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

10, 2016
Cisco, Ericsson, Intel Corp., LG Electronics, Nokia, Qualcomm Technologies Inc., Samsung & Verizon
V 1.4

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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".

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]
- $N_{\text{cells}}$: Number of configured cells
- $N_{\text{DL}}$: Downlink bandwidth configuration, expressed in units of $N_{\text{RB}}$ as defined in [2]
- $N_{\text{UL}}$: Uplink bandwidth configuration, expressed in units of $N_{\text{RB}}$ as defined in [2]
- $N_{\text{sym}}$: 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
- **xPBCCH** 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 $Q_{\text{out}}$. When the radio link quality is better than the threshold $Q_{\text{in}}$, 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 $T_A = 0, 1, 2, \ldots, 1200$, where an amount of the timing alignment is given by $N_{TA} = T_A \cdot N_{TA}$. $N_{TA}$ 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 $T_A = 0, 1, 2, \ldots, 63$, where $N_{TA,new} = N_{TA,old} + (T_A-31)$. 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 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 (= 5ms) : 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 xPUCCH or xPUSCH as indicated by 5G NB per clause 8.3. 5G NB 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 $N=\{1, 2, 4\}$ beams with the highest BRSRP in the candidate beam set, where $N$ is provided in the 2-bit BSI request from 5G NB. 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 NB 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 switching shall apply from the beginning of subframe $n+k_{\text{beamswitch-delay-mac}}$ where subframe $n$ is used for HARQ-ACK transmission associated with the MAC-CE and $k_{\text{beamswitch-delay-mac}} = 14$. The UE shall assume that the 5G NB beam associated with xPDCCH, xPDSCH,
CSI-RS, xPUCCH, xPUSCH, and SRS is switched to the beam indicated by the MAC-CE from the beginning of subframe \( n + k_{\text{beam-switch-delay-mac}} \).

For the DCI based beam switch procedure, 5GNB requests a BSI report via DCI and the \textit{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 switching shall apply from the beginning of subframe \( n + k_{\text{beam-switch-delay-dci}} \) where subframe \( n \) is used for sending the BSI report and \( k_{\text{beam-switch-delay-dci}} = 11 \).

If \textit{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 5GNB 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 5GNB.

A UE can be configured with up to 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**

<table>
<thead>
<tr>
<th>Value of resource allocation field</th>
<th>Subframe type allocation</th>
<th>Symbol type allocation</th>
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<tr>
<td>'00'</td>
<td>( 3^{th}, 4^{th}, \ldots, 7^{th} ) symbols (5 symbols in slot 0)</td>
<td>13(^{th}) symbol</td>
</tr>
<tr>
<td>'01'</td>
<td>( 8^{th}, 9^{th}, \ldots, 12^{th} ) symbols (5 symbols in slot 1)</td>
<td>14(^{th}) symbol</td>
</tr>
<tr>
<td>'10'</td>
<td>( 3^{th}, 4^{th}, \ldots, 12^{th} ) symbols (10 symbols)</td>
<td>13 &amp; 14(^{th}) symbols</td>
</tr>
<tr>
<td>'11'</td>
<td>Reserved</td>
<td>Reserved</td>
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**Table 5.2-2: BRRS process indication field for xPDCCH with DL or UL DCI**
## Value of process indication field

<table>
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<tr>
<th>Value of process indication field</th>
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<tr>
<td>'00'</td>
<td>The first BR process configured by the higher layers</td>
</tr>
<tr>
<td>'01'</td>
<td>The second BR process configured by the higher layers</td>
</tr>
<tr>
<td>'10'</td>
<td>The third BR process configured by the higher layers</td>
</tr>
<tr>
<td>'11'</td>
<td>The fourth BR process configured by the higher layers</td>
</tr>
</tbody>
</table>

A BR process comprises of up to 8 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

<table>
<thead>
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<th>Description</th>
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<tr>
<td>BRRS resource ID 0, BRRS resource ID 1, ..., BRRS resource ID 7</td>
<td>8*8=64 bits</td>
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<td>Antenna Ports to be measured for each BRRS resource (up to 8 ports)</td>
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<td>(8 bit bitmap for ports 600 to 607).</td>
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<tr>
<td>Resource allocation type</td>
<td>1 bit</td>
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<td>1 : symbol type allocation</td>
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<td>VCID</td>
<td>9 bits</td>
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<td>Virtual cell ID, N_{ID}^{BRRS}</td>
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</table>

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 8 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], 5GNB 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 switching shall apply from the beginning of subframe $n+K_{beamswitch-delay-mac}$ where subframe $n$ is used for HARQ-ACK transmission associated with the MAC-CE and $K_{beamswitch-delay-mac} = 14$. The UE shall assume that the 5GNB beam associated with xPDCCH, xPDSCH, CSI-RS, xPUCCH, xPUSCH, and SRS is switched to the beam indicated by the MAC-CE from the beginning of subframe $n+K_{beam-switch-delay-mac}$. 
For the DCI based beam switch procedure, 5G NB 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 switching shall apply from the beginning of subframe \( n + k_{\text{beam-switch-delay-dci}} \) where subframe \( n \) is used for sending the BRI report and \( k_{\text{beam-switch-delay-dci}} = 11 \).

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 and has BSIs for beam recovery, the UE shall perform beam recovery process.

