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Foreword

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1 Scope

The present document specifies and establishes the characteristics of the physicals layer procedures of data channels for 5G-NR.

2 References

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

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications"

[2] 3GPP TS 38.201: " NR; Physical Layer – General Description"

[3] 3GPP TS 38.202: "NR; Services provided by the physical layer"

[4] 3GPP TS 38.211: "NR; Physical channels and modulation"

[5] 3GPP TS 38.212: "NR; Multiplexing and channel coding"

[6] 3GPP TS 38.213: "NR; Physical layer procedures for control"

[7] 3GPP TS 38.215: "NR; Physical layer measurements"

[8] 3GPP TS 38.101: "NR; User Equipment (UE) radio transmission and reception"

[9] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"

[10] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"

[11] 3GPP TS 38.133: "NR; Requirements for support of radio resource management"

[12] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification"

[13] 3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities"

[14] 3GPP TS 38.423: "NG-RAN; Xn signalling transport"

3 Definitions, symbols and abbreviations

3.1 Definitions

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

3.2 Symbols

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

3.3 Abbreviations

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

BWP	Bandwidth part
CP	Cyclic prefix
CQI	Channel quality indicator
CRC	Cyclic redundancy version
CRI	CSI-RS Resource Indicator
CSI	Channel state information
CSI-RS	Channel state information reference signal
CSI-RSRP	CSI reference signal received power
CSI-RSRQ	CSI reference signal received quality
CSI-SINR	CSI signal-to-noise and interference ratio
CW	Codeword
DCI	Downlink control information
DL	Downlink
DM-RS	Dedicated demodulation reference signals
EPRE	Energy per resource element
L1-RSRP	Layer 1 reference signal received power
LI	Layer Indicator
MCS	Modulation and coding scheme
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PSS	Primary Synchronisation signal
PUCCH	Physical uplink control channel
QCL	Quasi co-location
PMI	Precoding Matrix Indicator
PRB	Physical resource block
PRG	Physical resource block group
PT-RS	Phase-tracking reference signal
RB	Resource block
RBG	Resource block group

RI	Rank Indicator
RIV	Resource indicator value
SLIV	Start and length indicator value
SRS	Sounding reference signal
SS	Synchronisation signal
SSS	Secondary Synchronisation signal
SS-RSRP	SS reference signal received power
SS-RSRQ	SS reference signal received quality
SS-SINR	SS signal-to-noise and interference ratio
TCI	Transmission Configuration Indicator
TDM	Time division multiplexing
UE	User equipment
UL	Uplink

4 Power control

4.1 Power allocation for downlink

The gNodeB determines the downlink transmit EPRE.

For the purpose of SS-RSRP, SS-RSRQ and SS-SINR measurements, the UE may assume downlink EPRE is constant across the bandwidth. For the purpose of SS-RSRP, SS-RSRQ and SS-SINR measurements, the UE may assume downlink EPRE is constant over SSS carried in different SS/PBCH blocks. For the purpose of SS-RSRP, SS-RSRQ and SS-SINR measurements, the UE may assume that the ratio of SSS EPRE to PBCH DM-RS EPRE is 0 dB.

For the purpose of CSI-RSRP, CSI-RSRQ and CSI-SINR measurements, the UE may assume downlink EPRE of a port of CSI-RS resource configuration is constant across the configured downlink bandwidth and constant across all configured OFDM symbols.

The downlink SS/PBCH SSS EPRE can be derived from the SS/PBCH downlink transmit power given by the parameter *SS-PBCH-BlockPower* provided by higher layers. The downlink SSS transmit power is defined as the linear average over the power contributions (in [W]) of all resource elements that carry the SSS within the operating system bandwidth.

The downlink CSI-RS EPRE can be derived from the SS/PBCH block downlink transmit power given by the parameter *SS-PBCH-BlockPower* and CSI-RS power offset given by the parameter *Pc_SS* provided by higher layers. The downlink reference-signal transmit power is defined as the linear average over the power contributions (in [W]) of the resource elements that carry the configured CSI-RS within the operating system bandwidth.

For downlink DM-RS associated with PDSCH, the UE may assume the ratio of PDSCH EPRE to DM-RS EPRE ($1/\beta_{\mathrm{DMRS}}$[dB]) is given by Table 4.1-1 according to the number of DM-RS CDM groups without data as signalled by DCI [5, TS 38.212].

