defined in TS 5G.331 [5]
- $\Delta_{\text{TF}}(i) = 10\log_{10}((2^{MPR\cdot K_S} - 1)\beta_{offset}^{PUSCH})$ for $K_S = 1.25$ and 0 for $K_S = 0$ where K_S is given by the UE specific parameter *deltaMCS-Enabled* provided by higher layers
    - $MPR = O_{CQI} / N_{RE}$ for control data sent via xPUSCH without UL-SCH data and $\sum_{r=0}^{C-1} K_r / N_{RE}$ for other cases.

- where C is the number of code blocks, K_r is the size for code block r, O_{CQI} is the number of CQI bits including CRC bits and N_{RE} is the number of resource elements determined as $N_{RE} = M_{sc}^{PUSCH-initial} \cdot N_{\mathrm{symb}}^{\mathrm{PUSCH\text{-}initial}}$, where C, K_r, $M_{sc}^{PUSCH-initial}$ and $N_{\mathrm{symb}}^{\mathrm{PUSCH\text{-}initial}}$ are defined in TS 5G.331 [3].

  - $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$ for control data sent via xPUSCH without UL-SCH data and 1 for other cases.

- δ_{PUSCH} is a UE specific correction value, also referred to as a TPC command and is included in xPDCCH with DCI format A1/A2. The current xPUSCH power control adjustment state is given by $f(i)$ which is defined by:
  - $f(i) = f(i-1) + \delta_{PUSCH}(i - K_{PUSCH})$ if accumulation is enabled based on the UE-specific parameter *Accumulation-enabled* provided by higher layers
    - where $\delta_{\mathrm{PUSCH}}(i - K_{PUSCH})$ was signalled on xPDCCH with DCI format A1/A2 on subframe $i - K_{PUSCH}$, and where $f(0)$ is the first value after reset of accumulation.
    - K_{PUSCH} is the number of subframes between the reception of the DCI format and the corresponding xPUSCH transmission.
    - The δ_{PUSCH} dB accumulated values signalled on xPDCCH with DCI format A1/A2 are given in Table 6.1.1.1-1.
    - The δ_{PUSCH} dB accumulated values signalled on xPDCCH with DCI format A1/A2 are one of the values given in Table 6.1.1.1-1.
    - If UE has reached maximum power, positive TPC commands shall not be accumulated
    - If UE has reached minimum power, negative TPC commands shall not be accumulated
    - UE shall reset accumulation
      - when $P_{\mathrm{O\_UE\_PUSCH}}$ value is changed by higher layers
      - when the UE receives random access response message for the serving cell
  - $f(i) = \delta_{\mathrm{PUSCH}}(i - K_{\mathrm{PUSCH}})$ if accumulation is not enabled based on the UE-specific parameter *Accumulation-enabled* provided by higher layers
    - where $\delta_{\mathrm{PUSCH}}(i - K_{PUSCH})$ was signalled on xPDCCH with DCI format A1/A2 on subframe $i - K_{PUSCH}$
    - K_{PUSCH} is the number of subframes between the reception of the DCI format A1/A2 and the corresponding xPUSCH transmission.
    - The δ_{PUSCH} dB absolute values signalled on xPDCCH with DCI format A1/A2 are given in Table 6.1.1.1-1.
  - For both types of $f(*)$ (accumulation or current absolute) the first value is set as follows:
    - If $P_{\mathrm{O\_UE\_PUSCH}}$ value is changed by higher layers,
      - $f(i) = 0$
    - Else
      - *f(0)* = 0 for the first subframe after the initial random access.

Table 6.1.1.1-1: Mapping of TPC Command Field in DCI format A1/A2 to absolute and accumulated δ_{PUSCH} values.

TPC Command Field in DCI format 0/3	Accumulated δ_{PUSCH} [dB]	Absolute δ_{PUSCH} [dB]
0	-1	-4
1	0	-1
2	1	1
3	3	4

6.1.1.2 Power headroom

The UE power headroom PH valid for subframe *i* for each serving cell is defined by

$$PH(i) = P_{\text{CMAX}} - \{10\log_{10}(M_{\text{PUSCH}}(i)) + P_{\text{O\_PUSCH}}(j) + \alpha(j)\cdot PL + \Delta_{\text{TF}}(i) + f(i)\} \text{ [dB]}$$

where, P_{CMAX}, $M_{\text{PUSCH}}(i)$, $P_{\text{O\_PUSCH}}(j)$, $\alpha(j)$, PL, $\Delta_{\text{TF}}(i)$ and $f(i)$ are defined in section 6.1.1.1.

The power headroom shall be rounded to the closest value in the range [[40]; [-23]] dB with steps of 1 dB and is delivered by the physical layer to higher layers.

6.1.2 Physical uplink control channel

6.1.2.1 UE behaviour

The setting of the UE Transmit power P_{PUCCH} for the physical uplink control channel (xPUCCH) transmission in subframe *i* is defined by

$$P_{\text{PUCCH}}(i) = \min\{P_{\text{CMAX}}, P_{\text{0\_PUCCH}} + PL + h(n_{CQI}, n_{BI}, n_{HARQ}, n_{SR}) + \Delta_{\text{F\_PUCCH}}(F) + \Delta_{\text{TxD}}(F') + g(i)\} \text{ [dBm]}$$

where

- All parameters are separately defined per serving cell, unless otherwise stated.
- P_{CMAX} is the configured UE transmitted power defined in [6]
- The parameter $\Delta_{\text{F\_PUCCH}}(F)$ is provided by higher layers. Each $\Delta_{\text{F\_PUCCH}}(F)$ value corresponds to a PUCCH format (*F*) defined in Table 5.4-1 [2].
- If the UE is configured by higher layers to transmit xPUCCH on two antenna ports, the value of $\Delta_{TxD}(F')$ is provided by higher layers where each xPUCCH format *F'* is defined in Table 5.4-1 of [2]; otherwise, $\Delta_{TxD}(F') = 0$. Note that $\Delta_{TxD}(F')$ is commonly defined for all serving cells.
- $h(n)$ is an xPUCCH format dependent value, where n_{CQI} and n_{BI} correspond to the number of information bits for the channel quality information and the beam related information, respectively, defined in section 5.2.3.3 and 5.2.3.4 in [3] and n_{HARQ} is the number of HARQ bits in subframe *i*. n_{SR} = 1 if subframe *i* is configured for SR for the UE not having any associated transport block for UL-SCH, otherwise n_{SR} =0.
- For PUCCH format 2 and when UE transmits HARQ-ACK/SR along with CSI, BSI, and/or BRI,
    - If the UE is configured by higher layers to transmit PUCCH format 2 on two antenna ports, or if the UE transmits more than 11 bits of HARQ-ACK, SR, CSI, BSI, and BRI

$$h(n_{CQI}, n_{BI}, n_{HARQ}, n_{SR}) = \frac{n_{HARQ} + n_{SR} + n_{CQI} + n_{BI} - 1}{3}$$

-
- $P_{\text{O\_PUCCH}}$ is a parameter composed of the sum of a cell specific parameter $P_{\text{O\_NOMINAL\_PUCCH}}$ provided by higher layers and a UE specific component $P_{\text{O\_UE\_PUCCH}}$ provided by higher layers.
- PL is the parameter as defined in Section 6.1.1.1.
- δ_{PUCCH} is a UE specific correction value, also referred to as a TPC command, included in an xPDCCH with DCI format B1/B2.
  - If the UE decodes an xPDCCH with DCI format B1/B2 and the corresponding detected RNTI equals the C-RNTI of the UE, the UE shall use the δ_{PUCCH} provided in that xPDCCH,
  - $g(i) = g(i-1) + \delta_{PUCCH}(i - k_0)$ where $g(i)$ is the current xPUCCH power control adjustment state.
    - k_0 is the delay between the DL DCI grant to the corresponding xPUCCH transmission.
    - The δ_{PUCCH} dB values signalled on xPDCCH with DCI format B1/B2 are given in Table 6.1.2.1-1.
    - The initial value of $g(i)$ is defined as $g(i) = 0$.
    - If UE has reached maximum power, positive TPC commands shall not be accumulated
    - If UE has reached minimum power, negative TPC commands shall not be accumulated
    - UE shall reset accumulation
      - at cell-change
      - when entering/leaving RRC active state
      - when $P_{\text{O\_UE\_PUCCH}}$ value is changed by higher layers
      - when the UE receives a random access response message
    - $g(i) = g(i-1)$ if i is a subframe without an xPUCCH symbol.

Table 6.1.2.1-1: Mapping of TPC Command Field in DCI format B1/B2 to δ_{PUCCH} values.