**NOTE:** UE can detect that the current serving beam is misaligned based on any UE implementation specific conditions.

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

In UL asynchronous 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 (EPR). 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.
6.1.1 Physical uplink shared channel

6.1.1.1 UE behaviour

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

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

where,

- \( P_{CMAX,c}(i) \) is the configured UE transmitted power defined in [FFS] in subframe \( i \) for serving cell \( c \).
- \( M_{xPUSCH,c}(i) \) is the bandwidth of the xPUSCH resource assignment expressed in number of resource blocks valid for subframe \( i \) for serving cell \( c \).
- \( P_{O,xPUSCH}(j) \) is a parameter composed of the sum of a cell specific nominal component

\[
P_{O,NOMINAL_{xPUSCH,c}}(j) \text{ for serving cell } c \text{ provided from higher layers and a UE specific component for serving cell } c \text{ } P_{O,UE,xPUSCH,c}(j) \text{ provided by higher layers. For xPUSCH (re)transmissions corresponding to a dynamic scheduled grant then } j=1 \text{ and for xPUSCH (re)transmissions corresponding to the random access response grant then } j=2. \]

\[
P_{O,NOMINAL_{xPUSCH,c}}(2) = P_{O,PRE} + \Delta_{PRE_{Msg{3}}} \text{, where the parameter }\]

\[
P_{O,PRE} \text{ and } \Delta_{PRE_{Msg{3}}} \text{ are signalled from higher layers.}
\]

- 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.
  - \( PL_c = \text{referenceBeamSignalPower} - \text{higher layer filtered B-RSRP} \), where

\[
\text{referenceBeamSignalPower} \text{ is provided by higher layers and B-RSRP is for serving cell } c \text{ and the higher layer filter configuration is defined in [5] for service cell } c.
\]

- \( \Delta_{TF,c}(i) = 10 \log_{10} \left( \left( 2^{BP_{PRE,K_S}} - 1 \right) \cdot \rho_{cPUSCH} \right) \text{ for } K_S = 1.25 \text{ and } 0 \text{ for } K_S = 0 \text{ where } K_S \text{ is given by the UE specific parameter } deltaMCS-Enabled \text{ provided by higher layers for each serving cell } c. \text{ } BP_{PRE} \text{ and } \rho_{cPUSCH} \text{, for each serving cell } c \text{, are computed as below. } K_S = 0 \text{ for transmission mode } 2.
\]

- \( BP_{PRE} = O_{CQI} / N_{RE} \) 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
\[ N_{RE} = M'_{SC}^{xPUSCH-initial} \cdot N_{symb}^{xPUSCH-initial} \], where \( C' \), \( K' \), \( M'_{SC}^{xPUSCH-initial} \) and \( N_{symb}^{xPUSCH-initial} \) 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.

• \( \delta_{PUSCH,c} \) 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:

\[ f_c(i) = f_c(i-1) + \delta_{PUSCH,c}(i - K_{PUSCH}) \] if accumulation is enabled based on the UE-specific parameter \( Accumulation-enabled \) provided by higher layers.

- where \( \delta_{PUSCH,c}(i - K_{PUSCH}) \) was signalled on xPDCCH with DCI format A1/A2 on subframe \( i - K_{PUSCH} \), and where \( f_c(0) \) 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 \( \delta_{PUSCH,c} \) dB accumulated values signalled on xPDCCH with DCI format A1/A2 are given in Table 6.1.1.1-1.

- The \( \delta_{PUSCH,c} \) 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 \( P_{O,UE,xPUSCH,c} \) value is changed by higher layers
  - when the UE receives random access response message for serving cell \( c \)

- \( f_c(i) = \delta_{PUSCH,c}(i - K_{PUSCH}) \) if accumulation is not enabled for serving cell \( c \) based on the UE-specific parameter \( Accumulation-enabled \) provided by higher layers.

- where \( \delta_{PUSCH,c}(i - K_{PUSCH}) \) 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 \( \delta_{PUSCH,c} \) 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 \( P_{O,UE,xPUSCH,c} \) 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 $\delta_{cPUSCH}$ values.

<table>
<thead>
<tr>
<th>TPC Command Field in DCI format A1/A2</th>
<th>Accumulated $\delta_{cPUSCH}$ [dB]</th>
<th>Absolute $\delta_{cPUSCH}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1</td>
<td>-4</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

6.1.1.2 Power headroom

The UE power headroom $PH$ valid for subframe $i$ for serving cell $c$ is defined by

$$
PH_c(i) = P_{CMAX,c}(i) - \left\{ 10 \log_{10} (M_{cPUSCH,c}(i)) + P_{cO_{PUSCH,c}}(j) + \alpha_c(j) \cdot PL_c + \Delta_{TF,c}(i) + f_c(i) \right\} [\text{dB}]
$$

where $P_{CMAX,c}(i)$, $M_{cPUSCH,c}(i)$, $P_{O_{PUSCH,c}}(j)$, $\alpha_c(j)$, $PL_c$, $\Delta_{TF,c}(i)$ 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 $P_{cPUSCH}$ for the physical uplink control channel ($cPUSCH$) transmission in subframe $i$ for serving cell $c$ is defined by

$$
P_{cPUSCH}(i) = \min \left\{ P_{CMAX,c}(i), P_{cPUSCH,c} + PL_c + h_c(n_{CQI}, n_{RI}, n_{HARQ}, n_{SR}) + \Delta_{F,cPUSCH,c}(F) + \Delta_{TxD}(F') + g_c(i) \right\} [\text{dBm}]
$$

where

- $P_{CMAX,c}(i)$ is the configured UE transmitted power defined in [FFS] in subframe $i$ for serving cell $c$
- The parameter $\Delta_{F,cPUSCH,c}(F)$ is provided by higher layers. Each $\Delta_{F,cPUSCH,c}(F)$ value corresponds to a $cPUSCH$ format $F$ defined in Table 5.4-1 [2].
- If the UE is configured by higher layers to transmit $cPUSCH$ on two antenna ports, the value of $\Delta_{TxD}(F')$ is provided by higher layers where $cPUSCH$ 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).

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

\( P_{O,xPUCCH,c} \) is a parameter composed of the sum of a cell specific parameter \( P_{O,NOMINAL,xPUCCH,c} \)
provided by higher layers for serving cell \( c \) and a UE specific component \( P_{O,UE,xPUCCH,c} \) provided by higher layers for serving cell \( c \).