Table 4.1-1: The ratio of PDSCH EPRE to DM-RS EPRE

Number of DM-RS CDM groups without data	DM-RS configuration type 1	DM-RS configuration type 2
1	0 dB	0 dB
2	-3 dB	-3 dB
3	-	-4.77 dB

When the UE is scheduled with N_{PTRS} PT-RS ports associated with the PDSCH and when the PT-RS port *i* is associated to $n_{DMRS}^{PTRS,i}$ DM-RS ports,

- if the UE is configured with the higher layer parameter *epre-RATIO* for PT-RS port *i*, the ratio of PDSCH EPRE to PT-RS EPRE per layer per RE for PT-RS port *i* ($\rho_{PTRS,i}$) is given by

$$\rho_{PTRS,i} = -10\log_{10}(N_{PTRS}) - \alpha_{PTRS,i}, \text{ [dB]}$$

where $\alpha_{PTRS,i}$ is ~~as~~ given by Table 4.1-2 according to the *epre-RATIO* for PT-RS port *i*, the PT-RS scaling factor $\beta_{PTRS,i}$ specified in subclause 7.4.1.2.2 of [4, TS 38.211] is given by $\beta_{PTRS,i} = 10^{-\frac{\rho_{PTRS,i}}{20}}$.

- otherwise, the UE shall assume *epre-RATIO* is set to state '0' in Table 4.1-2 if not configured.

Table 4.1-2: PDSCH EPRE to PT-RS EPRE per layer per RE for PT-RS port *i* ($\alpha_{PTRS,i}$)

PDSCH-to-PT-RS EPRE ratio* for PT-RS port *i	**The number of PDSCH layers within the DMRS port group containing DMRS port associated with the PT-RS port *i*, ($n_{DMRS}^{PTRS,i}$)**					
	1	**2**	**3**	**4**	**5**	**6**
0	0	3	4.77	6	7	7.78
1	0	0	0	0	0	0
2	reserved					
3	reserved					

The downlink PDCCH EPRE is assumed as the ratio of the PDCCH EPRE to NZP CSI-RS EPRE and takes the value of 0 dB.

5 Physical downlink shared channel related procedures

5.1 UE procedure for receiving the physical downlink shared channel

For downlink, a maximum of 16 HARQ processes per cell is supported by the UE. The number of processes the UE may assume will at most be used for the downlink is configured to the UE for each cell separately by higher layer parameter *nrofHARQ-processesForPDSCH*, and when no configuration is provided the UE may assume a default number of 8 processes.

A UE shall upon detection of a PDCCH with a configured DCI format 1_0 or 1_1 decode the corresponding PDSCHs as indicated by that DCI. The UE is not expected to receive another PDSCH for a given HARQ process until after the end of the expected transmission of HARQ-ACK for that HARQ process, where the timing is given by Subclause 9.2.3 of [6]. The UE is not expected to receive a PDSCH in slot *i*, with the corresponding HARQ-ACK assigned to be transmitted in slot *j*, and another PDSCH in slot after slot *i* with its corresponding HARQ-ACK assigned to be transmitted in a slot before slot *j*.

If the UE has received no *SSB-transmitted* through higher layer signalling about SS/PBCH block transmissions in the serving cell, the UE assumes SS/PBCH block transmission according to *SSB-transmitted-SIB1*, and if the PDSCH resource allocation overlaps with PRBs containing SS/PBCH block transmission resources the UE shall assume that PDSCH is rate matched around these PRBs in the OFDM symbols where SS/PBCH block is transmitted. The UE assumes the periodicity of the SS/PBCH block transmission resources based on *SSB-periodicity-serving-cell*.

If the UE has received a *SSB-transmitted* through higher layer signalling about SS/PBCH block transmissions in the serving cell, the UE assumes SS/PBCH block transmission according to the *SSB-transmitted*, and if the PDSCH resource allocation overlaps with PRBs containing SS/PBCH block transmission resources the UE shall assume that PDSCH is rate matched around these PRBs in the OFDM symbols where SS/PBCH block is transmitted. The UE assumes the periodicity of the SS/PBCH block transmission resources based on *SSB-periodicity-serving-cell.*

When receiving the PDSCH conveying [*SystemInformationBlockType1*], a UE shall assume that no SS/PBCH block is transmitted in REs used by the UE for a reception of the PDSCH.

