Verizon 5G TF;
Air Interface Working Group;
Verizon 5th Generation Radio Access;
Physical layer procedures
(Release 1)

06, 2016

Cisco, Ericsson, Intel Corp., LG Electronics, Nokia, Qualcomm Technologies Inc., Samsung Electronics & Verizon

V 1.3

Document History

Version	Date	Change	Verizon POC
0.1	2016-05-16	Draft version created	
0.8	2016-06-07	Agreements reached during 213 CCs #1-3	
	2016-06-15	Beam refinement, BRRS management & UE procedure for reporting BRI (agreements reached during CC - 8 June 16)	
	2016-06-15	Beam acquisition & tracking, and UE procedure for reporting BSI (agreements reached in email discussion after CC - 8 June 16)	
	2016-06-15	UE procedure for reporting HARQ-ACK	
0.9	2016-06-15	New draft release	
	2016-06-24	Correction to physical non-synchronized random access procedure	
	2016-06-24	Modulation order and transport block size determination and Storing soft channel bits	
	2016-06-24	UL PCRS procedures	
	2016-06-24	Beam Recovery Procedures	
	2016-06-24	DMRS procedures	
	2016-06-24	BRS based beam procedure	
	2016-06-24	DL codebook correction	
	2016-06-24	Add section 9.1.1, 9.1.2 and 9.1.3	
1.0	2016-06-24	First version approved	

Document Approvals

Name	Title	Company	Date of Approval

Table of Contents

List of Figures

List of Tables

1 Scope

The present document describes the physical layer procedures for Verizon 5G Radio.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a V5G document, a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1]: TS V5G.201: "Verizon 5G Radio Access (V5G RA); Physical layer; General description".
[2]: TS V5G.211: "Verizon 5G Radio Access (V5G RA); Physical channels and modulation".
[3]: TS V5G.212: "Verizon 5G Radio Access (V5G RA); Multiplexing and channel coding".
[4]: TS V5G.321: "Verizon 5G Radio Access (V5G RA); 5G Medium Access Control Protocol".
[5]: TS V5G.331: "Verizon 5G Radio Access (V5G RA); 5G Radio Resource Control (5G-RRC) Protocol Specification".

3 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 OFDM symbols in an uplink slot as defined in [2]

N_{sc}^{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.

5GNB	5G NodeB
CCE	Control Channel Element
CDD	Cyclic Delay Diversity
CSI	Channel-State Information
DCI	Downlink Control Information
DM-RS	Demodulation Reference Signal
PRB	Physical Resource Block
REG	Resource-Element Group
SCG	Secondary Cell Group
SRS	Sounding Reference Signal
VRB	Virtual Resource Block
xPBCH	5G Physical Broadcast CHannel
xPDCCH	5G Physical Downlink Control CHannel
xPDSCH	5G Physical Downlink Shared CHannel
xPRACH	5G Physical Random Access CHannel
xPUCCH	5G Physical Uplink Control CHannel
xPUSCH	5G Physical 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.

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 ports 300 – 313 and the antenna port for the primary/secondary synchronization signals of a serving cell are quasi co-located (as defined in [2]) with respect to Doppler shift and average delay.

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.

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, …, 656, where an amount of the timing alignment is given by $N_{TA} = T_A$. N_{TA} is defined in [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

UE acquires beams for downlink reception and uplink transmissions from beam reference signals (BRS). Up to 8 antenna ports are supported for beam reference signal (BRS). UE performs RSRP measurement on the beams transmitted in BRS by the 5GNB. UE determines BRS periodicity from 2-bit 'BRS period' value in xPBCH.

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). Initially, candidate beam set includes 4 beams with the highest BRSRP.

UE reports BSI on xPUCCH or xPUSCH as indicated by 5GNB per clause 8.3. 5GNB may send BSI trigger 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={1, 2, 4} beams with the highest BRSRP in the candidate beam set, where N is provided in the 2-bit BSI trigger from 5GNB. The BSI reports are sorted in decreasing order of BRSRP.

5.2 Beam refinement

BRRS is triggered by a 3-bit BRI request field in the DCI. A UE can also request BRRS using SR [4]. The Beam Adjustment Request (BAR) is used to request the serving 5GNB to transmit BRRS. The higher layers provide different combinations of band number, cyclic shift and parameter to the physical layer to transmit 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 5GNB.

A UE can be configured with one or more (up to 4) Beam Refinement (BR) processes by higher layers. A 2-bit resource configuration 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 configuration field for xPDCCH with DL or UL DCI

Value of resource configuration 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 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 one or more 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). FFS: Number of BRRS resources can be configured per BR process.	FFS
Resource allocation type	0 : subframe type allocation 1 : symbol type allocation	3 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 configuration, 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 a set of BRRS resources.

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, 5GNB 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

Downlink power control determines the energy per resource element (EPRE). The term resource element energy denotes the energy prior to CP insertion. The term resource element energy also denotes the average energy taken over all constellation points for the modulation scheme applied. Uplink power control determines the average power over an OFDM symbol in which the physical channel is transmitted.