\( PL_c \) is the parameter as defined in Section 6.1.1.1.

\( \delta_{xPUCCH,c} \) 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 \( \delta_{xPUCCH,c} \) provided in that xPDCCH.

\[ g_c(i) = g_c(i-1) + \delta_{xPUCCH,c}(i-k_0) \]

where \( g_c(i) \) is the current xPUCCH power control adjustment state for serving cell \( c \).

- \( k_0 \) is the delay between the DL DCI grant to the corresponding xPUCCH transmission.

- The \( \delta_{xPUCCH,c} \) 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

\[ P_{O,UE,xPUCCH,c} \] 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 \( P_{O,UE,xPUCCH,c} \) 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 \( \delta_{xPUCCH,c} \) values.
### TPC Command Field in DCI format B1/B2

<table>
<thead>
<tr>
<th>TPC Command Field in DCI format B1/B2</th>
<th>$\delta_{\text{PUCCH}}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

### 6.1.3 Sounding Reference Symbol

#### 6.1.3.1 UE behaviour

The setting of the UE Transmit power $P_{\text{xSRS},c}$ for the Sounding Reference Symbol transmitted on subframe $i$ for serving cell $c$ is defined by

$$P_{\text{xSRS},c}(i) = \min \left\{ P_{\text{CMAX},c}(i), P_{\text{ASRS OFFSET},c}(m) + 10 \log_{10}(M_{\text{SRS},c}) + P_{\text{O, xPUSCH},c}(j) + \alpha_c(j) \cdot PL_c + f_c(i) \right\} [\text{dBm}]$$

where

- $P_{\text{CMAX},c}(i)$ is the configured UE transmitted power defined in [FFS] in subframe $i$ for serving cell $c$.
- For $K_S = 1.25$, $P_{\text{ASRS OFFSET},c}$ is a 4-bit UE specific parameter semi-statically configured by higher layers with 1 dB step size in the range [-3, 12] dB for serving cell $c$.
- For $K_S = 0$, $P_{\text{ASRS OFFSET},c}$ 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 $c$.
- $M_{\text{SRS},c}$ 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.
- $P_{\text{O, xPUSCH},c}(j)$ 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.

### 6.1.4 UE behaviour for Uplink Carrier Aggregation

In case of uplink carrier aggregation, if the total transmit power in any OFDM symbol that does not contain xPUCCH for any serving cell in subframe $i$ exceeds $\hat{P}_{\text{CMAX}}(i)$ which is the linear value of the UE total configured maximum output power $P_{\text{CMAX}}$ defined in [FFS] in subframe $i$, the UE shall scale the transmit power for all physical channels in all the symbols that do not contain xPUCCH using a single scaling factor $\nu(i)$ computed as follows:

- For each OFDM symbol not containing xPUCCH, compute the total transmit power as the sum of the transmit powers for all physical channels across all cells that are transmitted on that symbol.
- Compute the maximum value of the per-symbol total transmit power across all those symbols.
- Compute a scaling factor $\nu(i)$ such that the maximum value of total transmit power in that symbol is equal or less than $\hat{P}_{\text{CMAX}}(i)$.
Note that \( V(i) \) values are the same across serving cells when \( V(i) > 0 \) but for certain serving cells \( V(i) \) may be zero.

If the total transmit power in an OFDM symbol that contains xPUCCH for any serving cell in subframe \( i \) exceeds \( \hat{P}_{\text{CMAX}}(i) \), the transmit power for physical channels in that OFDM symbol is scaled or set to 0 such that

\[
\sum_{j \in \text{xPUCCHCells}} \hat{P}_{\text{xPUCCH}}(i) \leq \hat{P}_{\text{CMAX}}(i),
\]

then

\[
\sum_{c \in \text{xPUSCHCells}} w(i) \cdot \left( \hat{P}_{\text{xPUSCH}}(c) + \hat{P}_{\text{xSRS}}(c) \right) \leq \left( \hat{P}_{\text{CMAX}}(i) - \sum_{j \in \text{xPUCCHCells}} \hat{P}_{\text{xPUCCH}}(i) \right).
\]

Else

\[
\sum_{j \in \text{xPUCCHCells}} w(i) \cdot \hat{P}_{\text{xPUCCH}}(j) \leq \hat{P}_{\text{CMAX}}(i), \text{ and } \hat{P}_{\text{xPUSCH}}(j), \hat{P}_{\text{xSRS}}(j) \text{ for the serving cell } c \not\in \text{xPUCCHCells} \text{ in that symbol is set to zero.}
\]

is satisfied where \( \text{xPUCCHCells} \) is the set of cells that UE is scheduled to transmit xPUCCH and its relevant cell is denoted as \( j \). \( \hat{P}_{\text{xPUCCH}}(j) \) is the linear value of \( P_{\text{xPUCCH}}(j) \), \( \hat{P}_{\text{xPUSCH}}(i) \) is the linear value of \( P_{\text{xPUSCH}}(i) \), \( \hat{P}_{\text{xSRS}}(c) \) is the linear value of \( P_{\text{xSRS}}(c) \), and \( w(i) \) is a scaling factor of \( \hat{P}_{\text{xPUSCH}}(i) \), \( \hat{P}_{\text{xSRS}}(i) \), or \( \hat{P}_{\text{xPUCCH}}(i) \) for serving cell \( c \) or \( j \) where \( 0 < w(i) \leq 1 \). Note that \( w(i) \) values are the same across serving cells. Note that \( w(i) \) values are the same across serving cells when \( w(i) > 0 \) but for certain serving cells \( w(i) \) may be zero in case of xPUSCH.