When receiving the PDSCH conveying [*RAR, OSI, Paging, Msg4*], the UE assumes SS/PBCH block transmission according to *SSB-transmitted-SIB1*, and if the PDSCH resource allocation overlaps with PRBs containing SS/PBCH block transmission resources the UE shall assume that PDSCH is rate matched around these PRBs in the OFDM symbols where SS/PBCH block is transmitted.

When receiving PDSCH for SIB1 or broadcasted Other System Info or paging the UE may assume that the DM-RS port of PDSCH is quasi co-located with the associated SS/PBCH block with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable.

When receiving PDSCH for Random Access Response (RAR) the UE may assume that the DM-RS port of PDSCH is quasi co-located with the SS/PBCH block or the CSI-RS resource the UE selected for RACH association and transmission with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable. When receiving a RAR triggered by a PDCCH order, the UE may assume that the DM-RS port of the received PDCCH order and the PDCCH of the corresponding RAR are quasi co-located with the same SS/PBCH block or CSI-RS with respect to [spatial RX parameters] Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable.

When receiving PDSCH conveying Msg4 of Random Access Procedure the UE may assume that the DM-RS port of PDSCH is quasi co-located with the SS/PBCH block the UE selected for RACH association and transmission with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable.

If the UE is not configured for PUSCH/PUCCH transmission for at least one serving cell configured with slot formats comprised of DL and UL symbols, and if the UE is not capable of simultaneous reception and transmission on serving cell c_1 and serving cell c_2, the UE is not expected to receive PDSCH on serving cell c_1 if the PDSCH overlaps in time with SRS transmission (including any interruption due to uplink or downlink RF retuning time [10]) on serving cell c_2 not configured for PUSCH/PUCCH transmission.

The UE is not expected to decode a PDSCH scheduled in the primary cell with C-RNTI and another PDSCH scheduled in the primary cell with CS-RNTI if the PDSCHs partially or fully overlap in time.

The UE is not expected to decode a PDSCH scheduled with C-RNTI or CS-RNTI if another PDSCH in the same cell scheduled with RA-RNTI partially or fully overlap in time.

On a frequency range 1 cell, the UE is not expected to decode a PDSCH scheduled with C-RNTI or CS-RNTI if in the same cell, during a process of P-RNTI triggered SI acquisition, another PDSCH with a TBS > 2216 bits scheduled with SI-RNTI partially or fully overlap in time.

On a frequency range 2 cell, the UE is not expected to decode a PDSCH scheduled with C-RNTI or CS-RNTI if in the same cell, during a process of P-RNTI triggered SI acquisition, another PDSCH scheduled with SI-RNTI partially or fully overlap in time.

The UE is expected to decode a PDSCH scheduled with C-RNTI or CS-RNTI during a process of autonomous SI acquisition.

5.1.1 Transmission schemes

Only one transmission scheme is defined for the PDSCH, and is used for all PDSCH transmission.

5.1.1.1 Transmission scheme 1

For transmission scheme 1 of the PDSCH, the UE may assume that a gNB transmission on the PDSCH would be performed with up to 8 transmission layers on antenna ports 1000-1011 as defined in Subclause 7.3.1.4 of [4, TS 38.211].

5.1.2 Resource allocation

5.1.2.1 Resource allocation in time domain

When the UE is scheduled to receive PDSCH by a DCI, the *Time domain resource assignment* field of the DCI provides a row index of a higher layer configured table *pdsch-symbolAllocation*, where the indexed row defines the slot offset K_0, the start and length indicator *SLIV*, and the PDSCH mapping type to be assumed in the PDSCH reception.

Given the parameter values of the indexed row:

- The slot allocated for the PDSCH is $\left\lfloor n \cdot \frac{2^{\mu_{PDSCH}}}{2^{\mu_{PDCCH}}} \right\rfloor + K_0$, where *n* is the slot with the scheduling DCI, and K_0 is based on the numerology of PDSCH, and
- The starting symbol *S* relative to the start of the slot, and the number of consecutive symbols *L* counting from the symbol *S* allocated for the PDSCH are determined from the start and length indicator *SLIV*:

  if $(L-1) \leq 7$ then

  $SLIV = 14 \cdot (L-1) + S$

  else

  $SLIV = 14 \cdot (14 - L + 1) + (14 - 1 - S)$

  where $0 < L \leq 14 - S$, and
- The PDSCH mapping type is set to Type A or Type B as defined in sub-clause 7.4.1.1.2 of [4, TS 38.211].