TPC Command Field in DCI format 1A/1B/1D/1/2A/2/3	δ_{PUCCH} [dB]
0	-1
1	0
2	1
3	3

6.1.3 Sounding Reference Symbol

6.1.3.1 UE behaviour

The setting of the UE Transmit power P_{SRS} for the Sounding Reference Symbol transmitted on subframe *i* for each serving cell is defined by

$$P_{\mathrm{SRS}}(i) = \min\{P_{\mathrm{CMAX}},\ P_{\mathrm{SRS\_OFFSET}} + 10\log_{10}(M_{\mathrm{SRS}}) + P_{\mathrm{O\_PUSCH}}(j) + \alpha(j)\cdot PL + f(i)\}\ \text{[dBm]}$$

where

- All parameters are separately defined per serving cell, unless otherwise stated.
- P_{CMAX} is the configured UE transmitted power defined in [FFS]
- For $K_S = 1.25$, $P_{\mathrm{SRS\_OFFSET}}$ is a 4-bit UE specific parameter semi-statically configured by higher layers with 1dB step size in the range [-3, 12] dB.
- For $K_S = 0$, $P_{\mathrm{SRS\_OFFSET}}$ is a 4-bit UE specific parameter semi-statically configured by higher layers with 1.5 dB step size in the range [-10.5,12] dB
- M_{SRS} is the bandwidth of the SRS transmission in subframe i expressed in number of resource blocks.
- $f(i)$ is the current power control adjustment state for the xPUSCH corresponding to the set index signalled in the xSRS scheduling grant, see Section 6.1.1.1.
- $P_{\mathrm{O\_PUSCH}}(j)$ and $\alpha(j)$ are parameters as defined in Section 6.1.1.1, where.
- PL is the parameter as defined in Section 6.1.1.1.

6.2 Downlink power allocation

The 5G Node determines the downlink transmit energy per resource element.

The UE may assume downlink cell-specific BRS EPRE is constant across the downlink system bandwidth and constant across all subframes until different cell-specific BRS power information is received. The downlink cell-specific BRS EPRE can be derived from the downlink BRS transmit power given by the parameter *referenceSignalPower* provided by higher layers. The downlink BRS transmit power is defined as the linear average over the power contributions (in [W]) of all resource elements that carry cell-specific BRS within the operating system bandwidth.

The UE may assume the ratio of xPDSCH EPRE to UE-specific DMRS EPRE within each OFDM symbol containing UE-specific DMRSs is 0 dB.

7 Random access procedures

Prior to initiation of the non-synchronized physical random access procedure, higher layers decide the component carrier for RACH transmission. Higher layers inform the corresponding Layer 1 if RACH will be transmitted. Layer 1 also receive the following information from the higher layers:

- Ingredients of the look up table that maps the symbol containing the strongest received sync beam to the symbol l of the RACH signal
- Root u and cyclic shift ν
- Parameter f'
- Band index n_{RACH}
- System Frame Number, SFN
- The BRS transmission period N_{BRS}
- The number of symbols N_{RACH} during the RACH subframe for which the 5G Node applies different rx –beams,
- The number of RACH subframes M in each radio frame

- The index of current RACH subframe m (here m ranges from 0 to M-1)
- The symbol with the strongest sync beam, $S_{Sync}^{BestBeam}$

7.1 Physical non-synchronized random access procedure

From the physical layer perspective, the L1 random access procedure encompasses the transmission of random access preamble and random access response. The remaining messages are scheduled for transmission by the higher layer on the shared data channel and are not considered part of the L1 random access procedure. A random access channel block occupies 48 resource blocks in a single subframe reserved for random access preamble transmissions.

The following steps are required for the L1 random access procedure:

- Layer 1 procedure is triggered upon request of a preamble transmission by higher layers. Higher layers will send such a request to the layer 1 of at most one component carrier at a time. As a result the UE will transmit the RACH signal only in one component carrier.
- A preamble sequence is determined from the root and cyclic shift provided by higher layers. The root is cell-specific.
- RACH transmission mode can be partitioned into contention-based RACH transmission and contention free RACH transmission by NumberOfRA-Preamble which is defined in TS 5G.331 [5]. NumberOfRA-preamble denotes preamble indices for contention based RACH transmission among available preambles.
- Physical layer uses SFN, NBRS, NRACH, M, m and S_{Sync}^{Beam} to calculate the symbol index l, as described in 5.7.2.1. of TS 5G.211[2]. The physical layer informs the upper layer whether the RACH opportunity came up in the specific RACH subframe number m
- A target preamble received power (PREAMBLE_RECEIVED_TARGET_POWER), a corresponding RA-RNTI and a xPRACH resource (symbol and band index) are indicated by higher layers as part of the request.
- A preamble transmission power P_{PRACH} is determined as P_{PRACH} = min{ $P_{CMAX}(i)$, PREAMBLE_RECEIVED_TARGET_POWER + PL}_[dBm], where $P_{CMAX}(i)$ is the configured UE transmit power defined in [6] for subframe i , PL is the downlink path loss estimate calculated in the UE based on the receive power of the BRS signal associated with best beam. It is assumed that PRACH is transmitted with the same subarray and beam that was used when the samples of the best beam were received during the sync subframe.
- A single preamble is transmitted with transmission power P_{PRACH} . UE may transmit a xPRACH at available RACH subframe.
- Detection of a xPDCCH message with the indicated RA-RNTI is attempted during a window controlled by higher layers (see subclause 5.1.4 of TS 5G.321 [4]). If detected, the corresponding DL-SCH transport block is passed to higher layers. The higher layers parse the transport block, extract the uplink grant and pass it to the physical layer. The grant is processed according to subclause 7.2.

7.1.1. Timing

For the L1 random access procedure, the uplink transmission timing after a random access preamble transmission is as follows.

a) If a xPDCCH with associated RA-RNTI is detected in subframe n, and the corresponding DL-SCH transport block contains a response to the transmitted preamble sequence, the UE shall, according to the information in the response, transmit an UL-SCH transport block in the first subframe $n+k_1$, where $k_1 \geq 6$ equals the value associated with UL delay field within the DL-SCH block. For the bit patterns 00, 01, 10, 11 the associated UL delay equals 6,7,8 or 9 subframes, respectively.

b) If a random access response is received in subframe n, and the corresponding DL-SCH transport block does not contain a response to the transmitted preamble sequence, the UE shall, if requested by higher layers, be ready to transmit a new preamble sequence during one of next RACH subframes.

c) If no random access response is received in subframe n, where subframe n is the last subframe of the random access response window, the UE shall, if requested by higher layers, be ready to transmit a new preamble sequence during one of the next RACH subframes.

In case a random access procedure is initiated by a “xPDCCH order” in subframe n, the UE shall, if requested by higher layers, transmit random access preamble in the subframe $n+k_2$, $k_2 \geq 6$, where a xPRACH subframe is available.

7.2 Random Access Response Grant

The random access response grant will contain bit fields similar to the bit fields of an uplink grant for one layer (A1) as it is outlined in 5G-212 subclause 5.3.3.1 Specifically the random access response grant will contain the bit fields for xPUSCH range, resource block assignment, Modulation and Coding scheme , TPC command and UL delay, . The content of these 23 bits starting with MSB and ending with LSB are as follows:

- xPUSCH range – 2 bits, as defined in section 9.2
- Resource block assignment – 9 bits
  - If the indicated value is smaller than or equal to 324, then this field assigns more than zero RB as described in section 9.2
  - Otherwise, then this format is assumed to be misconfigured and UE shall discard the corresponding grant
- Modulation and coding scheme – 4 bits, as defined in section 9.6
- TPC command – 3 bits, as defined in Table 7.2-1
- UL delay – 2 bits, as defined in section 7.1.1
- Reserved – 3 bits

The UE shall use the single-antenna port uplink transmission scheme with DMRS port 40 for the PUSCH transmission corresponding to the random access response grant and the PUSCH retransmission for the same transport block. The UE shall use the same antenna subarray and the same beam as it used for the transmission of PRACH. The UE shall assume that HARQ ID is ‘0’ and NDI is ‘0’ for the xPUSCH transmission corresponding to the random access response grant.

The TPC command δ_{msg2} shall be used for setting the power of the xPUSCH, and is interpreted according to Table 7.2-1.

Table 7.2-1: TPC Command δ_{msg2} for Scheduled PUSCH

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

In non-contention based random access procedure, the CSI request field is interpreted to determine whether a CQI, PMI, and RI report is included in the corresponding PUSCH transmission according to subclause 8.2.1. In contention based random access procedure, the CSI request field is reserved.

7.3 Scheduling Request

A UE shall transmit a Scheduling Request Symbol (SR) during a RACH subframe if instructed by higher layers. As outlined in subclause 5.7.4 in TS 5G.211[2] the physical layer has to be provided the following parameters

- band number N_{SR}
- cyclic shift ν
- root u
- Parameter f'
- System Frame Number, SFN
- The BRS transmission period N_{BRS}
- The number of symbols N_{RACH} during the RACH subframe for which the 5G Node applies different rx –b eams
- The number of RACH subframes M in each radio frame
- The index of current RACH subframe m (here m ranges between 0 to M-1)
- The symbol with the strongest sync beam, $S_{Sync}^{BestBeam}$

Here the root u is cell specific. UE uses SFN, N_{BRS}, N_{RACH}, M, m and $S_{Sync}^{BestBeam}$ to calculate the symbol index *l*, as described in 5.7.2.1 of TS 5G.211 [2].