## 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 \( n_{\text{RACH}} \)
- System Frame Number, SFN :
- The BRS transmission period \( N_{\text{BRS}} \)
- The number of symbols \( N_{\text{RACH}} \) during the RACH subframe for which the 5GNB applies different rx – beams,
- The number of RACH subframes \( M \) in 4 radio frames
- The index of current RACH subframe \( m \) (here \( m \) ranges from 0 to \( M-1 \))
- The symbol with selected sync beam, \( S_{\text{BestBeam}}^{\text{Sync}} \)
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 $\sum_{\text{sync beam}}$ 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 is available 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
  \[
  P_{PRACH} = \min\{ P_{C_{\text{MAX}}}^{(i)} \cdot \text{PREAMBLE\_RECEIVED\_TARGET\_POWER} + PL \}_{\text{[dBm]}},
  \]
  where $P_{C_{\text{MAX}}}^{(i)}$ 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 xPDCCCH 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 xPDCCCH 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 the 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 “$x$PDCCH order” in subframe $n$, the UE shall, if requested by higher layers, transmit random access preamble in the subframe $n+k_1$, $k_1 \geq 6$, where a $x$PRACH 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 $x$PUSCH range, resource block assignment, Modulation and Coding scheme, TPC command, UL delay, number of BSI reports, BSI beta offset value index, and UL dual PCRS. The content of these 27 bits starting with the MSB and ending with the LSB are as follows:

- $x$PUSCH 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
- Number of BSI reports – 2 bits (i.e. ‘00’ : {1 BSI report}, ‘01’ : {2 BSI reports}, ‘10’ : {4 BSI reports}, ‘11’ : No BSI report), as described in section 5.3
- Index of BSI beta offset used in Msg3-$I_{BSI,o_t f,s e t,R A R}^{BSI}$: 4 bits, as defined in section 9.6.3
- UL dual PCRS – 1 bits, as defined in section 5.3.3.1 of [3].

The UE shall assume that HARQ ID is ‘0’ and NDI is ‘0’ for the $x$PUSCH transmission corresponding to the random access response grant. The UE shall use the single-antenna port uplink transmission scheme with RE mapping index 0 for the $x$PUSCH transmission corresponding to the random access response grant and the $x$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 $x$PRACH.

The TPC command $\delta_{msg2}$ shall be used for setting the power of the $x$PUSCH, and is interpreted according to Table 7.2-1.
Table 7.2-1: TPC Command $\delta_{\text{msg2}}$ for Scheduled xPUSCH

<table>
<thead>
<tr>
<th>TPC Command</th>
<th>Value (in dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td>1</td>
<td>-4</td>
</tr>
<tr>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

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 $\nu$
- root $u$
- Parameter $f'$
- System Frame Number, SFN
- The BRS transmission period $N_{BRS}$
- The number of symbols $N_{\text{RACH}}$ during the RACH subframe for which the 5GNB applies different rx beams,
- The number of RACH subframes $M$ in 4 radio frames
- The index of current RACH subframe $m$ (here $m$ ranges between 0 to $M-1$)
- The symbol with the selected sync beam, $S_{\text{sync}}$

Here the root $u$ is cell specific. UE uses SFN, $N_{BRS}$, $N_{\text{RACH}}$, $M$, $m$ and $S_{\text{sync}}$ 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 recovery request and beam refinement reference signal initiation request. The physical layer informs the upper layer whether the SR opportunity is available in the specific RACH subframe number $m$. A target preamble received power...
(PREAMBLE_RECEIVED_TARGET_POWER) and a SR resource are indicated by higher layers as part of the request.

- An SR preamble transmission power $P_{SR}$ is determined as
  
  \[ P_{SR} = \min\{ P_{CMAX}(i), \text{PREAMBLE\_RECEIVED\_TARGET\_POWER + PL}\} \text{[dBm]}, \]

  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 the beam determined by UE. It is assumed that SR 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 $P_{SR}$. UE may transmit an SR at available RACH subframe.

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>
<thead>
<tr>
<th>DCI format</th>
<th>Transmission scheme of xPDSCH corresponding to xPDCCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI format B1</td>
<td>Transmit Diversity (see subclause 8.1.2)</td>
</tr>
</tbody>
</table>

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

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, $n_{DMRS,i}^{ID}$, $i = 0, 1$ 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
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

<table>
<thead>
<tr>
<th>DCI format</th>
<th>Transmission scheme of xPDSCH corresponding to xPDCCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI format B1</td>
<td>Transmit diversity (see subclause 8.1.2)</td>
</tr>
</tbody>
</table>

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 NB transmission on the xPDSCH would be performed according to subclause 6.3.4.1 of [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 a 5G NB transmission on the xPDSCH would be performed according to subclause 6.3.4.2 of [2].

8.1.3 Multiplexing scheme
For the up to 2 layer transmission scheme of the xPDSCH, the UE may assume that a 5G NB 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 [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

$$
if \ (L_{CVRBGS} - 1) \leq \left\lfloor \frac{N_{VRBG}^{DL}}{2} \right\rfloor \ then
$$
\[ RIV = N_{VRBG}^{DL}(L_{VRBG} - 1) + VRBG_{\text{start}} \]

else

\[ RIV = N_{VRBG}^{DL}(N_{VRBG}^{DL} - L_{VRBG} + 1) + (N_{VRBG}^{DL} - 1 - VRBG_{\text{start}}) \]

where \( L_{VRBG} \geq 1 \) and shall not exceed \( N_{VRBG}^{DL} - VRBG_{\text{start}} \).

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.

The 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. The UE assumes that misconfiguration occurs when a DL DCI is successfully decoded in the 2nd symbol and the MSB value of xPDSCH range field in the DL DCI is set to 0. If misconfiguration is detected, the 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**

<table>
<thead>
<tr>
<th>MCS Index ( I_{MCS} )</th>
<th>Modulation Order ( Q_m )</th>
<th>Parity check matrix for LDPC codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
</tbody>
</table>
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 $0 \leq I_{MCS} \leq 15$.