The UE shall consider the *S* and *L* combinations defined in table 5.1.2.1-1 as valid PDSCH allocations:

Table 5.1.2.1-1: Valid *S* and *L* combinations

PDSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	**L**	**S+L**	**S**	**L**	**S+L**
Type A	{0,1,2,3}	{3,…,14}	{3,…,14}	{0,1,2,3}	{3,…,12}	{3,…,12}
Type B	{0,…,12}	{2,4,7}	{2,…,14}	{0,…,10}	{2,4,6}	{2,…,12}

When the UE is configured with aggregationFactorDL > 1, the same symbol allocation is applied across the *aggregationFactorDL* consecutive slots. The UE may expect that the TB is repeated within each symbol allocation among each of the *aggregationFactorDL* consecutive slots and the PDSCH is limited to a single transmission layer.

If the UE procedure for determining slot configuration as defined in Subclause 11.1 of [6, TS 38.213] determines symbol of a slot allocated for PDSCH as uplink symbols, the transmission on that slot is omitted for multi-slot PDSCH transmission.

5.1.2.2 Resource allocation in frequency domain

The UE shall determine the resource block assignment in frequency domain using the resource allocation field in the detected PDCCH DCI. Two downlink resource allocation schemes, type 0 and type 1, are supported. The UE shall assume that when the scheduling grant is received with DCI format 1_0, then downlink resource allocation type 1 is used.

If the scheduling DCI is configured to indicate the downlink resource allocation type as part of the *Frequency-domainPDSCHresource* field, the UE shall use downlink resource allocation type 0 or type 1 as defined by this field. Otherwise the UE shall use the downlink frequency resource allocation type as defined by the higher layer parameter *Resource-allocation-config* for PDSCH.

If a bandwidth part indicator field is not configured in the scheduling DCI, the RB indexing for downlink type 0 and type 1 resource allocation is determined within the UE's active carrier bandwidth part. If a bandwidth part indicator field is configured in the scheduling DCI, the RB indexing for downlink type 0 and type 1 resource allocation is determined within the UE's carrier bandwidth part indicated by bandwidth part indicator field value in the DCI, except for the case when DCI format 1_0 is decoded in the common search space in CORESET 0 in which case the initial bandwidth part shall be used. The UE shall upon detection of PDCCH intended for the UE determine first the downlink carrier bandwidth part and then the resource allocation within the carrier bandwidth part.

5.1.2.2.1 Downlink resource allocation type 0

In downlink resource allocation of type 0, the resource block assignment information includes a bitmap indicating the Resource Block Groups (RBGs) that are allocated to the scheduled UE where a RBG is a set of consecutive virtual resource blocks defined by higher layer parameter *rbg-Size* configured for PDSCH and the size of the carrier bandwidth part as defined in Table 5.1.2.2.1-1.

Table 5.1.2.2.1-1: Nominal RBG size *P*

Bandwidth Part Size	Configuration 1	Configuration 2
1 – 36	2	4
37 – 72	4	8
73 – 144	8	16
145 – 275	16	16

The total number of RBGs (N_{RBG}) for a downlink carrier bandwidth part *i* of size $N_{\mathrm{BWP,i}}^{size}$ PRBs is given by $N_{RBG} = \left\lceil \left(N_{BWP,i}^{size} + \left(N_{BWP,i}^{start} \bmod P\right)\right)/P \right\rceil$, where

- the size of the first RBG is $RBG_0^{size} = P - N_{BWP,i}^{start} \bmod P$,
- the size of last RBG is $RBG_{last}^{size} = \left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod P$ if $\left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod P > 0$ and *P* otherwise,
- the size of all other RBGs is *P*.

The bitmap is of size N_{RBG} bits with one bitmap bit per RBG such that each RBG is addressable. The RBGs shall be indexed in the order of increasing frequency and starting at the lowest frequency of the carrier bandwidth part. The order of RBG bitmap is such that RBG 0 to RBG $N_{\mathrm{RBG}} - 1$ are mapped from MSB to LSB. The RBG is allocated to the UE if the corresponding bit value in the bitmap is 1, the RBG is not allocated to the UE otherwise.