The scheduling request region can be used to transmit beam change request and beam refinement reference signal initiation request. The higher layer provide different combinations of band number, cyclic shift and parameter to the physical layer to transmit beam change request and beam refinement reference signal initiation request. The physical layer uses these parameters, along with SFN, N_{BRS}, N_{RACH}, M, m and $S_{Sync}^{BestBeam}$, to calculate the symbol index *l* to transmit beam change request and beam refinement reference signal initiation request.

8 Physical downlink shared channel related procedures

There shall be a maximum of 10 HARQ processes in the downlink

8.1 UE procedure for receiving the physical downlink shared channel

UE shall upon detection of a xPDCCH of the serving cell with DCI format A1, A2, B1, or B2, intended for the UE in a subframe decode the corresponding xPDSCH in the same subframe with the restriction of the number of transport blocks defined in the higher layers.

If a UE is configured by higher layers to decode xPDCCH with CRC scrambled by the RA-RNTI, the UE shall decode the xPDCCH and the corresponding xPDSCH according to the combination defined in Table 8.1-1. The scrambling initialization of xPDSCH corresponding to these xPDCCHs is by RA-RNTI.

When RA-RNTI and C-RNTI are assigned in the same subframe, the UE is not required to decode a xPDSCH on the primary cell indicated by a xPDCCH with a CRC scrambled by C-RNTI.

Table 8.1-1: xPDCCH and xPDSCH configured by RA-RNTI

DCI format	Search Space	Transmission scheme of xPDSCH corresponding to xPDCCH
DCI format B1	UE specific	Transmit Diversity (see subclause 8.1.2)

If a UE is configured by higher layers to decode xPDCCH with CRC scrambled by the C-RNTI, the UE shall decode the xPDCCH and any corresponding xPDSCH according to the respective combinations defined in Table 8.1-2. The scrambling initialization of xPDSCH corresponding to these xPDCCHs is by C-RNTI.

A UE configured in transmission mode 3 can be configured with scrambling identities, $n_{\mathrm{ID}}^{\mathrm{DMRS},i}$, $i = 0,1$ by higher layers for UE-specific reference signal generation as defined in subclause 6.7.2.1 of [3] to decode xPDSCH according to a detected xPDCCH with CRC scrambled by the C-RNTI with DCI format B1 or B2 intended for the UE.

Table 8.1-2: xPDCCH and xPDSCH configured by C-RNTI

Transmission mode	DCI format	Search Space	Transmission scheme of xPDSCH corresponding to xPDCCH
Mode 1	DCI format B1	UE specific by C-RNTI	Single-antenna port (see subclause 8.1.1)
Mode 2	DCI format B1	UE specific by C-RNTI	Transmit diversity (see subclause 8.1.2)
Mode 3	DCI format B1	UE specific by C-RNTI	Transmit diversity (see subclause 8.1.2)
	DCI format B2	UE specific by C-RNTI	Up to 8 layer transmission, ports 8-15 (see subclause 8.1.3)

If a UE is configured by higher layers to decode xPDCCH with CRC scrambled by the Temporary C-RNTI and is not configured to decode xPDCCH with CRC scrambled by the C-RNTI, the UE shall decode the xPDCCH and the corresponding xPDSCH according to the combination defined in Table 8.1-3. The scrambling initialization of xPDSCH corresponding to these xPDCCHs is by Temporary C-RNTI.

Table 8.1-3: xPDCCH and xPDSCH configured by Temporary C-RNTI

DCI format	Search Space	Transmission scheme of xPDSCH corresponding to xPDCCH
DCI format B1	UE specific	Transmit diversity (see subclause 8.1.2)

The transmission schemes of the xPDSCH are described in the following sub-clauses.

8.1.1 Single-antenna port scheme

For the single-antenna port transmission schemes (port 8/9/10/11/12/13/14/15) of the xPDSCH, the UE may assume that a 5G Node transmission on the xPDSCH would be performed according to subclause 6.3.4.1 of TS 5G.211 [2]. The UE cannot assume that the other antenna ports in the set $p \in \{8,12\}$ or $p \in \{9,13\}$ or $p \in \{10,14\}$ or $p \in \{11,15\}$ is not associated with transmission of xPDSCH to another UE.

8.1.2 Transmit diversity scheme

For the transmit diversity transmission scheme of the xPDSCH, the UE may assume that a5G Node transmission on the xPDSCH would be performed according to subclause 6.3.4.2 of TS 5G.211 [2].

8.1.3 Multiplexing scheme

For the up to 2 layer transmission scheme of the xPDSCH, the UE may assume that a 5G Node transmission on the xPDSCH would be performed with up to 2 transmission layers on antenna ports 8 - 15 as defined in subclause 6.3.4.3 of TS 5G.211 [2].

8.1.4 Resource allocation

The resource block assignment information indicates to a scheduled UE a set of contiguously allocated localized virtual resource blocks. Localized VRBG allocations for a UE vary from a single VRBG up to a maximum number of VRBGs spanning the system bandwidth.

The resource allocation field consists of a resource indication value (*RIV*) corresponding to a starting virtual resource block group ($VRBG_{start}$) and a length in terms of virtually contiguously allocated virtual resource block groups L_{CVRBGs} . The resource indication value is defined by if $(L_{VCRBGs}-1)\leq\left\lfloor N_{VRBG}^{DL}/2\right\rfloor$ then

$$RIV=N_{VRBG}^{DL}(L_{VCRBGs}-1)+VRBG_{start}$$

else

$$RIV=N_{VRBG}^{DL}(N_{VRBG}^{DL}-L_{VCRBGs}+1)+(N_{VRBG}^{DL}-1-VRBG_{start})$$

where $L_{VCRBGs}\geq 1$ and shall not exceed $N_{VRBG}^{DL}-VRBG_{start}$.

8.1.4.1 xPDSCH starting and ending position

The starting and stopping OFDM symbol for the xPDSCH is given by the field of xPDSCH range in DCI format B1 and B2 as follows.

- MSB (starting of xPDSCH including DMRS symbol) : 0 is the second symbol, 1 is the third symbol
- LSB (stopping of xPDSCH) : 0 is the 12th symbol, 1 is the 14th symbol.

8.1.5 Modulation order and transport block size determination

To determine the modulation order and transport block size(s) in the physical downlink shared channel, the UE shall first

- read the 4-bit "modulation and coding scheme" field (I_{MCS}) in the DCI

The 5G Node shall select MCS/TBS combinations such that the effective code rate is less than 0.93 for the subframe used for first transmission. The effective code rate is defined as the number of downlink information bits (including CRC bits) divided by the number of physical channel bits on PDSCH. For retransmission, 5G Node shall ensure that the number of RB’s available for a re-transmission is identical to the first transmission, in addition to maintaining the same MCS index.

8.1.5.1 Modulation order and code rate determination

The UE shall use I_{MCS} and Table 8.1.5.1-1 to determine the modulation order (Q_m) and code rate (parity check matrix) used in the physical downlink shared channel.

Table 8.1.5.1-1: Modulation and code rate index table for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	Code Rate C_R	Parity check matrix for Type 1 LDPC codes	Parity check matrix for Type 2 LDPC codes
0	2	1/14	Table 5.1.3.2-5 in [3]	
1	2	1/5	Table 5.1.3.2-5 in [3]	
2	2	1/3	Table 5.1.3.2-5 in [3]	
3	2	1/2	Table 5.1.3.2-5 in [3]	
4	2	2/3	Table 5.1.3.2-4 in [3]	
5	2	5/6	Table 5.1.3.2-2 in [3]	
6	4	1/2	Table 5.1.3.2-5 in [3]	
7	4	3/5	Table 5.1.3.2-4 in [3]	Table 5.1.3.2-6 in [3]
8	4	2/3	Table 5.1.3.2-4 in [3]	
9	4	3/4	Table 5.1.3.2-3 in [3]	
10	4	5/6	Table 5.1.3.2-2 in [3]	
11	6	3/5	Table 5.1.3.2-4 in [3]	
12	6	2/3	Table 5.1.3.2-4 in [3]	
13	6	3/4	Table 5.1.3.2-3 in [3]	
14	6	5/6	Table 5.1.3.2-2 in [3]	
15	Not used			

Parity check matrix for LDPC encoding is described in Tables from 5.1.3.2-2 to 5.1.3.2-5 in TS 5G.212 [3].

8.1.5.2 Transport block size determination

The UE shall determine its TBS by the procedure in subclause 8.1.5.2.1 for $0 \le I_{MCS} \le 15$.

8.1.5.2.1 Transport blocks not mapped to two or more layer spatial multiplexing

The TBS is by the (I_{MCS}, N_{PRB}) entry of Table 8.1.5.2.1-1.