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

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

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

<table>
<thead>
<tr>
<th>$I_{MCS}$</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>24</th>
<th>28</th>
<th>32</th>
<th>36</th>
<th>40</th>
<th>44</th>
<th>48</th>
<th>52</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>56</td>
<td>128</td>
<td>208</td>
<td>280</td>
<td>360</td>
<td>432</td>
<td>504</td>
<td>584</td>
<td>656</td>
<td>736</td>
<td>808</td>
<td>888</td>
<td>960</td>
</tr>
<tr>
<td>1</td>
<td>192</td>
<td>400</td>
<td>616</td>
<td>824</td>
<td>1032</td>
<td>1248</td>
<td>1456</td>
<td>1672</td>
<td>1880</td>
<td>2088</td>
<td>2304</td>
<td>2512</td>
<td>2728</td>
</tr>
<tr>
<td>2</td>
<td>328</td>
<td>680</td>
<td>1032</td>
<td>1384</td>
<td>1736</td>
<td>2088</td>
<td>2440</td>
<td>2792</td>
<td>3144</td>
<td>3496</td>
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<td>6840</td>
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<td>2088</td>
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<td>4904</td>
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<td>11416</td>
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<td>7</td>
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<td>11384</td>
<td>12648</td>
<td>13920</td>
<td>15184</td>
<td>16456</td>
</tr>
<tr>
<td>8</td>
<td>1384</td>
<td>2792</td>
<td>4200</td>
<td>5608</td>
<td>7016</td>
<td>8424</td>
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<td>12648</td>
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<td>1880</td>
<td>3784</td>
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<td>7584</td>
<td>9480</td>
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<td>10536</td>
<td>12648</td>
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<td>18984</td>
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</tr>
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<td>13</td>
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<td>16608</td>
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<td>14</td>
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<td>5256</td>
<td>7896</td>
<td>10536</td>
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<td>23736</td>
<td>26376</td>
<td>29016</td>
<td>31656</td>
<td>34296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$I_{MCS}$</th>
<th>56</th>
<th>60</th>
<th>64</th>
<th>68</th>
<th>72</th>
<th>76</th>
<th>80</th>
<th>84</th>
<th>88</th>
<th>92</th>
<th>96</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1032</td>
<td>1112</td>
<td>1184</td>
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<td>1336</td>
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<td>1864</td>
</tr>
<tr>
<td>1</td>
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<td>3568</td>
<td>3784</td>
<td>3992</td>
<td>4200</td>
<td>4416</td>
<td>4624</td>
<td>4840</td>
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<td>7016</td>
<td>7368</td>
<td>7720</td>
<td>8072</td>
<td>8424</td>
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</tr>
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<td>11064</td>
<td>11592</td>
<td>12120</td>
<td>12648</td>
<td>13176</td>
</tr>
</tbody>
</table>
8.1.5.2.2 Transport blocks mapped to two-layer spatial multiplexing
The TBS is calculated by adding 24 to twice of the \((I_{\text{MCS}}, N_{\text{VRB}})\) 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 four PRBs mapped to a single VRB in the frequency domain.

For the xPDSCH assigned by DCI format B2,

- If \(I_{\text{PRG}} = 0\), a UE may assume that precoding granularity for xPDSCH is four PRBs mapped to a single VRB in the frequency domain
- If \(I_{\text{PRG}} = 1\), a UE may assume that precoding granularity for xPDSCH is all assigned PRBs in the frequency domain

where \(I_{\text{PRG}}\) 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

<table>
<thead>
<tr>
<th>Value of field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'00'</td>
<td>CSI process #0 configured by higher layers</td>
</tr>
<tr>
<td>'01'</td>
<td>CSI process #1 configured by higher layers</td>
</tr>
<tr>
<td>'10'</td>
<td>CSI process #2 configured by higher layers</td>
</tr>
<tr>
<td>'11'</td>
<td>CSI process #3 configured by higher layers</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>PMI Feedback Type</th>
<th>xPUSCH CQI Feedback Type</th>
<th>No PMI</th>
<th>Single PMI</th>
<th>Multiple PMI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wideband (wideband CQI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UE Selected (subband CQI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Higher Layer-configured (subband CQI)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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
  o Mode 1-0 description:
    ▪ A UE shall report a wideband CQI value which is calculated assuming transmission on set S subbands.
  o 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>
<thead>
<tr>
<th>Value of field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'00'</td>
<td>CSI process #0 configured by higher layers</td>
</tr>
<tr>
<td>'01'</td>
<td>CSI process #1 configured by higher layers</td>
</tr>
<tr>
<td>'10'</td>
<td>CSI process #2 configured by higher layers</td>
</tr>
<tr>
<td>'11'</td>
<td>CSI process #3 configured by higher layers</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>xPUCCH CQI Feedback Type</th>
<th>PMI Feedback Type</th>
<th>PMI Feedback Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No PMI</td>
<td>Single PMI</td>
</tr>
<tr>
<td>Wideband (wideband CQI)</td>
<td>Mode 1-0</td>
<td>Mode 1-1</td>
</tr>
<tr>
<td>UE Selected (subband CQI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Layer-configured (subband CQI)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>CQI index</th>
<th>modulation</th>
<th>code rate</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>out of range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/14</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>1/5</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>QPSK</td>
<td>1/3</td>
<td>0.67</td>
</tr>
<tr>
<td>4</td>
<td>QPSK</td>
<td>1/2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>QPSK</td>
<td>2/3</td>
<td>1.33</td>
</tr>
<tr>
<td>6</td>
<td>QPSK</td>
<td>5/6</td>
<td>1.67</td>
</tr>
<tr>
<td>7</td>
<td>16QAM</td>
<td>1/2</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>16QAM</td>
<td>3/5</td>
<td>2.4</td>
</tr>
<tr>
<td>9</td>
<td>16QAM</td>
<td>2/3</td>
<td>2.67</td>
</tr>
<tr>
<td>10</td>
<td>16QAM</td>
<td>3/4</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>16QAM</td>
<td>5/6</td>
<td>3.33</td>
</tr>
<tr>
<td>12</td>
<td>64QAM</td>
<td>3/5</td>
<td>3.6</td>
</tr>
<tr>
<td>13</td>
<td>64QAM</td>
<td>2/3</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>64QAM</td>
<td>3/4</td>
<td>4.5</td>
</tr>
<tr>
<td>15</td>
<td>64QAM</td>
<td>5/6</td>
<td>5</td>
</tr>
</tbody>
</table>

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 \( \nu = 1 \).
• 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 \( \nu = 2 \).