5.1.2.2.2 Downlink resource allocation type 1

In downlink resource allocation of type 1, the resource block assignment information indicates to a scheduled UE a set of contiguously allocated localized or distributed virtual resource blocks within the active carrier bandwidth part of size N_{BWP}^{size} PRBs except for the case when DCI format 1_0 is decoded in the common search space in CORESET 0 in which case the initial bandwidth part of size N_{BWP}^{size} shall be used.

A downlink type 1 resource allocation field consists of a resource indication value (*RIV*) corresponding to a starting virtual resource block (RB_{start}) and a length in terms of contiguously allocated resource blocks L_{RBs}. The resource indication value is defined by

if $(L_{RBs} - 1) \le \left\lfloor N_{BWP}^{size}/2 \right\rfloor$ then

$$RIV = N_{BWP}^{size}(L_{RBs} - 1) + RB_{start}$$

else

$$RIV = N_{BWP}^{size}(N_{BWP}^{size} - L_{RBs} + 1) + (N_{BWP}^{size} - 1 - RB_{start})$$

where $L_{RBs} \geq 1$ and shall not exceed $N_{BWP}^{size} - RB_{start}$.

5.1.2.3 Physical resource block (PRB) bundling

A UE may assume that precoding granularity is multiple resource blocks in the frequency domain.

Precoding Resource Block Group (PRGs) partition the carrier bandwidth part *i* with $P'_{BWP.i}$ consecutive PRBs $P'_{BWP.i}$ can be equal to one of the values among {2, 4, wideband}. Actual number of consecutive PRBs in each PRG could be one or more.

$P'_{BWP.i}$ for each carrier bandwidth part is equal to 2 PRBs unless configured by the higher layer parameter *prb-BundlingType*. When receiving PDSCH scheduled by PDCCH with CRC scrambled by SI-RNTI, RA-RNTI, P-RNTI or TC-RNTI, the UE shall assume that $P'_{BWP.i}$ $P'_{BWP.i}$ is equal to 2 PRBs.

If $P'_{BWP.i}$ $P'_{BWP.i}$ is determined as "wideband", the UE is not expected to be scheduled with non-contiguous resource allocation and the UE may assume that the same precoding is applied to the allocated resource.

When $P'_{BWP.i}$ is determined as one of the values among {2, 4}, the first PRG size is given by $P'_{BWP,i} - N^{\mathrm{start}}_{\mathrm{BWP},i} \bmod P'_{BWP}$ and the last PRG size given by $(N^{start}_{BWP,i} + N^{size}_{BWP,i}) \bmod P'_{BWP,i}$ if $(N^{start}_{BWP,i} + N^{size}_{BWP,i}) \bmod P'_{BWP,i} \neq 0$, and the last PRG size is $P'_{BWP,i}$ if $(N^{start}_{BWP,i} + N^{size}_{BWP,i}) \bmod P'_{BWP,i} = 0$.

The UE may assume the same precoding is applied for any downlink contiguous allocation of PRBs in a PRG partitioned above.

For PDSCH carrying SIB1 scheduled by PDCCH with CRC scrambled by SI-RNTI, PRG is partitioned from the lowest numbered resource block of the CORESET signalled in PBCH.

If the higher layer parameter *prb-BundlingType* is set to 'dynamic', and the UE is scheduled a PDSCH with DCI format 1_0 scrambled with C-RNTI and CS-RNTI, then the UE shall assume that $P'_{BWP.i}$ is equal to 2 PRBs.

If the higher layer parameter *prb-BundlingType* is set to 'dynamic', the higher layer parameter *bundleSizeSet1* and *bundleSizeSet*2 configures two sets of $P'_{BWP.i}$ values, the first set includes one or two $P'_{BWP.i}$ values among {2, 4, wideband}, and the second set includes one $P'_{BWP.i}$ value. The UE is not expected to be configured with (2, 4) in the first set.

If the *PRB bundling size indicator* signalled in DCI format 1_1 as defined in Subclause 7.3.1.2.2 of [2, TS 38.212]

- is set to '0', the UE shall use the $P'_{BWP.i}$ value from the second set of PRG values when receiving PDSCH scheduled by the same DCI.
- is set to '1' and one value is configured for the first set of $P'_{BWP.i}$ values, the UE shall use this $P'_{BWP.i}$ value when receiving PDSCH scheduled by the same DCI

- is set to '1' and two values are configured for the first set of $P'_{BWP,i}$ values as n2-wideband' (corresponding to two $P'_{BWP,i}$ values 2 and wideband) or n4-wideband' (corresponding to two $P'_{BWP,i}$ values 4 and wideband), the UE shall use the value when receiving PDSCH scheduled by the same DCI as follows:
  - If the scheduled PRBs are contiguous and the size of the scheduled PRBs is larger than $N^{size}_{BWP,i}/2$, $P'_{BWP,i}$ is the same as the scheduled bandwidth, otherwise $P'_{BWP,i}$ is set to the remaining configured value of 2 or 4, respectively.