6.1 Uplink power control

Uplink power control controls the transmit power of the different uplink physical channels.
In cases of multiple component carrier or multiple beam transmission, the UE shall, for subframe *i*,

- Compute the transmit power for each scheduled xPUSCH, xPUCCH, SRS transmission independently according to the procedures in Sections 6.1.1, 6.1.2 and 6.1.3 for subframe *i*.
- If the total transmit power in any OFDM symbol in subframe *i* exceeds the UE's maximum allowed transmit power limit, the UE shall scale the transmit power for all physical channels and OFDM symbols in subframe *i* using one single scaling value such that its maximum transmit power does not exceed the UE's maximum allowed power limit for all OFDM symbols within subframe *i*.
- Compute the power headroom described in Section 6.1.1.2 per component carrier/beam.

6.1.1 Physical uplink shared channel

6.1.1.1 UE behaviour

The setting of the UE Transmit power $P_{\mathrm{xPUSCH,c}}(i)$ for the physical uplink shared channel (xPUSCH) transmission in subframe *i* for the serving cell *c* is defined by

$$P_{\text{xPUSCH,c}}(i) = min\left\{\begin{matrix} P_{\text{CMAX},c}(i), \\ 10\log_{10}(M_{\text{xPUSCH,c}}(i)) + P_{\text{O\_xPUSCH,c}}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF,c}}(i) + f_c(i) \end{matrix}\right\} \text{ [dBm]}$$

where,

- $P_{\text{CMAX,c}}(i)$ is the configured UE transmitted power defined in [5GTF.101] in subframe *i* for serving cell *c*
- $M_{\text{xPUSCH.c}}(i)$ is the bandwidth of the xPUSCH resource assignment expressed in number of resource blocks valid for subframe *i* for serving cell *c*.
- $P_{\text{O\_xPUSCH}}(j)$ is a parameter composed of the sum of a cell specific nominal component $P_{\text{O\_NOMINAL\_ xPUSCH,c}}(j)$ for serving cell *c* provided from higher layers and a UE specific component for serving cell *c* $P_{\text{O\_UE\_xPUSCH,c}}(j)$ provided by higher layers. For xPUSCH (re)transmissions corresponding to a dynamic scheduled grant then *j=1* and for xPUSCH (re)transmissions corresponding to the random access response grant then *j=2*. $P_{\text{O\_UE\_xPUSCH,c}}(2) = 0$ and $P_{\text{O\_NOMINAL\_xPUSCH,c}}(2) = P_{\text{O\_PRE}} + \Delta_{PREAMBLE\_Msg3}$, where the parameter PREAMBLE_INITIAL_RECEIVED_TARGET_POWER [4] ($P_{\text{O\_PRE}}$) and $\Delta_{PREAMBLE\_Msg3}$ are signalled from higher layers.
- For *j*=*1*, $\alpha_c(j) \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ where these parameter value is provided from higher layer for serving cell *c*. For *j*=2, $\alpha_c(j) = 1.$
- PL_c is the downlink beamformed pathloss estimate calculated in the UE for serving cell *c* in dB:
  - PL_c is derived from the B-RSRP measurement by the UE, using the BRS reference signal for serving cell *c*, computed for serving beam for the UE.
  - PL_c = referenceBeamSignalPower – higher layer filtered B-RSRP, where referenceBeamSignalPower is provided by higher layers and B-RSRP is for serving cell *c* and the higher layer filter configuration is defined in [5] for service cell *c*.
- $\Delta_{TF,c}(i) = 10\log_{10}\left(\left(2^{BPRE \cdot K_s} - 1\right) \cdot \beta_{offset}^{xPUSCH}\right)$ 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 for each serving cell c. $BPRE$ and β_{offset}^{xPUSCH}, for each serving cell c, are computed as below. $K_S = 0$ for transmission mode 2.
  - $BPRE = O_{\text{CQI}} / N_{\text{RE}}$ 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 $N_{RE} = M_{sc}^{xPUSCH-initial} \cdot N_{symb}^{xPUSCH\text{-}initial}$, where C, K_r, $M_{sc}^{xPUSCH-initial}$ and $N_{symb}^{xPUSCH\text{-}initial}$ are defined in [3].
  - $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$ for control data sent via xPUSCH without xUL-SCH data and 1 for other cases.