Table 8.1.5.2.1-1: Transport block size table (dimension 15×25)

I_{MCS}	N_{PRB} (bits)											
	4	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**	**44**	**48**	**52**
0	56	128	208	280	360	432	504	584	656	736	808	888	960
1	192	400	616	824	1032	1248	1456	1672	1880	2088	2304	2512	2728
2	328	680	1032	1384	1736	2088	2440	2792	3144	3496	3848	4200	4552
3	504	1032	1560	2088	2616	3144	3672	4200	4728	5256	5784	6312	6840
4	680	1384	2088	2792	3496	4200	4904	5608	6312	7016	7720	8424	9128
5	856	1736	2616	3496	4376	5256	6136	7016	7896	8776	9656	10536	11416
6	1032	2088	3144	4200	5256	6312	7368	8424	9480	10536	11592	12648	13704
7	1248	2512	3784	5048	6312	7584	8848	10120	11384	12648	13920	15184	16456
8	1384	2792	4200	5608	7016	8424	9832	11240	12648	14056	15464	16872	18280
9	1560	3144	4728	6312	7896	9480	11064	12648	14232	15816	17400	18984	20568
10	1736	3496	5256	7016	8776	10536	12296	14056	15816	17576	19336	21096	22856
11	1880	3784	5680	7584	9480	11384	13288	15184	17088	18984	20888	22792	24688
12	2088	4200	6312	8424	10536	12648	14760	16872	18984	21096	23208	25320	27432
13	2352	4728	7104	9480	11856	14232	16608	18984	21360	23736	26112	28488	30864
14	2616	5256	7896	10536	13176	15816	18456	21096	23736	26376	29016	31656	34296
I_{MCS}	N_{PRB} (bits)												
	56	**60**	**64**	**68**	**72**	**76**	**80**	**84**	**88**	**92**	**96**	**100**	
0	1032	1112	1184	1264	1336	1416	1488	1560	1640	1712	1792	1864	
1	2936	3144	3360	3568	3784	3992	4200	4416	4624	4840	5048	5256	
2	4904	5256	5608	5960	6312	6664	7016	7368	7720	8072	8424	8776	
3	7368	7896	8424	8952	9480	10008	10536	11064	11592	12120	12648	13176	
4	9832	10536	11240	11944	12648	13352	14056	14760	15464	16168	16872	17576	
5	12296	13176	14056	14936	15816	16696	17576	18456	19336	20216	21096	21976	
6	14760	15816	16872	17928	18984	20040	21096	22152	23208	24264	25320	26376	

7	17720	18984	20256	21520	22792	24056	25320	26592	27856	29128	30392	31656	
8	19688	21096	22504	23912	25320	26728	28136	29544	30952	32360	33768	35176	
9	22152	23736	25320	26904	28488	30072	31656	33240	34824	36408	37992	39576	
10	24616	26376	28136	29896	31656	33416	35176	36936	38696	40456	42216	43976	
11	26592	28488	30392	32296	34192	36096	37992	39896	41800	43696	45600	47496	
12	29544	31656	33768	35880	37992	40104	42216	44328	46440	48552	50664	52776	
13	33240	35616	37992	40368	42744	45120	47496	49872	52248	54624	57000	59376	
14	36936	39576	42216	44856	47496	50136	52776	55416	58056	60696	63336	66392	

8.1.5.2.2 Transport blocks mapped to two-layer spatial multiplexing

The TBS is calculated by adding 24 to twice of the (I_{MCS}, N_{PRB}) entry of Table 8.1.5.2.1-1.

8.1.6 Precoding granularity of xPDSCH

For the xPDSCH assigned by DCI format B1, a UE may assume that precoding granularity for xPDSCH is 4 PRBs mapped to a single VRBG in the frequency domain,

For the xPDSCH assigned by DCI format B2,

- If $I_{\mathrm{PRG}} = 0$, a UE may assume that precoding granularity for xPDSCH is 4 PRBs mapped to a single VRBG in the frequency domain
- If $I_{\mathrm{PRG}} = 1$, a UE may assume that precoding granularity for xPDSCH is all assigned PRBs in the frequency domain

where I_{PRG} is delivered to a UE via RRC signalling. A UE may assume that the same precoder and beam direction applies on all physical resources within a precoding granularity.

8.2 UE procedure for reporting Channel State Information (CSI)

The time and frequency resources that can be used by the UE to report CSI which consists of, Channel Quality Indicator (CQI), precoding matrix indicator (PMI), and/or rank indication (RI) are controlled by the 5G Node. The UE shall determine a RI corresponding to the number of useful transmission layers. For transmit diversity as given in TS 5G.211 [2], RI is equal to one.

A UE can be configured with one or more CSI processes by higher layers. Each CSI process is associated with a CSI-RS transmission. A CSI reported by the UE corresponds to a set of CSI processes configured by higher layers. A CSI-RS transmission spans 1 or 2 OFDM symbols and allocated according to a CSI-RS configuration bitmap [2]

CSI reporting is aperiodic.

8.2.1 CSI Reporting using xPUSCH

If a value of CSI request field is triggered by uplink DCI in subframe n, then CSI-RS is allocated in subframe $n+m$ and a UE shall perform CSI reporting using xPUSCH in subframe $n+4+m+l$, where the CSI-RS allocation offset m is indicated in range of 0 to 3 by uplink DCI, and the xPUSCH transmission delay offset l is indicated in range of 0 to 7 by uplink DCI.

A 2-bit Process indication field in uplink DCI as described in Table 8.2.1-1A indicates CSI process corresponding to the CSI reference resource.

Table 8.2.1-1A: Process indication field for xPDCCH with uplink DCI format

Value of field	Description
'00'	CSI process #0 configured by higher layers
'01'	CSI process #1 configured by higher layers
'10'	CSI process #2 configured by higher layers
'11'	CSI process #3 configured by higher layers

A UE is not expected to receive more than one CSI report request for a given subframe.

A UE is semi-statically configured by higher layers to feed back CQI and PMI and corresponding RI on the same xPUSCH using one of the following CSI reporting modes given in Table 8.2.1-1 and described below.

Table 8.2.1-1: CQI and PMI Feedback Types for xPUSCH CSI reporting Modes

		PMI Feedback Type		
		No PMI	**Single PMI**	**Multiple PMI**
xPUSCH CQI Feedback Type	**Wideband (wideband CQI)**	Mode 1-0	Mode 1-1	
	UE Selected (subband CQI)			
	Higher Layer-configured (subband CQI)			

For each of the transmission modes defined in subclause 8.1, the following reporting modes are supported on xPUSCH:

Transmission mode 1 : Modes 1-0
Transmission mode 2 : Modes 1-0
Transmission mode 3 : Modes 1-1 if the UE is configured with PMI/RI reporting and number of CSI-RS ports > 1; modes 1-0 if the UE is configured without PMI/RI reporting or number of CSI-RS ports=1.

- Wideband feedback
  - Mode 1-0 description:
    - A UE shall report a wideband CQI value which is calculated assuming transmission on set *S* subbands.
  - Mode 1-1 description:
    - A single precoding matrix is selected from the codebook assuming transmission on set S subbands.
    - A UE shall report a wideband CQI value which is calculated assuming the use of the single precoding matrix in all subbands.
    - The UE shall report the selected single precoding matrix indicator.

8.2.2 CSI Reporting using xPUCCH

If CSI request is triggered by downlink DCI in subframe n, then CSI-RS is allocated in subframe $n+m$ and a UE shall perform CSI reporting using xPUCCH in subframe $n+4+m+k$, where the CSI-RS allocation offset m is indicated in range of 0 to 3 by downlink DCI, and the xPUCCH transmission delay offset k is indicated in range of 0 to 7 by downlink DCI.

A 2-bit Process indication field in downlink DCI as described in Table 8.2.2-1A indicates CSI process corresponding to the CSI reference resource.

Table 8.2.2-1A: Process indication field for xPDCCH with downlink DCI format

Value of field	Description
'00'	CSI process #0 configured by higher layers
'01'	CSI process #1 configured by higher layers
'10'	CSI process #2 configured by higher layers
'11'	CSI process #3 configured by higher layers

A UE is not expected to receive more than one CSI report request for a given subframe.

A UE is semi-statically configured by higher layers to feed back CQI and PMI and corresponding RI on the same xPUCCH using one of the following CSI reporting modes given in Table 8.2.2-1 and described below.

Table 8.2.2-1: CQI and PMI Feedback Types for xPUCCH CSI reporting Modes

		PMI Feedback Type		
		No PMI	Single PMI	Multiple PMI
xPUCCH CQI Feedback Type	Wideband (wideband CQI)	Mode 1-0	Mode 1-1	
	UE Selected (subband CQI)			
	Higher Layer-configured (subband CQI)			

For each of the transmission modes defined in subclause 9.1, the following reporting modes are supported on xPUCCH:

Transmission mode 1 : Modes 1-0
Transmission mode 2 : Modes 1-0
Transmission mode 3 : Modes 1-1 if the UE is configured with PMI/RI reporting and number of CSI-RS ports > 1; modes 1-0 if the UE is configured without PMI/RI reporting or number of CSI-RS ports=1.

- Wideband feedback
  - Mode 1-0 description:
    - A UE shall report a wideband CQI value which is calculated assuming transmission on set *S* subbands.
  - Mode 1-1 description:
    - A single precoding matrix is selected from the codebook assuming transmission on set S subbands.
    - A UE shall report a wideband CQI value which is calculated assuming the use of the single precoding matrix in all subbands.
    - The UE shall report the selected single precoding matrix indicator.