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 \( n \in \{0,1,\ldots,15\} \) corresponds to the codebook index \( n \) given in Table 8.2.4-2 with \( \nu \) 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 \( W_n = I - 2u_nu_n^H/Iu_n^Hu_n \) where \( I \) is the \( 4 \times 4 \) 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

<table>
<thead>
<tr>
<th>Codebook index</th>
<th>Number of layers ( \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>( \frac{1}{\sqrt{2}} ) \begin{bmatrix} 1 \ 1 \end{bmatrix} \sqrt{2} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix} \begin{bmatrix} 1 \ 1 \end{bmatrix}</td>
</tr>
<tr>
<td>1</td>
<td>( \frac{1}{\sqrt{2}} ) \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix} \begin{bmatrix} 1 \ -1 \end{bmatrix}</td>
</tr>
<tr>
<td>2</td>
<td>( \frac{1}{\sqrt{2}} ) \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix} \begin{bmatrix} 1 \ j \end{bmatrix}</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{1}{\sqrt{2}} ) \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix} \begin{bmatrix} 1 \ -j \end{bmatrix}</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Codebook index</th>
<th>( u_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of layers ( \nu )</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>( I )</td>
<td>\begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix} \begin{bmatrix} 1 \ 0 \end{bmatrix}</td>
</tr>
</tbody>
</table>
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 $\varphi_n$ and $v_m$ are given by

$$
\varphi_n = e^{j\varphi_n/2}, \quad v_m = \left[1 \quad e^{j2m/32} \quad e^{j4m/32} \quad e^{j6m/32}\right]^T
$$

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

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

<table>
<thead>
<tr>
<th>$i_1$</th>
<th>$i_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15</td>
<td>$W_{11,0}$ $W_{11,1}$ $W_{11,2}$ $W_{11,3}$ $W_{11,4}$ $W_{11,5}$ $W_{11,6}$ $W_{11,7}$</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>
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+m 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 {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 request in DL DCI, UL DCI, and RAR grant.

If UE receives BSI request in DL DCI, 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 beams with the highest BRSRP in the candidate beam set, where N is provided in the DCI or the RAR grant.

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, \( N = \{1, 2, 4\} \), is indicated in UL DCI.

A UE shall report N BSIs corresponding to the 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 in subframe \( n + 4 + m + k \), where parameters \( m = 0 \) and \( k = \{0, 1, \ldots, 7\} \) is indicated by the DL DCI.

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

The mapping of BRSRP to measured quantity value is defined in Table 8.3.3.1-1. Each BRSRP index is mapped to its corresponding binary representation using 7 bits.

Table 8.3.3.1-1: 7-bit BRSRP Table

<table>
<thead>
<tr>
<th>BRSRP index</th>
<th>Measured quantity value [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BRSRP &lt; -140</td>
</tr>
<tr>
<td>1</td>
<td>-140 ≤ BRSRP &lt; -139</td>
</tr>
<tr>
<td>2</td>
<td>-139 ≤ BRSRP &lt; -138</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>95</td>
<td>-46 ≤ BRSRP &lt; -45</td>
</tr>
<tr>
<td>96</td>
<td>-45 ≤ BRSRP &lt; -44</td>
</tr>
<tr>
<td>97</td>
<td>-44 ≤ BRSRP</td>
</tr>
</tbody>
</table>

From UE measurement quantity perspective, BRSRP is defined in Table 8.3.3.1-2.

Table 8.3.3.1-2: UE measurement capability: BRSRP

<table>
<thead>
<tr>
<th>Definition</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beam reference signal received power (BRSRP), is defined as the linear average over the power contributions (in W) of the resource elements that carry beam-specific reference signals within the considered measurement frequency bandwidth. For BRSRP determination the beam reference signal (BRS) according to [2] shall be used. The reference point shall be the input point on baseband of the UE, and implementation loss/gain in the RF domain shall be compensated to measure BRSRP. The RF loss/gain is the maximum estimated value by the manufacturer. If receiver diversity is in use by the UE, the reported value shall not be lower than the corresponding BRSRP of any of the individual diversity branches.</td>
</tr>
<tr>
<td>Applicable for</td>
<td>5G-RRC_IDLE intra-frequency, 5G-RRC_CONNECTED intra-frequency.</td>
</tr>
</tbody>
</table>

NOTE 1: The number of resource elements within the considered measurement frequency bandwidth and within the measurement period that are used by the UE to determine BRSRP is left up to the UE implementation with the limitation that corresponding measurement accuracy requirements have to be fulfilled.

NOTE 2: The power per resource element is determined from the energy received during the useful part of the symbol, excluding the CP.

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 [Table 6.7.4.3-2 of [2]], which is indicated by 9 bits.

Each beam index is mapped to 9 bits based on its natural binary representation.
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 $m \in \{0, 1, 2, 3\}$ 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 $l = \{0, 1, \ldots, 7\}$ 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 layer.

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 $m \in \{0, 1, 2, 3\}$ is indicated by the DL DCI.