- $\delta_{\mathrm{PUSCH,c}}$ is a UE specific correction value, also referred to as a TPC command and is included in xPDCCH with DCI format A1/A2 for serving cell c . The current xPUSCH power control adjustment state is given by $f_c(i)$ which is defined by:
  - $f_c(i) = f_c(i-1) + \delta_{\mathrm{xPUSCH,c}}(i - K_{\mathrm{xPUSCH}})$ if accumulation is enabled based on the UE-specific parameter *Accumulation-enabled* provided by higher layers
    - where $\delta_{\mathrm{xPUSCH,c}}(i - K_{\mathrm{xPUSCH}})$ was signalled on xPDCCH with DCI format A1/A2 on subframe $i - K_{\mathrm{xPUSCH}}$, and where $f_c(0)$ is the first value after reset of accumulation.
    - K_{xPUSCH} is the number of subframes between the reception of the DCI format and the corresponding xPUSCH transmission.
    - The $\delta_{\mathrm{xPUSCH,c}}$ dB accumulated values signalled on xPDCCH with DCI format A1/A2 are given in Table 6.1.1.1-1.
    - The $\delta_{\mathrm{xPUSCH,c}}$ 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 for serving cell *c*
      - when $P_{\mathrm{O\_UE\_xPUSCH,c}}$ value is changed by higher layers
      - when the UE receives random access response message for serving cell *c*
  - $f_c(i) = \delta_{\mathrm{PUSCH,c}}(i - K_{\mathrm{PUSCH}})$ if accumulation is not enabled for serving cell *c* based on the UE-specific parameter *Accumulation-enabled* provided by higher layers
    - where $\delta_{\mathrm{PUSCH,c}}(i - K_{\mathrm{PUSCH}})$ was signalled on xPDCCH with DCI format A1/A2 on subframe $i - K_{\mathrm{xPUSCH}}$
    - K_{xPUSCH} is the number of subframes between the reception of the DCI format A1/A2 and the corresponding xPUSCH transmission.
    - The $\delta_{\mathrm{xPUSCH,c}}$ dB absolute values signalled on xPDCCH with DCI format A1/A2 are given in Table 6.1.1.1-1.
    - $f_c(i) = f_c(i-1)$ for a subframe where no xPDCCH with DCI format A1/A2 is decoded for serving cell *c* or where DRX occurs or *i* is not an uplink subframe in TDD.
  - For both types of $f_c(*)$ (accumulation or current absolute) the first value is set as follows:
    - If $P_{\mathrm{O\_UE\_xPUSCH,c}}$ value is changed by higher layers,
      - $f_c(0) = 0$
    - Else
      - $f_c(0) = 0$ 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_{xPUSCH} values.

TPC Command Field in DCI format A1/A2	Accumulated $\delta_{\mathrm{xPUSCH,c}}$ [dB]	Absolute $\delta_{\mathrm{xPUSCH,c}}$ [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 serving cell *c* is defined by

$$\mathrm{PH(i)} = \mathrm{P_{CMAX}}\text{-}\left\{10\log_{10}\left(\mathrm{M_{PUSCH}(i)}\right) + \mathrm{P_{O_{PUSCH}}} + \alpha \cdot \mathrm{PL} + \Delta_{\mathrm{TF}}(\mathrm{i}) + \mathrm{f(i)}\right\}$$

$$PH_{\mathrm{c}}(i) = P_{\mathrm{CMAX},c}(i) - \left\{10\log_{10}(M_{\mathrm{PUSCH,c}}(i)) + P_{\mathrm{O\_PUSCH,c}}(j) + \alpha_c(j)\cdot PL_c + \Delta_{\mathrm{TF,c}}(i) + f_c(i)\right\}$$

[dB]

where, $\mathrm{P_{CMAX}}, \mathrm{M_{PUSCH}(i)}, \mathrm{P_{O\_PUSCH}}, \alpha, \mathrm{PL}, \Delta_{\mathrm{TF}}(\mathrm{i}), \mathrm{f(i)}$ $P_{\mathrm{CMAX},c}(i)$, $M_{\mathrm{PUSCH,c}}(i)$, $P_{\mathrm{O\_PUSCH,c}}(j)$, $\alpha_c(j)$, PL_c, $\Delta_{\mathrm{TF},c}(i)$ and $f_c(i)$ 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* for serving cell *c* is defined by

$$P_{\mathrm{xPUCCH,c}}(i) = min\begin{Bmatrix} P_{\mathrm{CMAX,c}}(i), \\ P_{\mathrm{0\_xPUCCH,c}} + PL_c + h_c\left(n_{CQI}, n_{BI}, n_{HARQ}, n_{SR}\right) + \Delta_{\mathrm{F\_xPUCCH,c}}(F) + \Delta_{TxD}(F') + g(i) \end{Bmatrix}$$

[dBm]

where

- $P_{\mathrm{CMAX,c}}(i)$ is the configured UE transmitted power defined in [5GTF 101] in subframe *i* for serving cell *c*
- The parameter $\Delta_{\mathrm{F\_xPUCCH,c}}(F)$ is provided by higher layers. Each $\Delta_{\mathrm{F\_xPUCCH,c}}(F)$ value corresponds to a xPUCCH format (*F*) relative to xPUCCH format 1a, where each xPUCCH format (*F*) is 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, $\Delta_{TxD}(F')=0$.
- $h_c(n_{CQI}, n_{BI}, n_{HARQ}, n_{SR})$ is an xPUCCH format dependent value for serving cell *c*, where n_{CQI} corresponds to the number information bits for the channel quality information defined in section 5.2.3.3.1 in [3], n_{BI} corresponds to the number information bits for the beam-related information defined in section 5.2.3.4.1 and section 5.2.3.4.2 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 xPUCCH format 2 and when UE transmits HARQ-ACK along with CSI, BSI, and/or BRI.
    – If the UE is configured by higher layers to transmit xPUCCH format 2 on two antenna ports, or if the UE transmits more than 11 bits of HARQ-ACK, SR, CSI, and BI(BSI or BRI).