8.2.3 Channel quality indicator (CQI) definition

The CQI indices and their interpretations are given in Table 8.2.3-1.The UE shall derive for each CQI value reported in uplink subframe *n* the highest CQI index between 1 and 15 in Table 8.2.3-1 which satisfies the following condition, or CQI index 0 if CQI index 1 does not satisfy the condition:

- A single xPDSCH transport block with a combination of modulation scheme and transport block size corresponding to the CQI index, and occupying a group of downlink physical resource blocks termed the CSI reference resource, could be received with a transport block error probability not exceeding 0.1.

The UE shall derive the channel measurements for computing the CQI value reported in uplink subframe *n* and corresponding to a CSI process, based on only the CSI-RS resources for the candidate beam within the CSI process.

The UE shall derive the interference measurements for computing the CQI value reported in uplink subframe *n* and corresponding to a CSI process, based on the IMR within the CSI process.
A combination of modulation scheme and transport block size corresponds to a CQI index if:

- the combination could be signalled for transmission on the xPDSCH in the CSI reference resource according to the relevant Transport Block Size table, and
- the modulation scheme is indicated by the CQI index, and
- the combination of transport block size and modulation scheme when applied to the reference resource results in the effective channel code rate which is the closest possible to the code rate indicated by the CQI index. If more than one combination of transport block size and modulation scheme results in an effective channel code rate equally close to the code rate indicated by the CQI index, only the combination with the smallest of such transport block sizes is relevant.

The UE shall assume the following for the purpose of deriving the CQI index, and if also configured, PMI and RI:

- The first 2 OFDM symbols are occupied by control signaling
- The ratio of PDSCH EPRE to CSI-RS EPRE is as given in subclause 8.2.5.
- The UE-specific reference signal overhead shall be taken into account.
- PCRS overhead is zero.
- The precoding matrix shall be taken into account.

Table 8.2.3-1: 4-bit CQI Table

CQI index	modulation	code rate	efficiency
0	out of range		
1	QPSK	7/100	0.14
2	QPSK	1/5	0.4
3	QPSK	1/3	0.6667
4	QPSK	1/2	1
5	QPSK	2/3	1.333
6	QPSK	5/6	1.667
7	16QAM	1/2	2
8	16QAM	3/5	2.4
9	16QAM	2/3	2.667
10	16QAM	3/4	3
11	16QAM	5/6	3.333
12	64QAM	3/5	3.6
13	64QAM	2/3	4
14	64QAM	3/4	4.5
15	64QAM	5/6	5

8.2.4 Precoding Matrix Indicator (PMI) definition

For transmission modes 3, the UE shall report PMI if configured with PMI/RI reporting and the number of CSI-RS ports is larger than 1. A UE shall report PMI based on the feedback modes described in 8.2.1 and 8.2.2. For other transmission modes, PMI reporting is not supported.
For 2 antenna ports, each PMI value corresponds to a codebook index given in Table 8.2.4-1 as follows:

- For 2 antenna ports and an associated RI value of 1, a PMI value of $n \in \{0,1,2,3\}$ corresponds to the codebook index n given in Table 8.2.4-1 with $\upsilon = 1$.
- For 2 antenna ports and an associated RI value of 2, a PMI value of $n \in \{0,1,2\}$ corresponds to the codebook index n given in Table 8.2.4-1 of [3] with $\upsilon = 2$.

For 4 antenna ports, each PMI value corresponds to a codebook index given in Table 8.2.4-2 as follows:
A PMI value of $n \in \{0,1,\cdots,15\}$ corresponds to the codebook index n given in Table 8.2.4-2 with υ equal to the associated RI value. The quantity $W_n^{\{s\}}$ denotes the matrix defined by the columns given by the set $\{s\}$ from the expression $W_n = I - 2u_n u_n^H / u_n^H u_n$ where I is the 4×4 identity matrix and the vector u_n is given by Table 8.2.4-2.

Table 8.2.4-1: Codebook for CSI reporting using two antenna ports

Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1&0\\0&1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&1\\1&-1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&1\\j&-j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 8.2.4-2: Codebook for CSI reporting using four antenna ports

Codebook index	u_n	Number of layers υ	
		1	2
0	$u_0 = [1\ \ -1\ \ -1\ \ -1]^T$	$W_0^{\{1\}}$	$W_0^{\{14\}}/\sqrt{2}$
1	$u_1 = [1\ \ -j\ \ 1\ \ j]^T$	$W_1^{\{1\}}$	$W_1^{\{12\}}/\sqrt{2}$
2	$u_2 = [1\ \ 1\ \ -1\ \ 1]^T$	$W_2^{\{1\}}$	$W_2^{\{12\}}/\sqrt{2}$
3	$u_3 = [1\ \ j\ \ 1\ \ -j]^T$	$W_3^{\{1\}}$	$W_3^{\{12\}}/\sqrt{2}$
4	$u_4 = \left[1\ \ (-1-j)/\sqrt{2}\ \ -j\ \ (1-j)/\sqrt{2}\right]^T$	$W_4^{\{1\}}$	$W_4^{\{14\}}/\sqrt{2}$
5	$u_5 = \left[1\ \ (1-j)/\sqrt{2}\ \ j\ \ (-1-j)/\sqrt{2}\right]^T$	$W_5^{\{1\}}$	$W_5^{\{14\}}/\sqrt{2}$
6	$u_6 = \left[1\ \ (1+j)/\sqrt{2}\ \ -j\ \ (-1+j)/\sqrt{2}\right]^T$	$W_6^{\{1\}}$	$W_6^{\{13\}}/\sqrt{2}$
7	$u_7 = \left[1\ \ (-1+j)/\sqrt{2}\ \ j\ \ (1+j)/\sqrt{2}\right]^T$	$W_7^{\{1\}}$	$W_7^{\{13\}}/\sqrt{2}$
8	$u_8 = [1\ \ -1\ \ 1\ \ 1]^T$	$W_8^{\{1\}}$	$W_8^{\{12\}}/\sqrt{2}$
9	$u_9 = [1\ \ -j\ \ -1\ \ -j]^T$	$W_9^{\{1\}}$	$W_9^{\{14\}}/\sqrt{2}$
10	$u_{10} = [1\ \ 1\ \ 1\ \ -1]^T$	$W_{10}^{\{1\}}$	$W_{10}^{\{13\}}/\sqrt{2}$
11	$u_{11} = [1\ \ j\ \ -1\ \ j]^T$	$W_{11}^{\{1\}}$	$W_{11}^{\{13\}}/\sqrt{2}$
12	$u_{12} = [1\ \ -1\ \ -1\ \ 1]^T$	$W_{12}^{\{1\}}$	$W_{12}^{\{12\}}/\sqrt{2}$
13	$u_{13} = [1\ \ -1\ \ 1\ \ -1]^T$	$W_{13}^{\{1\}}$	$W_{13}^{\{13\}}/\sqrt{2}$
14	$u_{14} = [1\ \ 1\ \ -1\ \ -1]^T$	$W_{14}^{\{1\}}$	$W_{14}^{\{13\}}/\sqrt{2}$
15	$u_{15} = [1\ \ 1\ \ 1\ \ 1]^T$	$W_{15}^{\{1\}}$	$W_{15}^{\{12\}}/\sqrt{2}$

For 8 antenna ports, each PMI value corresponds to a pair of codebook indices given in Table 8.2.4-3 or 8.2.4-4, where the quantities φ_n and v_m are given by

$$\varphi_n = e^{j\pi n/2}$$
$$v_m = \begin{bmatrix} 1 & e^{j2\pi m/32} & e^{j4\pi m/32} & e^{j6\pi m/32} \end{bmatrix}^T$$

- as follows:For 8 antenna ports, a first PMI value of $i_1 \in \{0,1,\cdots,f(\upsilon)-1\}$ and a second PMI value of $i_2 \in \{0,1,\cdots,g(\upsilon)-1\}$ corresponds to the codebook indices i_1 and i_2 given in Table 8.2.4-3 and 8.2.4-4 with υ equal to the associated RI value, $f(\upsilon)=\{16,16\}$ and $g(\upsilon)=\{16,16\}$.