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 request, the UE shall report BRI using xPUCCH in subframe $n+4+m+k$, where parameters $m = \{0, 1, 2, 3\}$ and $k = \{0, 1, \ldots, 7\}$ 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 measured quantity value 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

<table>
<thead>
<tr>
<th>BRRS-RP index</th>
<th>Measured quantity value [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BRRS-RP &lt; -140</td>
</tr>
<tr>
<td>1</td>
<td>-140 ≤ BRRS-RP &lt; -139</td>
</tr>
<tr>
<td>2</td>
<td>-139 ≤ BRRS-RP &lt; -138</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>95</td>
<td>-46 ≤ BRRS-RP &lt; -45</td>
</tr>
<tr>
<td>96</td>
<td>-45 ≤ BRRS-RP &lt; -44</td>
</tr>
</tbody>
</table>
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 BRRS resource ID is mapped to BRRS-RI as in Table 8.4.3.2-1. Each BRRS-RI is mapped to its corresponding binary representation using 3 bits.

Table 8.4.3.2-1: BRRS-RI mapping

<table>
<thead>
<tr>
<th>BRRS-RI</th>
<th>BRRS resource ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

From UE measurement quantity perspective, BRRS-RP is defined in Table 8.4.3.1-2.

Table 8.4.3.1-2: UE measurement capability: BRRS-RP

| Definition | Beam refinement reference signal received power (BRRS-RP), is defined as the linear average over the power contributions (in [W]) of the resource elements that carry beam-specific reference signals within the considered measurement frequency bandwidth. For BRRS-RP determination the beam refinement reference signal (BRRS) according to [2] shall be used.
|           | The reference point shall be the input point on baseband of the UE, and implementation loss/gain in the RF domain shall be compensated to measure BRRS-RP. The RF loss/gain is the maximum estimated value by the manufacturer.
|           | If receiver diversity is in use by the UE, the reported value shall not be lower than the corresponding BRRS-RP of any of the individual diversity branches.
| Applicable for | 5G-RRC_IDLE intra-frequency,
|               | 5G-RRC_CONNECTED intra-frequency,

NOTE 1: The number of resource elements within the considered measurement frequency bandwidth and within the measurement period that are used by the UE to determine BRRS-RP is left up to the UE implementation with the limitation that corresponding measurement accuracy requirements have to be fulfilled.

NOTE 2: The power per resource element is determined from the energy received during the useful part of the symbol, excluding the CP.

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 $a_0, ..., a_{Bc-1}$ where $a_0$ is the MSB and $a_{Bc-1}$ 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 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 \( \mathcal{H}_{\text{xPUCCH}}^{(2)} = \{0, 1, \ldots, 15\} \) 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 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 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 and the TBS as determined in subclause 9.6.2, 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

<table>
<thead>
<tr>
<th>Transmission mode</th>
<th>DCI format</th>
<th>Transmission scheme of xPUSCH corresponding to xPDCCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1</td>
<td>DCI format A1</td>
<td>Single-antenna port</td>
</tr>
<tr>
<td>Mode 2</td>
<td>DCI format A1</td>
<td>- Single-antenna port, if DCI indicates 1 layer transmission</td>
</tr>
<tr>
<td></td>
<td>DCI format A2</td>
<td>- Transmit diversity, if DCI indicates 2 layer transmission</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed-loop spatial multiplexing, up to 2 layer transmission</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>DCI format</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCI format A1</td>
</tr>
</tbody>
</table>

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 5.3.3.1 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 5.3.3.3 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 5.3.3.2 of [2].

9.2 Resource Allocation for xPUSCH 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 starting 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

For a UE, the range of xPUSCH shall not include the OFDM symbols for the transmission of SRS or xPUCCH.

### 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].

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 \( T_{TC} \)
- Starting physical resource block assignment \( n_{RRC} \)
- SRS bandwidth \( B_{SRS} \), as defined in subclause 5.5.3.2 of [3]
- Cyclic shift \( n_{SRS}^{c} \), 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
- 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

<table>
<thead>
<tr>
<th>MCS Index $I_{MCS}$</th>
<th>Modulation Order $Q_m$</th>
<th>Parity check matrix for LDPC codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Table 5.1.3.2-2 in [3]</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Table 5.1.3.2-5 in [3]</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>Table 5.1.3.2-3 in [3]</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>Table 5.1.3.2-2 in [3]</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>Table 5.1.3.2-4 in [3]</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>Table 5.1.3.2-3 in [3]</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>Table 5.1.3.2-2 in [3]</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>

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 8.1.5.2.1.
9.6.3 Control information MCS offset determination

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

Table 9.6.3-1: Mapping of RI offset values and the index signalled by higher layers
<table>
<thead>
<tr>
<th>$I_{\text{offset}}^{RI}$ or $I_{\text{offset,ML}}^{RI}$</th>
<th>$\beta_{\text{offset}}^{RI}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.250</td>
</tr>
<tr>
<td>1</td>
<td>1.625</td>
</tr>
<tr>
<td>2</td>
<td>2.000</td>
</tr>
<tr>
<td>3</td>
<td>2.500</td>
</tr>
<tr>
<td>4</td>
<td>3.125</td>
</tr>
<tr>
<td>5</td>
<td>4.000</td>
</tr>
<tr>
<td>6</td>
<td>5.000</td>
</tr>
<tr>
<td>7</td>
<td>6.250</td>
</tr>
<tr>
<td>8</td>
<td>8.000</td>
</tr>
<tr>
<td>9</td>
<td>10.000</td>
</tr>
<tr>
<td>10</td>
<td>12.625</td>
</tr>
<tr>
<td>11</td>
<td>15.875</td>
</tr>
<tr>
<td>12</td>
<td>20.000</td>
</tr>
<tr>
<td>13</td>
<td>reserved</td>
</tr>
<tr>
<td>14</td>
<td>reserved</td>
</tr>
<tr>
<td>15</td>
<td>reserved</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>$I_{\text{offset}}^{CQI}$ or $I_{\text{offset,ML}}^{CQI}$</th>
<th>$\beta_{\text{offset}}^{CQI}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>reserved</td>
</tr>
<tr>
<td>1</td>
<td>reserved</td>
</tr>
<tr>
<td>2</td>
<td>1.125</td>
</tr>
<tr>
<td>3</td>
<td>1.250</td>
</tr>
<tr>
<td>4</td>
<td>1.375</td>
</tr>
<tr>
<td>5</td>
<td>1.625</td>
</tr>
<tr>
<td>6</td>
<td>1.750</td>
</tr>
<tr>
<td>7</td>
<td>2.000</td>
</tr>
<tr>
<td>8</td>
<td>2.250</td>
</tr>
<tr>
<td>9</td>
<td>2.500</td>
</tr>
<tr>
<td>10</td>
<td>2.875</td>
</tr>
<tr>
<td>3.125</td>
<td>11</td>
</tr>
<tr>
<td>-------</td>
<td>----</td>
</tr>
<tr>
<td>3.500</td>
<td>12</td>
</tr>
<tr>
<td>4.000</td>
<td>13</td>
</tr>
<tr>
<td>5.000</td>
<td>14</td>
</tr>
<tr>
<td>6.250</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 9.6.3-3: Mapping of BSI offset values and the index signalled by higher layers or in RAR