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

- $P_{\mathrm{O\_xPUCCH,c}}$ is a parameter composed of the sum of a cell specific parameter $P_{\mathrm{O\_NOMINAL\_xPUCCH,c}}$ provided by higher layers for serving cell *c* and a UE specific component $P_{\mathrm{O\_UE\_xPUCCH,c}}$ provided by higher layers for serving cell *c*.
- PL_c is the parameter as defined in Section 6.1.1.1.
- $\delta_{\mathrm{xPUCCH,c}}$ is a UE specific correction value for serving cell *c*, also referred to as a TPC command, included in a xPDCCH with DCI format B1/B2 for serving cell *c*.
  – If the UE decodes a xPDCCH with DCI format B1/B2 and the corresponding detected RNTI equals the C-RNTI of the UE, the UE shall use the $\delta_{\mathrm{PUCCH,c}}$ provided in that xPDCCH.
  – $g_c(i) = g_c(i-1) + \delta_{\mathrm{xPUCCH,c}}(i-k_0)$ where $g_c(i)$ is the current xPUCCH power control adjustment state for serving cell *c*.
    – $k_0 = 4$ is the delay between the DL DCI grant to the corresponding xPUCCH transmission.
    – The $\delta_{\mathrm{xPUCCH,c}}$ dB values signalled on xPDCCH with DCI format B1/B2 are given in Table 6.1.2.1-1.
    – The initial value of $g_c(i)$ is defined as
      – $P_{\mathrm{O\_UE\_xPUCCH,c}}$ value is changed by higher layers,
        – $g_c(i) = 0$
    – 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 $P_{\mathrm{O\_UE\_xPUCCH,c}}$ value for serving cell *c* is changed by higher layers
      – when the UE receives a random access response message
    – $g_c(i) = g_c(i-1)$ if i is not an uplink subframe in serving cell *c*.

Table 6.1.2.1-1: Mapping of TPC Command Field in DCI format B1/B2 to $\delta_{\mathrm{xPUCCH},c}$ values.

TPC Command Field in DCI format B1/B2	$\delta_{\mathrm{xPUCCH},c}$ [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 $P_{\mathrm{xSRS},c}$ for the Sounding Reference Symbol transmitted on subframe *i* for serving cell *c* is defined by

$$P_{\mathrm{xSRS},c}(i) = min\left\{ P_{\mathrm{CMAX},c}(i), P_{\mathrm{xSRS\_OFFSET},c}(m) + 10log_{10}(M_{\mathrm{xSRS},c}) + P_{\mathrm{O\_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + f_c(i) \right\}$$

[dBm]

where

- $P_{\mathrm{CMAX},c}(i)$ is the configured UE transmitted power defined in [5GTF 101] in subframe *i* for serving cell *c*
- For $K_S = 1.25$, $P_{\mathrm{xSRS\_OFFSET},c}$ is a 4-bit UE specific parameter semi-statically configured by higher layers with 1dB step size in the range [-3, 12] dB for serving cell *c*.
- For $K_S = 0$, $P_{\mathrm{xSRS\_OFFSET},c}$ 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 for serving cell *c*
- $M_{\mathrm{xSRS},c}$ is the bandwidth of the SRS transmission in subframe *i* for serving cell *c* expressed in number of resource blocks.
- $f_c(i)$ is the current xPUSCH power control adjustment state for serving cell *c* see Section 6.1.1.1.
- $P_{\mathrm{O\_PUSCH},c}(j)$ and $\alpha_c(j)$ are parameters as defined in Section 6.1.1.1, where $j = 1$,.
- PL_c is the parameter as defined in Section 6.1.1.1.

7 Random access procedure

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 receives the following information from the higher layers:

- Ingredients of the look up table that maps the symbol containing strong received sync beam to the symbol l of the RACH signal
- Root u and cyclic shift v.
- 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 5GNB 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 selected 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 [5]. NumberOfRA-preamble denotes preamble indices for contention based RACH transmission among available preambles.
- Physical layer uses SFN, NBRS, NRACH, *M*, *m* and $S_{Sync}^{BestBeam}$ to calculate the symbol index l, as described in 5.7.2.1. of [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 $P_{\text{CMAX}}(i)$ 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 the beam determined by UE . It is assumed that xPRACH is transmitted with the same subarray and beam that was used when the samples of the 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 [4], subclause 5.1.4). 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 subframe $n+k_1$, where k_1 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 as it is outlined in [3]. 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 UE shall use the single-antenna port uplink transmission scheme for the xPUSCH transmission corresponding to the random access response grant and the xPUSCH 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 xPRACH. TPC command requires 3 bits.

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 xPUSCH

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

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 [2] the physical layer is 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 5GNB applies different rx –beams,
- 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 selected sync beam, S_{sync}^{beam}

Here the root u is cell specific. UE uses SFN, N_{BRS}, N_{RACH}, M, m and S_{sync}^{beam} to calculate the symbol index l, as described in 5.7.2.1 of [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 single transport block.

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	Transmission scheme of xPDSCH corresponding to xPDCCH
DCI format B1	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	Transmission scheme of xPDSCH corresponding to xPDCCH
Mode 1	DCI format B1	Single-antenna port (see subclause 8.1.1)
Mode 2	DCI format B1	Transmit diversity (see subclause 8.1.2)
Mode 3	DCI format B1	Transmit diversity (see subclause 8.1.2)
	DCI format B2	Up to 2 layer transmission (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	Transmission scheme of xPDSCH corresponding to xPDCCH
DCI format B1	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 an 5GNB transmission on the xPDSCH would be performed according to subclause 6.3.4.1 of [3]. 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 an 5GNB transmission on the xPDSCH would be performed according to subclause 6.3.4.3 of [2].