Table 8.2.4-3: Codebook for 1-layer CSI reporting using eight antenna ports

i_1	i_2							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0 – 15	$W^{(1)}_{2i_1,0}$	$W^{(1)}_{2i_1,1}$	$W^{(1)}_{2i_1,2}$	$W^{(1)}_{2i_1,3}$	$W^{(1)}_{2i_1+1,0}$	$W^{(1)}_{2i_1+1,1}$	$W^{(1)}_{2i_1+1,2}$	$W^{(1)}_{2i_1+1,3}$
i_1	i_2							
	8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
0 - 15	$W^{(1)}_{2i_1+2,0}$	$W^{(1)}_{2i_1+2,1}$	$W^{(1)}_{2i_1+2,2}$	$W^{(1)}_{2i_1+2,3}$	$W^{(1)}_{2i_1+3,0}$	$W^{(1)}_{2i_1+3,1}$	$W^{(1)}_{2i_1+3,2}$	$W^{(1)}_{2i_1+3,3}$
where $W^{(1)}_{m,n} = \frac{1}{\sqrt{8}}\begin{bmatrix} v_m \\ \varphi_n v_m \end{bmatrix}$								

Table 8.2.4-4: Codebook for 2-layer CSI reporting using eight antenna ports

i_1	i_2			
	0	**1**	**2**	**3**
0 – 15	$W^{(2)}_{2i_1,2i_1,0}$	$W^{(2)}_{2i_1,2i_1,1}$	$W^{(2)}_{2i_1+1,2i_1+1,0}$	$W^{(2)}_{2i_1+1,2i_1+1,1}$
i_1	i_2			
	4	**5**	**6**	**7**
0 – 15	$W^{(2)}_{2i_1+2,2i_1+2,0}$	$W^{(2)}_{2i_1+2,2i_1+2,1}$	$W^{(2)}_{2i_1+3,2i_1+3,0}$	$W^{(2)}_{2i_1+3,2i_1+3,1}$
i_1	i_2			
	8	**9**	**10**	**11**
0 – 15	$W^{(2)}_{2i_1,2i_1+1,0}$	$W^{(2)}_{2i_1,2i_1+1,1}$	$W^{(2)}_{2i_1+1,2i_1+2,0}$	$W^{(2)}_{2i_1+1,2i_1+2,1}$
i_1	i_2			
	12	**13**	**14**	**15**
0 – 15	$W^{(2)}_{2i_1,2i_1+3,0}$	$W^{(2)}_{2i_1,2i_1+3,1}$	$W^{(2)}_{2i_1+1,2i_1+3,0}$	$W^{(2)}_{2i_1+1,2i_1+3,1}$
where $W^{(2)}_{m,m',n} = \frac{1}{4}\begin{bmatrix} v_m & v_{m'} \\ \varphi_n v_m & -\varphi_n v_{m'} \end{bmatrix}$				

8.2.5 Channel-State Information – Reference Signal (CSI-RS) definition

A UE can be configured with one or more CSI-RS resources. If CSI request is triggered via DCI in subframe n, then CSI-RS is allocated in subframe $n+m_{\text{offset}}$, where the CSI-RS allocation offset, m_{offset}, is indicated in range of 0 to 3 via DCI. The CSI-RS can be allocated on OFDM symbol(s) {13}, {14}, or {13 and 14} via DCI. The following parameters configured via higher layer signaling are associated with a CSI-RS resource.

- CSI-RS resource identity
- Number of CSI-RS ports. The allowable values and port mapping are given in subclause 6.7.3 of TS 5G.211[2].
- CSI RS RE mapping (see Table 6.7.3.2-1in TS 5G.211[2])
- UE assumption on reference PDSCH transmitted power for CSI feedback P_c

- Pseudo-random sequence generator parameter, n_{ID}

P_c is the assumed ratio of PDSCH EPRE to CSI-RS EPRE when UE derives CSI feedback and takes values in the range of [-8, 15] dB with 1 dB step size.

A UE may assume the CSI-RS antenna ports of a CSI-RS resource are quasi co-located with respect to delay spread, Doppler spread, Doppler shift, average gain, and average delay.

8.2.6 Channel-State Information – Interference Measurement (CSI-IM) Resource definition

A UE can be configured with one or more CSI-IM resources. The following parameters are configured via higher layer signaling for each CSI-IM resource:

- CSI-IM resource configuration (see 6.7.3.2 in TS 5G.211 [2])

8.3 UE procedure for reporting Beam State Information (BSI)

UE reports BSI on xPUCCH or xPUSCH as indicated by 5G Node. 5G Node can send BSI request in DL DCI, UL DCI, and RAR grant.

If a UE receives BSI request in DL DCI, the UE reports a BSI on xPUCCH. The time/frequency resource for xPUCCH is indicated in the DL DCI. When reporting BSI on xPUCCH, UE reports a BSI for a beam with the highest BRSRP in the candidate beam set.

If UE receives BSI request in UL DCI or in RAR grant, UE reports BSIs on xPUSCH. The time/frequency resource for xPUSCH is indicated in the UL DCI or RAR grant that requests BSI report. When reporting BSI on xPUSCH, UE reports BSI for $N \in \{1,2,4\}$ beams with the highest BRSRP in the candidate beam set, where N is provided in the DCI.

If BSI reporting is indicated on both xPUCCH and xPUSCH in the same subframe, UE reports BSI on xPUSCH only and discards the xPUCCH trigger.

8.3.1 BSI reporting using xPUSCH

Upon decoding in subframe n an UL DCI with a BSI request, UE shall report BSI using xPUSCH in subframe $n + 4 + m + l$, where parameters $m = 0$ and $l = \{0, 1, \ldots 7\}$ is indicated by the UL DCI.

The number of BSIs to report, $N \in \{1,2,4\}$, is indicated in UL DCI.

A UE shall report N BSIs corresponding to N beams in the candidate beam set.

A BSI report contains N BIs and corresponding BRSRPs. A UE shall report wideband BRSRPs.

A UE is not expected to receive more than one request for BSI reporting on xPUSCH for a given subframe.

8.3.2 BSI reporting using xPUCCH

Upon decoding in subframe n a DL DCI with a BSI request, UE shall report BSI using xPUCCH subframe index $n+4+m+k$, where parameters $m = 0$ and $k = \{0, 1, \ldots 7\}$ is indicated by the DL DCI.

When reporting BSI on xPUCCH, UE reports BSI for a beam with the highest BRSRP in the candidate beam set.

A BSI report contains BI and corresponding BRSRP. A UE shall report wideband BRSRP.

A UE is not expected to receive more than one request for BSI reporting on xPUCCH for a given subframe.

8.3.3 BSI definition

8.3.3.1 BRSRP definition

The BRSRP indices and their interpretations are given in Table 8.3.3.1-1. The reporting range of BRSRP is defined from -140 dBm to -44 dBm with 1 dB resolution as shown in Table 8.3.3.1-1.

The UE shall derive BRSRP values from the beam measurements based on BRS defined in 5G.211. The UE shall derive BRSRP index from the measured BRSRP value. Each BRSRP index is mapped to its corresponding binary representation using 7 bits.

Table 8.3.3.1-1: 7-bit BRSRP Table

BRSRP index	Measured quantity value [dBm]
0	BRSRP < -140
1	-140 ≤ BRSRP < -139
2	-139 ≤ BRSRP < -138
…	…
95	-46 ≤ BRSRP < -45
96	-45 ≤ BRSRP < -44
97	-44 ≤ BRSRP

8.3.3.2 Beam index definition

BI indicates a selected beam index. The BI is the logical beam index associated with antenna port, OFDM symbol index and BRS transmission period [2], which is indicated by 9 bits.

8.4 UE procedure for reporting Beam Refinement Information (BRI)

8.4.1 BRI reporting using xPUSCH

If the uplink DCI in subframe n indicates a BRRS transmission, the BRRS is allocated in subframe $n + m$ where m ={0,1,2,3} is indicated by a 2 bit RS allocation timing in the DCI.

A BRI report is associated with one BR process that is indicated in the uplink DCI for the UE. Upon decoding in subframe n an UL DCI with a BRI request, the UE shall report BRI using xPUSCH in subframe n+4+m+l, where parameters m = {0, 1, 2, 3} and l = {0, 1, … 7} are indicated by the UL DCI.

A UE shall report wideband BRRS-RP values and BRRS-RI values corresponding to the best N_{BRRS} BRRS resource ID where N_{BRRS} is configured by higher layers

If the number of configured BRRS resource ID associated with the BR process is less than or equal to N_{BRRS} then the UE shall report BRRS-RP and BRRS-RI corresponding to all the configured BRRS resources.

A UE is not expected to receive more than one BRI report request for a given subframe.

8.4.2 BRI reporting using xPUCCH

If the DL DCI in subframe n indicates a BRRS transmission, the BRRS is allocated in subframe n+m where m ={0,1,2,3} is indicated by the DL DCI.

A BRI report is associated with one BRRS process that is indicated in the downlink DCI for the UE. Upon decoding in subframe n a DL DCI with a BRI request, the UE shall report BRI using xPUCCH in subframe n+4+m+k, where parameters m = {0, 1, 2, 3} and k = {0, 1, … 7} are indicated by the DL DCI.

A UE shall report a wideband BRRS-RP value and a BRRS-RI value corresponding to the best BRRS resource ID.

A UE is not expected to receive more than one BRI report request for a given subframe.

8.4.3 BRI definition

8.4.3.1 BRRS-RP definition

The reporting range of BRRS-RP is defined from -140 dBm to -44 dBm with 1 dB resolution.

The mapping of BRRS-RP to 7 bits is defined in Table 8.4.3.1-1. . Each BRRS-RP index is mapped to its corresponding binary representation using 7 bits.

Table 8.4.3.1-1: 7-bit BRRS-RP mapping

Reported value	Measured quantity value	Unit
0	BRRS-RP < -140	dBm
1	-140 ≤ BRRS-RP < -139	dBm
2	-139 ≤ BRRS-RP < -138	dBm
…	…	…
95	-46 ≤ BRRS-RP < -45	dBm
96	-45 ≤ BRRS-RP < -44	dBm
97	-44 ≤ BRRS-RP	dBm

8.4.3.2 BRRS-RI definition

BRRS-RI indicates a selected BRRS resource ID. A BR process may comprise of a maximum of 8 BRRS resource IDs. The selected BRRS resource ID is indicated by 3 bits as in Table 8.4.3.2-1.