<table>
<thead>
<tr>
<th>$I_{\text{offset}}^{\text{BSI}}$ or $I_{\text{offset,ML}}^{\text{BSI}}$ or $I_{\text{offset,RAR}}^{\text{BSI}}$</th>
<th>$\beta_{\text{offset}}^{\text{BSI}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>reserved</td>
</tr>
<tr>
<td>1</td>
<td>reserved</td>
</tr>
<tr>
<td>2</td>
<td>1.125</td>
</tr>
<tr>
<td>3</td>
<td>1.250</td>
</tr>
<tr>
<td>4</td>
<td>1.375</td>
</tr>
<tr>
<td>5</td>
<td>1.625</td>
</tr>
<tr>
<td>6</td>
<td>1.750</td>
</tr>
<tr>
<td>7</td>
<td>2.000</td>
</tr>
<tr>
<td>8</td>
<td>2.250</td>
</tr>
<tr>
<td>9</td>
<td>2.500</td>
</tr>
<tr>
<td>10</td>
<td>2.875</td>
</tr>
<tr>
<td>11</td>
<td>3.125</td>
</tr>
<tr>
<td>12</td>
<td>3.500</td>
</tr>
<tr>
<td>13</td>
<td>4.000</td>
</tr>
<tr>
<td>14</td>
<td>5.000</td>
</tr>
<tr>
<td>15</td>
<td>6.250</td>
</tr>
</tbody>
</table>

Table 9.6.3-4: Mapping of BRI offset values and the index signalled by higher layers

<table>
<thead>
<tr>
<th>$I_{\text{offset}}^{\text{BRI}}$ or $I_{\text{offset,ML}}^{\text{BRI}}$</th>
<th>$\beta_{\text{offset}}^{\text{BRI}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>reserved</td>
</tr>
<tr>
<td>1</td>
<td>reserved</td>
</tr>
<tr>
<td>2</td>
<td>1.125</td>
</tr>
<tr>
<td>3</td>
<td>1.250</td>
</tr>
</tbody>
</table>
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 $S_{\text{search}}$ is mapped to the resource elements constituting xREGs with a set of index where

\[ n_{\text{xREG}} \in \{2S_{\text{search}} + 2, 2S_{\text{search}} + 1\}, \quad \text{if } 0 \leq S_{\text{search}} \leq 7 \]
\[ n_{\text{xREG}} \in \{4(S_{\text{search}} - 8), \ldots, 4(S_{\text{search}} - 8) + 3\}, \quad \text{if } 8 \leq S_{\text{search}} \leq 11 \]
\[ n_{\text{xREG}} \in \{8(S_{\text{search}} - 12), \ldots, 8(S_{\text{search}} - 12) + 7\}, \quad \text{if } 12 \leq S_{\text{search}} \leq 13 \]
\[ n_{\text{xREG}} \in \{0, \ldots, 15\}, \quad \text{if } S_{\text{search}} = 14 \]
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.

<table>
<thead>
<tr>
<th>Type</th>
<th>Aggregation level</th>
<th>Size [in xREGs]</th>
<th>$N_{\text{Symbol, xPDCCH}} = 1$</th>
<th>$N_{\text{Symbol, xPDCCH}} = 2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE-specific</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>16</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

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 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 triggered by UL DCI.

The UE shall use xPUCCH resource \( n^{(2)}_{PUCCH} \) in subframe \( n \), \( n^{(2)}_{PUCCH} \) 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 \( (p \in \{p_0, p_1\}) \).

UE does not expect to receive multiple xPUSCH grants for the same subframe in a given carrier.

### 11.1.1 xPUCCH information

Using the xPUCCH formats defined in subclauses 5.4.1 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 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.

- If DCI assigns single DL PCRS port regardless of the number of allocated DL DMRS port, a UE may assume that the PCRS port and the allocated DL DMRS port(s) are associated with the same phase noise value.
- If DCI assigns two DL PCRS ports \( (q_1, q_2) \) and two DL DMRS ports \( (p_1, p_2) \), a UE may assume that the PCRS port \( q_i \) and the DMRS port \( p_i \) are associated with the same phase noise value for \( i = 1 \) and \( i = 2 \), respectively.
- If DCI assigns two PCRS ports and a single DMRS port, a UE assumes there is a misconfiguration for this DCI.

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. 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 RE mapping indices is equal to 1, then UE shall transmit UL PCRS in subframe \( n + 4 + m + l \) using a RE mapping index indicated in the DCI and also using an additional RE mapping index which has the same subcarrier position with the assigned RE mapping index 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

<table>
<thead>
<tr>
<th>Transmission scheme</th>
<th>Relative Transmit Power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-layer transmission</td>
<td>3dB</td>
</tr>
<tr>
<td>Two-layer transmission</td>
<td>6dB</td>
</tr>
</tbody>
</table>

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.