8.1.3 Multiplexing scheme

For the up to 2 layer transmission scheme of the xPDSCH, the UE may assume that an 5GNB transmission on the xPDSCH would be performed with up to 2 transmission layers on antenna ports 8 - 15 as defined in subclause 6.3.4.4 of [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 $(L_{VCRBGs} - 1) \le \left\lfloor N_{VRBG}^{DL} / 2 \right\rfloor$ 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 $L_{VCRBGs} \ge 1$ 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.

UE shall discard the xPDCCH in the 2nd symbol when a DL DCI is successfully decoded in the 1st symbol and the MSB value of xPDSCH range field in the DL DCI is set to 0. UE assume that misconfiguration occurs when a DL DCI is successfully decoded in the 2nd symbol and MSB value of xPDSCH range field in the DL DCI is set to 0. If misconfiguration is detected, a UE shall discard the DL DCI.

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 5GNB 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 xPDSCH. For retransmission, 5GNB 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 parity check matrix determination

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

Table 8.1.5.1-1: Modulation and parity check matrix index table for xPDSCH

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

Parity check matrix for LDPC coding is described in Tables from 5.1.3.2-2 to 5.1.3.2-5 in [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_{TBS}	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 8.1.6.2.1-1.

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 four PRBs mapped to a single VRBG in the frequency domain,

For the xPDSCH assigned by DCI format B2,

- If I_{PRG} = 0, a UE may assume that precoding granularity for xPDSCH is four PRBs mapped to a single VRBG in the frequency domain
- If I_{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 5GNB. For spatial multiplexing, as given in [2], the UE shall determine a RI corresponding to the number of useful transmission layers. For transmit diversity as given in [2], RI is equal to one.

A UE can be configured with one or more CSI processes per serving cell by higher layers. Each CSI process is associated with a CSI-RS resource (defined in subclause 8.2.5) and a CSI-interference measurement (CSI-IM) resource (defined in subclause 8.2.6). A CSI reported by the UE corresponds to a CSI process configured by higher layers. Each CSI process can be configured with or without PMI/RI reporting by higher layer signalling.

If CSI reporting request is triggered via downlink DCI, then CSI shall be reported on xPUCCH. Otherwise, if CSI reporting request is triggered via uplink DCI, then CSI shall be reported on xPUSCH.

CSI reporting is aperiodic.

8.2.1 CSI Reporting using xPUSCH

If CSI request 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 $n+4+m+l$. 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 via 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 $n+4+m+k$. 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 for reporting CQI based on QPSK, 16QAM and 64QAM.

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 (defined in [2]) within a configured CSI-RS resource associated with 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 only the configured CSI-IM resource associated with 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.

In the CSI reference resource, 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 3rd OFDM symbol is occupied by DM-RS.
- Phase noise compensation reference signal (PCRS) overhead is zero.
- The precoding shall be taken into account.
- If CSI-RS is used for channel measurements, the ratio of xPDSCH EPRE to CSI-RS EPRE is as given in subclause 8.2.5

Table 8.2.3-1: 4-bit CQI Table

CQI index	modulation	code rate	efficiency
0	out of range		
1	QPSK	1/14	0.14
2	QPSK	1/5	0.4
3	QPSK	1/3	0.67

4	QPSK	1/2	1
5	QPSK	2/3	1.33
6	QPSK	5/6	1.67
7	16QAM	1/2	2
8	16QAM	3/5	2.4
9	16QAM	2/3	2.67
10	16QAM	3/4	3
11	16QAM	5/6	3.33
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	$u_0=\begin{bmatrix}1 & -1 & -1 & -1\end{bmatrix}^T$	$W_0^{\{1\}}$	$W_0^{\{14\}}/\sqrt{2}$
1	$u_1=\begin{bmatrix}1 & -j & 1 & j\end{bmatrix}^T$	$W_1^{\{1\}}$	$W_1^{\{12\}}/\sqrt{2}$
2	$u_2=\begin{bmatrix}1 & 1 & -1 & 1\end{bmatrix}^T$	$W_2^{\{1\}}$	$W_2^{\{12\}}/\sqrt{2}$
3	$u_3=\begin{bmatrix}1 & j & 1 & -j\end{bmatrix}^T$	$W_3^{\{1\}}$	$W_3^{\{12\}}/\sqrt{2}$
4	$u_4=\begin{bmatrix}1 & (-1-j)/\sqrt{2} & -j & (1-j)/\sqrt{2}\end{bmatrix}^T$	$W_4^{\{1\}}$	$W_4^{\{14\}}/\sqrt{2}$
5	$u_5=\begin{bmatrix}1 & (1-j)/\sqrt{2} & j & (-1-j)/\sqrt{2}\end{bmatrix}^T$	$W_5^{\{1\}}$	$W_5^{\{14\}}/\sqrt{2}$
6	$u_6=\begin{bmatrix}1 & (1+j)/\sqrt{2} & -j & (-1+j)/\sqrt{2}\end{bmatrix}^T$	$W_6^{\{1\}}$	$W_6^{\{13\}}/\sqrt{2}$
7	$u_7=\begin{bmatrix}1 & (-1+j)/\sqrt{2} & j & (1+j)/\sqrt{2}\end{bmatrix}^T$	$W_7^{\{1\}}$	$W_7^{\{13\}}/\sqrt{2}$
8	$u_8=\begin{bmatrix}1 & -1 & 1 & 1\end{bmatrix}^T$	$W_8^{\{1\}}$	$W_8^{\{12\}}/\sqrt{2}$
9	$u_9=\begin{bmatrix}1 & -j & -1 & -j\end{bmatrix}^T$	$W_9^{\{1\}}$	$W_9^{\{14\}}/\sqrt{2}$
10	$u_{10}=\begin{bmatrix}1 & 1 & 1 & -1\end{bmatrix}^T$	$W_{10}^{\{1\}}$	$W_{10}^{\{13\}}/\sqrt{2}$
11	$u_{11}=\begin{bmatrix}1 & j & -1 & j\end{bmatrix}^T$	$W_{11}^{\{1\}}$	$W_{11}^{\{13\}}/\sqrt{2}$
12	$u_{12}=\begin{bmatrix}1 & -1 & -1 & 1\end{bmatrix}^T$	$W_{12}^{\{1\}}$	$W_{12}^{\{12\}}/\sqrt{2}$
13	$u_{13}=\begin{bmatrix}1 & -1 & 1 & -1\end{bmatrix}^T$	$W_{13}^{\{1\}}$	$W_{13}^{\{13\}}/\sqrt{2}$
14	$u_{14}=\begin{bmatrix}1 & 1 & -1 & -1\end{bmatrix}^T$	$W_{14}^{\{1\}}$	$W_{14}^{\{13\}}/\sqrt{2}$
15	$u_{15}=\begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}^T$	$W_{15}^{\{1\}}$	$W_{15}^{\{12\}}/\sqrt{2}$