Table 8.4.3.2-1: BRRS-RI mapping

BRRS-RI	BRRS resource ID
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7

8.5 UE procedure for reporting HARQ-ACK

For a serving cell c, ACK/NACK multiplexing mode is performed within a bitmap message across multiple codewords received at the different subframes. For ACK/NACK multiplexing, the bitmap forms the bit sequence $a_0, \ldots, a_{B_c\text{-}1}$ where a_0 is the MSB and $a_{B_c\text{-}1}$ is the LSB. The size of the bitmap message $B_c \in \{4, 6, 8\}$ is delivered to the UE by RRC signalling, and the default value of B_c is 4. When a new bitmap message is generated, all bits in the bitmap shall be initialized with the value of NACK.

If xPDSCH RB resources are assigned to a UE by a DL DCI, the corresponding information of HARQ-ACK reporting channel shall be included within the DL DCI. The information of HARQ-ACK reporting channel includes transmission timing information and xPUCCH frequency resource information of which the HARQ-ACK reporting channel is transmitted.

If the UE detects $k \in \{0, 1, \ldots, 7\}$ and $m \in \{0, 1, 2, 3\}$ for the transmission timing information within the DL DCI at subframe n, then corresponding HARQ-ACK reporting channel is transmitted at the subframe $l = n + 4 + k + m$. The parameter m and k are indicated by a DL DCI.

If the UE detects i for the xPUCCH frequency resource information from the DL DCI at subframe n, then the corresponding HARQ-ACK reporting channel is associated with the i-th index of a set $n^{(2)}_{\text{xPUCCH}} = \{0, 1, \ldots, 15\}$ which is defined in [2]. UE shall not expect more than one HARQ-ACK reporting channel assignment in frequency domain at subframe index l.

If the UE also has a grant of xPUSCH transmission at the subframe index l, then the UE transmits both of xPUSCH and xPUCCH, and the HARQ-ACK reporting is delivered by xPUCCH.

In DL DCI, *bit-mapping index for HARQ-ACK multiplexing (BMI)* field explicitly indicates the value of $b \in \{0, \ldots, B_c-1\}$ which represents the specific position within the bitmap message. If multiple DL DCIs indicate the same subframe index l, then the BMI values in those DCIs shall be different.

If UE detects multiple DL DCIs at different subframes indicating the same subframe index l and the same xPUCCH index i, then all ACK/NACK bits associated with the detected DL DCIs are shall be multiplexed within a single bitmap message based on the indicated BMI values. If a UE successfully decodes the received codeword upon detection of the DL DCI, then the UE updates a_b in the bit sequence of the bitmap message to ACK. If the value of b in the detected DL DCI is larger than B_c-1, UE shall discard the DL DCI.

If a DL DCI indicates a new subframe index l for HARQ-ACK reporting channel, then a new bitmap message is generated.

9 Physical uplink shared channel related procedures

There shall be a maximum of 10 HARQ processes in the uplink

9.1 UE procedure for transmitting the physical uplink shared channel

UE shall upon detection of a xPDCCH with DCI format A1/A2 in subframe n intended for the UE, adjust the corresponding xPUSCH transmission in subframe $n+4+m+l$, where parameters l and m are given by DCI format A1/A2.

If a UE is configured by higher layers to decode xPDCCHs with the CRC scrambled by the C-RNTI, the UE shall decode the xPDCCH according to the combination defined in Table 9.1-1 and transmit the corresponding xPUSCH. If transmission mode is not configured by higher-layer signalling, then mode 1 is selected by UE as a default mode. The scrambling initialization of this xPUSCH corresponding to these xPDCCHs and the xPUSCH retransmission for the same transport block is by C-RNTI.

Table 9.1-1: xPDCCH and xPUSCH configured by C-RNTI

Transmission mode	DCI format	Transmission scheme of xPUSCH corresponding to xPDCCH
Mode 1	DCI format A1	Single-antenna port
Mode 2	DCI format A1	- Single-antenna port, if DCI indicates 1 layer transmission - Transmit diversity, if DCI indicates 2 layer transmission
	DCI format A2	Closed-loop spatial multiplexing, up to 2 layer transmission

If a UE is configured by higher layers to decode xPDCCHs with the CRC scrambled by the Temporary C-RNTI regardless of whether UE is configured or not configured to decode xPDCCHs with the CRC scrambled by the C-RNTI, the UE shall decode the xPDCCH according to the combination defined in Table 9.1-2 and transmit the corresponding xPUSCH. The scrambling initialization of xPUSCH corresponding to these xPDCCH is by Temporary C-RNTI.

If a Temporary C-RNTI is set by higher layers, the scrambling of xPUSCH corresponding to the Random Access Response Grant in subclause 7.2 and the xPUSCH retransmission for the same transport block is by Temporary C-RNTI. Else, the scrambling of xPUSCH corresponding to the Random Access Response Grant in subclause 7.2 and the xPUSCH retransmission for the same transport block is by C-RNTI.

Table 9.1-2: xPDCCH configured by Temporary C-RNTI

DCI format
DCI format A1

9.1.1 Single-antenna port scheme

For the single-antenna port transmission schemes of the xPUSCH, the UE transmission on the xPUSCH is performed according to subclause 5.3.3A.1 of TS 5G.211 [2].

9.1.2 Transmit diversity scheme

For the transmit diversity transmission scheme of the xPUSCH, the UE may assume that the UE transmission on the xPUSCH is performed according to subclause 5.3.3A.2 of TS 5G.211 [2]

9.1.3 Closed-loop spatial multiplexing scheme

For the closed-loop spatial multiplexing transmission scheme of the xPUSCH, the UE transmission on the xPUSCH is performed according to the applicable number of transmission layers as defined in subclause 5.3.3A.3 of TS 5G.211 [2].

9.2 Resource Allocation for xPDCCH with uplink DCI Formats

Generally, the resource allocation of xPUSCH is identical to that of xPDSCH in the section 8.1.6 except the positions of the staring symbol and the final symbol.

If a subframe is assigned as uplink subframe, the starting OFDM symbol for the xPUSCH is always the third symbol, and the final symbol is given by the field of xPUSCH range in DCI format A1 and A2 as follows.

- 00 : the stopping of xPUSCH is the 12th symbol
- 01 : the stopping of xPUSCH is the 13th symbol
- 10 : the stopping of xPUSCH is the final (14th) symbol
- 11 : Reserved

9.3 UE sounding procedure

The UE sounding procedure can be triggered by a DL or an UL grant when the appropriate bit is set. The transmission occurs k' subframes after the grant. Thereby k' = k + 1, where the value of k equals the offset of xPUCCH or xPUSCH transmission that is denoted by the corresponding bit fields of DCI formats B1/B2 or A1/A2, respectively as outlined in subclause 5.3.3.1 of TS 5G.212[3].

For a UE, the transmission of SRS shall not be allocated in the same OFDM symbols for the transmission of xPUSCH or xPUCCH.

The following SRS parameters are semi-statically configurable by higher layers:

- Transmission comb $\bar{k}_{TC}$
- Starting physical resource block assignment n_{RRC}
- SRS bandwidth B_{SRS}, as defined in subclause 5.5.3.2 of [3]

- Cyclic shift n_{SRS}^{cs}, as defined in subclause 5.5.3.1 of [3]
- Number of antenna ports N_p

A UE may be configured to transmit SRS on N_p antenna ports. The UE shall transmit SRS for all the configured transmit antenna ports within one symbol. The SRS transmission bandwidth and starting physical resource block assignment are the same for all the configured antenna ports.

9.4 UE HARQ-ACK procedure

Void

Note: Uplink HARQ procedure is grant-based and is handled by higher layers. No explicit HARQ-ACK indicator is supported in the downlink control signalling.

9.5 UE Reference Symbol procedure

UE applies high speed configuration according to sub-clause 5.5.4 of [3] for xPUSCH DMRS if configured by higher layers.

If UL sequence-group hopping or sequence hopping is configured in a serving cell, it applies to sounding reference symbols (SRS). If disabling of the sequence-group hopping and sequence hopping is configured for the UE in the serving cell through the higher-layer parameter *Disable-sequence-group-hopping*, the sequence-group hopping and sequence hopping are disabled.

9.6 Modulation order, redundancy version and transport block size determination

To determine the modulation order, redundancy version and transport block size for the physical uplink shared channel, the UE shall first

- read the "modulation and coding scheme and redundancy version" field (I_{MCS}), and
- compute the total number of allocated PRBs (N_{PRB}) based on the procedure defined in subclause 9.2, and
- compute the number of coded symbols for control information.

9.6.1 Modulation order and code rate determination

The UE shall use I_{MCS} and Table 9.6.1-1 to determine the modulation order (Q_m) and code rate (parity check matrix) used in the physical downlink shared channel.