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 resource configuration(s). If CSI request is triggered via DCI in subframe n, then CSI-RS is allocated in subframe n+moffset, where the CSI-RS allocation offset, moffset, is indicated in range of 0 to 3 via DCI. The CSI-RS can be allocated on {13th}, {14th}, or {13th and 14th} OFDM symbol(s) via DCI. The following parameters for CSI-RS are configured via higher layer signaling for each CSI-RS resource configuration:

- CSI-RS resource configuration identity
- Number of CSI-RS ports. The allowable values and port mapping are given in subclause 6.7.3 of [2].

- CSI-RS Configuration
- UE assumption on reference xPDSCH transmitted power for CSI feedback P_c for each CSI process.
- Pseudo-random sequence generator parameter, n_{ID}.

P_c is the assumed ratio of xPDSCH 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 configuration are quasi co-located (as defined in [3]) with respect to delay spread, Doppler spread, Doppler shift, average gain, and average delay.

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

A UE can be configured with one or more CSI-IM resource configuration(s). A CSI-IM is allocated in the same subframe CSI-RS is allocated. The following parameters are configured via higher layer signaling for each CSI-IM resource configuration:

- CSI-IM Configuration

8.3 UE procedure for reporting Beam State Information (BSI)

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

If UE receives BSI trigger in DL DCI, UE reports BSI on xPUCCH. The time/frequency resource for xPUCCH is indicated in the DL DCI that triggers BSI.. When reporting on xPUCCH, UE reports BSI for a beam with the highest BRSRP in the candidate beam set.If UE receives BSI trigger in UL DCI or in RAR grant, UE reports BSI on xPUSCH. The time/frequency resource for xPUSCH is indicated in the UL DCI or RAR grant that triggers BSI. When reporting BSI on xPUSCH, UE reports BSI for N={1, 2, 4} beams with the highest BRSRP in the candidate beam set, where N is provided in the 2-bit BSI trigger from 5GNB.

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 trigger, UE shall report BSI using xPUSCH in subframe $n+4+m+l$, where parameters $m=0$ and $l=\{0, 1, \dots 7\}$ is indicated by the UL DCI.

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

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

A UE shall report BSI for a beam with the highest BRSRP in the candidate beam set.

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 BRSRP definition

The BRSRP indices and their interpretations are given in Table 8.3.3-1. 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.

The UE shall derive BRSRP values from the beam measurements based on BRS defined in [2]. The UE shall derive BRSRP index from the measured BRSRP value.

Table 8.3.3-1: 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

8.3.4 BRS management

There are two beam switch procedures, which are MAC-CE based beam switch and DCI based beam switch.

For the MAC-CE [4] based beam switch, 5GNB commands UE to switch the beam via MAC-CE. The beam switch command includes a logical beam index defined in section 6.7.4.3 of [2].

The serving beam at UE is changed to the beam corresponding to the beam indicated by MAC-CE commad. The beam swiching shall apply from the beginning of subframe $n+k_{beamswitch\text{-}delay\text{-}mac}$ where subframe n is the timing of ACK transmission and $k_{beamswitch\text{-}delay\text{-}mac} = 14$. The UE shall assume that the 5GNB beam associated with xPDCCH, xPDSCH, CSI-RS, xPUCCH, xPUSCH, xSRS is swiched to the beam indicated in the 5GNB command from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}mac}$.

For the DCI based beam switch, 5GNB tirggers BSI reporting via DCI. The UE reports N beams in the candidate beam set as described in Section 5.1, 8.3.1 and 8.3.2.