Table 9.6.1-1: Modulation and code rate index table for PUSCH

MCS Index I_{MCS}	Modulation Order Q_m	Code Rate C_R	Parity check matrix for Type 1 LDPC codes	Parity check matrix for Type 2 LDPC codes
0	2	1/14	Table 5.1.3.2-5 in [3]	Table 5.1.3.2-6 in [3]
1	2	1/5	Table 5.1.3.2-5 in [3]	
2	2	1/3	Table 5.1.3.2-5 in [3]	
3	2	1/2	Table 5.1.3.2-5 in [3]	
4	2	2/3	Table 5.1.3.2-4 in [3]	
5	2	5/6	Table 5.1.3.2-2 in [3]	
6	4	1/2	Table 5.1.3.2-5 in [3]	
7	4	3/5	Table 5.1.3.2-4 in [3]	
8	4	2/3	Table 5.1.3.2-4 in [3]	
9	4	3/4	Table 5.1.3.2-3 in [3]	
10	4	5/6	Table 5.1.3.2-2 in [3]	
11	6	3/5	Table 5.1.3.2-4 in [3]	
12	6	2/3	Table 5.1.3.2-4 in [3]	
13	6	3/4	Table 5.1.3.2-3 in [3]	
14	6	5/6	Table 5.1.3.2-2 in [3]	
15	Not used			

Parity check matrix for LDPC encoding is described in Tables from 5.1.3.2-2 to 5.1.3.2-6 in [3].

9.6.2 Transport block size determination

The TBS is determined by the procedure in sub-clause 8.1.5.2.1.

9.6.3 Control information MCS offset determination

Offset values are defined for single layer PUSCH transmission and multiple layer PUSCH transmission. Single layer PUSCH transmission offsets $\beta_{\text{offset}}^{\text{RI}}$, $\beta_{\text{offset}}^{\text{CQI}}$ shall be configured to values according to Table 9.6.3-1,2,3,4 with the higher layer signalled indexes $I_{\text{offset}}^{\text{RI}}$ and $I_{\text{offset}}^{\text{CQI}}$ respectively. Multiple layer PUSCH transmission offsets $\beta_{\text{offset}}^{\text{RI}}$ and $\beta_{\text{offset}}^{\text{CQI}}$ shall be configured to values according to Table 9.6.3-1,2 with the higher layer signalled indexes $I_{\text{offset,ML}}^{\text{RI}}$ and $I_{\text{offset,ML}}^{\text{CQI}}$ respectively. For Msg3 transmission on xPUSCH, a value of $I_{\text{offset}}^{\text{CQI}}$ is specified in the random access response (RAR) message for transmission of BSI with Msg3 [4].

Table 9.6.3-1: Mapping of RI offset values and the index signalled by higher layers

I_{offset}^{RI} or $I_{offset,ML}^{RI}$	β_{offset}^{RI}
0	1.250
1	1.625
2	2.000
3	2.500
4	3.125
5	4.000
6	5.000
7	6.250
8	8.000
9	10.000
10	12.625
11	15.875
12	20.000
13	reserved
14	reserved
15	reserved

Table 9.6.3-2: Mapping of CQI offset values and the index signalled by higher layers

I_{offset}^{CQI} or $I_{offset,ML}^{CQI}$	β_{offset}^{CQI}
0	reserved
1	reserved
2	1.125
3	1.250
4	1.375
5	1.625
6	1.750
7	2.000
8	2.250
9	2.500
10	2.875
11	3.125
12	3.500
13	4.000
14	5.000
15	6.250

10 Physical downlink control channel procedures

10.1 UE procedure for determining physical downlink control channel assignment

Total of 15 search spaces are defined for each OFDM symbol, and the location of each search space is commonly defined for all UEs. Search space of index S_{search} is mapped to the resource elements constituting xREGs with a set of index where

$$\begin{cases} n_{xREG} \in \{2S_{\text{search}},\ 2S_{\text{search}}+1\}, & \text{if } 0 \le S_{search} \le 7 \\ n_{xREG} \in \{4(S_{\text{search}}-8),\ldots,4(S_{\text{search}}-8)+3\}, & \text{if } 8 \le S_{search} \le 11 \\ n_{xREG} \in \{8(S_{\text{search}}-12),\ldots,8(S_{\text{search}}-12)+7\}, & \text{if } 12 \le S_{search} \le 13 \\ n_{xREG} \in \{0,\ldots,15\}, & \text{if } S_{search} = 14 \end{cases}$$

The number of candidate OFDM symbols used for the transmission of xPDCCH is based on $N_{\text{Symbol, xPDCCH}}$ which is delivered by higher-layer signalling.

- If $N_{\text{Symbol, xPDCCH}} = 1$, then UE shall blindly decode the xPDCCH candidates in search space of index {0, 1,…, 14} at OFDM symbol index 0
- If $N_{\text{Symbol, xPDCCH}} = 2$, then UE shall blindly decode the xPDCCH candidates in search space of index {0, 1, 2, 3} and {8, 9, …, 14} both at OFDM symbol index 0 and 1

If no value for $N_{\text{Symbol, xPDCCH}}$ is provided by higher layers, then UE shall assume $N_{\text{Symbol, xPDCCH}} = 2$ as a default value.

Table 10.1-1: xPDCCH candidates monitored by a UE

Search space			Number of xPDCCH candidates	
Type	Aggregation level L	Size [in xREGs]	$N_{\text{Symbol, xPDCCH}} = 1$	$N_{\text{Symbol, xPDCCH}} = 2$
UE specific	2	2	8	8
	4	4	4	8
	8	8	2	4
	16	16	1	2

10.2 Precoding granularity of xPDCCH

A UE may assume that precoding granularity for xPDCCH is multiple REs mapped to a single xREG in the frequency domain. A UE may assume that the same precoder and beam direction applies on all physical resources within a precoding granularity.

11 Physical uplink control channel procedures

11.1 UE procedure for determining physical uplink channel assignment

In subframe *n*, uplink control information (UCI) shall be transmitted

- on xPUCCH if the UCI transmission is triggered by DL DCI and if the UCI payload size is not larger than 22 bits.
- on xPUCCH if the UCI transmission is triggered by DL DCI and if the UCI payload size is larger than 22 bits, in which case UCIs with lower priority are dropped according to the following priority rule; HARQ-ACK, SR, BSI, BRI, CQI/PMI/RI with decreasing order of the priority.
- on xPUSCH if the UCI transmission is triggerd by UL DCI.

The UE shall use xPUCCH resource ($n_{PUCCH}^{(2)}$) in subframe n, $n_{PUCCH}^{(2)}$ shall be indicated in the DCI.

A UE transmits xPUCCH only on the cell where xPDCCH is transmitted.

A UE transmits only one xPUCCH in a subframe.

For a UE, the transmission of xPUCCH shall not be allocated in the same OFDM symbols for the transmission of xPUSCH or SRS.

A UE is configured by higher layers to transmit xPUCCH on one antenna port $(p = p_0)$ or two antenna ports $(p \in [p_0, p_1])$, and one antenna port transmission is the default xPUCCH transmission mode.

11.1.1 xPUCCH information

Using the xPUCCH formats defined in subclauses 5.4.1 and 5.4.2 in [2], the following combinations of UCI on xPUCCH are supported:

- 1-bit to 22-bit of UCI including HARQ-ACK and/or SR and/or CSI report and/or beam state information (BSI) feedback and/or beam refinement information (BRI) feedback

The scrambling initialization of xPUCCH is by C-RNTI.

11.1.2 HARQ-ACK feedback procedures

For a serving cell *c*, ACK/NACK multiplexing mode is supported across multiple codewords received at the different subframes where the number of HARQ-ACK bits is configured by higher-layer signalling. Cross-carrier HARQ-ACK reporting is not supported.

A UE uses xPUCCH format 2 for HARQ-ACK reporting.

11.1.3 Scheduling Request (SR) procedure

For the case of SR transmission on xPUCCH, 1 bit scheduling request information (1 = positive SR; 0 = negative SR) is always multiplexed when other UCI(s) are transmitted on xPUCCH. UE shall perform SR-only transmission using xPUCCH triggered by a DL DCI which has the RB assignment as ‘zero RB’, i.e., ‘state 325’ and the CSI / BSI / BRI request as none, i.e., ‘state 000’ [3].

11.2 Uplink HARQ-ACK timing

The timing follows the rule defined in Section 8.4.

12 Phase Compensation Reference Signal related procedures

12.1 DL PCRS procedures

If UE detects an xPDCCH with DCI format B1 or B2 in subframe *n* intended for the UE and the DL PCRS field in the detected DCI is not set to 00, the UE shall receive DL PCRS at the PCRS antenna port(s) indicated in the DCI according to subclause 6.7.6 of [2] in the corresponding subframe.

12.2 UL PCRS procedures

If UE detects a xPDCCH with DCI format A1 or A2 in subframe *n* intended for the UE and the UL PCRS field in the detected DCI is not set to 00, then UE shall transmit UL PCRS according to subclause 5.5.5 of [2] in subframe $n+4+l+m$ using antenna port indicated in the DCI. The parameters m and l are indicated by the DCI.

13 DMRS procedures

In both DL and UL, UE shall assume the relative transmit power of the DMRS compared to the xPDSCH/xPUSCH per layer is set to 6 dB.