If *beam_switch_indication* field=1 in the DCI, the serving beam at UE is changed to the beam corresponding to the first beam of the reported N beams. The beam swiching shall apply from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}dic}$ where n is the timing of BSI/R-BSI reporting and $k_{beam\text{-}switch\text{-}delay\text{-}dci}$ = 11.

If *beam_switch_indication* field=0 in the DCI, the UE shall not adjust the serving beam. The UE shall assume that the 5GNB beam is not switched.

For any given subframe, if there is a conflict between UE beam adjustment according to a the beam switch command and BSI/R-BSI request DCI, the UE beam adjustment is chosen that is associated with the most recently received command/request. A UE is not expected to receive multiple command/request for UE beam adjustment in the same subframe.

8.4 UE procedure for reporting Beam Refinement Information (BRI)

8.4.1 BRI reporting using xPUSCH

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

The 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 trigger, UE shall report RBI 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 is not expected to receive more than one BRI report request for a given subframe.

A UE is semi-statically configured by higher layers to feed back BRRS-RP corresponding to the best $k_{BRRS\_Resource}$ BRRS resources. BRI feedback

- For each of the best $k_{BRRS\_Resource}$ BRRS resources:
  - A UE shall report a wideband BRRS-RP value and a BRRS-RI value
  - The reported BRRS-RP value is calculated conditioned on the reported BRRS-RI.

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

8.4.2 BRI reporting using xPUCCH

The DL DCI indicated in subframe n is associated with a BRRS transmission in subframe n+m where m ={0,1,2,3} is indicated by the DL DCI. A UE is not expected to receive more than one BRI report request for a given subframe.

The 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 trigger, 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.

- BRI feedback
  - For the best BRRS resource:
    - A UE shall report a wideband BRRS-RP value and a BRRS-RI value

- The reported BRRS-RP value is calculated conditioned on the reported BRRS-RI.

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.

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 resources. The selected BBRS resource 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
…	…
7	7

8.4.4 BRRS management

A MAC-CE based beam switch procedure is defined for the BRRS [4].

There are two beam switch procedures, which are MAC-CE based beam switch and DCI based beam switch.

For the MAC-CE [4] based beam switch, 5GNB commands UE to switch the beam via MAC-CE. The beam switch command includes BRRS resource ID and the associated BR process ID.

The serving beam at UE is changed to the beam corresponding to the beam indicated by MAC-CE commad. The beam swiching shall apply from the beginning of subframe $n+k_{beamswitch\text{-}delay\text{-}mac}$ where subframe n is the timing of HARQ-ACK transmission associated with the MAC-CE and $k_{beamswitch\text{-}delay\text{-}mac}$ = 14 [FFS]. The UE shall assume that the 5GNB beam associated with xPDCCH, xPDSCH, CSI-RS, xPUCCH, xPUSCH, xSRS is swiched to the beam indicated in the 5GNB command from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}mac}$.

For the DCI based beam switch, 5GNB tirggers BRI reporting via DCI. The UE reports N beams in the candidate beam set as described in Section 8.4.1 and 8.4.2.

If *beam_switch_indication* field=1 in the DCI, the serving beam at UE is changed to the beam corresponding to the first beam of the reported N beams. The beam swiching shall apply from the beginning of subframe $n+k_{beam\text{-}switch\text{-}delay\text{-}dic}$ where n is the timing of BSI/R-BSI reporting and $k_{beam\text{-}switch\text{-}delay\text{-}dci}$ = 11 [FFS].

If *beam_switch_indication* field=0 in the DCI, the UE shall not adjust the serving beam. The UE shall assume that the 5GNB beam is not switched.

For any given subframe, if there is a conflict between UE beam adjustment according to a the beam switch command and BSI/BRI request DCI, the UE beam adjustment is chosen that is associated with the most recently received command/request. A UE is not expected to receive multiple command/request for UE beam adjustment in the same subframe.

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 $a_{B\text{-}1}, \ldots, a_0$ where a_0 is the LSB and $a_{B\text{-}1}$ is the MSB. The size of the bitmap message $B \in \{4, 6, 8\}$ is delivered to the UE by RRC signalling, and the defult value of B is 4. When a new bitmap message is generaged, 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 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 $n^{(2)}_{\mathrm{xPUCCH}}$ = {0, 1, …, 15} which is defined in [2]. UE shall not expect more than one HARQ-ACK reporting channel assignment in freqneucy 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.

If information of HARQ-ACK reporting channel is detected from multiple DL DCIs at different subframes and also if these information indicates the same subframe index *l* and the same xPUCCH index *i*, then all ACK/NACK bits associated with the detected DL DCIs are multiplexed within a single bitmap message. Within a DL DCI, a 3-bit field is included to explicitly indicate the value of $b \in \{0, \ldots, B\text{-}1\}$ which represents the specific position within the bitmap message. If a UE successfully decode 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*-1, UE shall discard the DL DCI.

If information of HARQ-ACK reporting channel detected by a DL DCI indicates a new subframe index *l*, 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.

NDI as signalled on xPDCCH, [the RV as determined in subclause 8.6.1, and the TBS as determined in subclause 8.6.2, shall be delivered to higher layers.]

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	Transmit diversity
	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 6.2 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 6.2 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 5.3.2A.1 of [2].

9.1.2 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 5.3.2A.2 of [2].

9.1.3 Transmit diversity scheme

For the transmit diversity transmission scheme of the xPUSCH, the UE transmission on the xPUSCH is performed according to subclause 5.3.2A.3 of [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 8.1.5 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 in a DL or an UL grant. The transmission occurs k'=k+1 subframes after the grant, where k equals the offset of xPUCCH or xPUSCH transmission given by the respective timing field in DCI as outlined in subclause 5.3.3.1 of [3].

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

No specific HARQ-ACK procedure is required

9.5 UE Reference Symbol procedure

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 and transport block size determination

To determine the modulation order 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
- check the "CSI request" bit field, 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 parity check matrix determination

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

Table 9.6.1-1: Modulation and parity check matrix index table for xPUSCH

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

Parity check matrix for LDPC coding is described in Tables from 5.1.3.2-2 to 5.1.3.2-5 in [3].

9.6.2 Transport block size determination

The TBS is determined by the procedure in sub-clause 8.1.6.2.1.

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 as shown in Figure 10.1-1, 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

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

-

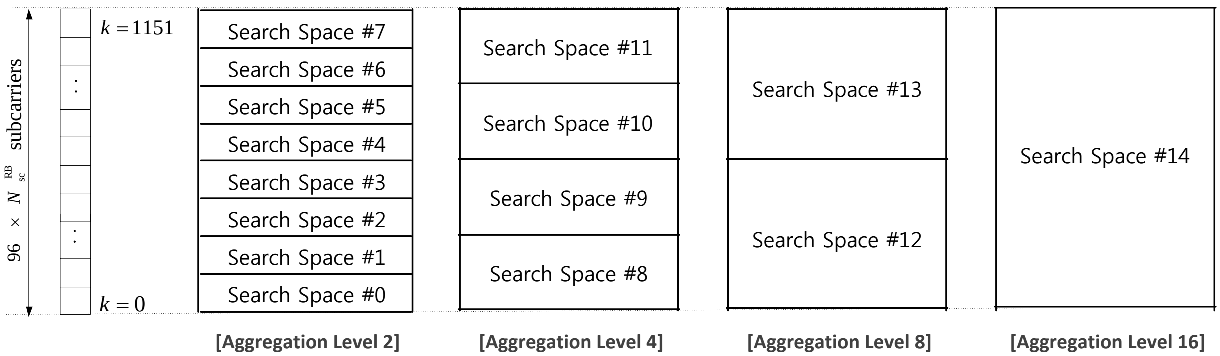

Figure 10.1-1: Search space for blind decoding of xPDCCH

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			Total number of xPDCCH candidates	
Type	**Aggregation level**	**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 xPDCCH control information procedure

A UE shall discard the xPDCCH if consistent control information is not detected.

10.3 xPDCCH precoding granularity

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 using format 2 if the UCI transmission is triggered by DL DCI and if the UCI payload size is not larger than 22 bits.
- on xPUCCH using format 2 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, RI, and CQI/PMI with decreasing order of the priority.
- on xPUSCH if the UCI transmission is triggerd by UL DCI.

The UE shall use xPUCCH resource ($n_{\text{xPUCCH}}^{(i)}$) for transmission of format $i \in \{1/1\text{a}/1\text{b}/2\}$ in subframe *n*, $n_{\text{xPUCCH}}^{(i)}$ shall be indicated in the DCI.

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

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

11.1.1 xPUCCH format 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:

- Format 2 for 3-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 format 2 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

A UE is configured by higher layers to transmit the SR on one antenna port or two antenna ports.

The xPUCCH resource for SR transmission, $n^{(1)}_{\text{xPUCCH}}$ shall be indicated in the DCI.

11.2 Uplink HARQ-ACK timing

The timing follows the rule defined in Section 8.4.

12 Phase Compensation Reference Signal procedures

12.1 DL PCRS procedures

If UE detects an xPDCCH with DCI format B1 or B2 in subframe *n* intended for the UE, 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 a UE detects an xPDCCH with DCI format A1 or A2 in subframe *n* intended for the UE, then UE shall transmit UL PCRS according to subclause 5.5.5 of [2] in subframe $n+4+m+l$ using one or two PCRS antenna ports which are the same as the assigned DM-RS antenna port(s) indicated in the DCI except the following condition. The parameters m and l are indicated by the xPDCCH with DCI format A1 or A2.

- If the dual PCRS field in the detected DCI is set to 1 and the number of assigned DM-RS port for xPUSCH is equal to 1, then UE shall transmit UL PCRS in subframe $n+4+m+l$ using a PCRS port which is the same as the assigned DM-RS antenna port indicated in the DCI and an additional PCRS antenna port which has the same subcarrier position with the assigned PCRS antenna port according to subclause 5.5.5 of [2].
- The relative transmit power ratio of PCRS and xPUSCH is determined by the transmission scheme as defined in Table 12.2-1.

Table 12.2-1: The relative transmit power ratio of PCRS and xPUSCH data on a given layer

Transmission scheme	Relative Transmit Power ratio
Single-layer transmission	3dB
Two-layer transmission	6dB

13 DMRS procedures

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