If the higher layer parameter *prb-BundlingType* is set to 'static', the $P'_{BWP,i}$ value is configured with the single value indicated by the higher layer parameter *bundleSize*.

When a UE is configured with RBG = 2 according to Section 5.1.2.2.1, or when a UE is configured with resource block bundle size of 2 for VRB to PRB mapping provided by the higher layer parameter *VRB-to-PRB-interleaver*, the UE is not expected to be configured with $P'_{BWP,i}$ = 4.

5.1.3 Modulation order, target code rate, and transport block size determination

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

- read the 5-bit modulation and coding scheme field (I_{MCS}) in the DCI to determine the modulation order (Q_m) and target code rate (R) based on the procedure defined in Subclause 5.1.3.1.

and second

- the UE shall use the number of layers (υ), the total number of allocated PRBs before rate matching (n_{PRB}) to determine to the transport block size based on the procedure defined in Subclause 5.1.3.2.

The UE may skip decoding a transport block in an initial transmission if the effective channel code rate is higher than 0.95, where the effective channel code rate is defined as the number of downlink information bits (including CRC bits) divided by the number of physical channel bits on PDSCH. If the UE skips decoding, the physical layer indicates to higher layer that the transport block is not successfully decoded.

5.1.3.1 Modulation order and target code rate determination

For the PDSCH assigned by a PDCCH with DCI format 1_0 or format 1_1 with CRC scrambled by C-RNTI, TC-RNTI, CS-RNTI, SI-RNTI, RA-RNTI, or P-RNTI,

if the higher layer parameter *MCS-Table-PDSCH* is not set to '256QAM', and the PDSCH is scheduled with C-RNTI

- the UE shall use I_{MCS} and Table 5.1.3.1-1 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel.

else

- the UE shall use I_{MCS} and Table 5.1.3.1-2 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel scheduled with C-RNTI and table 5.1.3.1-1 with other RNTI.

end

The UE shall use I_{MCS} and Table 5.1.3.1-2 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel scheduled with other RNTIs than C-RNTI. The UE is not expected to decode a PDSCH scheduled with SI-RNTI and (Q_m) > 2

Table 5.1.3.1-1: MCS index table 1 for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate *R* x [1024]	Spectral efficiency
0	2	120	0.2344
1	2	157	0.3066
2	2	193	0.3770
3	2	251	0.4902
4	2	308	0.6016
5	2	379	0.7402
6	2	449	0.8770
7	2	526	1.0273
8	2	602	1.1758
9	2	679	1.3262
10	4	340	1.3281
11	4	378	1.4766
12	4	434	1.6953
13	4	490	1.9141
14	4	553	2.1602
15	4	616	2.4063
16	4	658	2.5703
17	6	438	2.5664
18	6	466	2.7305
19	6	517	3.0293
20	6	567	3.3223
21	6	616	3.6094
22	6	666	3.9023
23	6	719	4.2129
24	6	772	4.5234
25	6	822	4.8164
26	6	873	5.1152
27	6	910	5.3320
28	6	948	5.5547
29	2	reserved	
30	4	reserved	
31	6	reserved	

Table 5.1.3.1-2: MCS index table 2 for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x [1024]	Spectral efficiency
0	2	120	0.2344
1	2	193	0.3770
2	2	308	0.6016
3	2	449	0.8770
4	2	602	1.1758
5	4	378	1.4766
6	4	434	1.6953
7	4	490	1.9141
8	4	553	2.1602
9	4	616	2.4063
10	4	658	2.5703
11	6	466	2.7305
12	6	517	3.0293
13	6	567	3.3223
14	6	616	3.6094
15	6	666	3.9023
16	6	719	4.2129
17	6	772	4.5234
18	6	822	4.8164
19	6	873	5.1152
20	8	682.5	5.3320
21	8	711	5.5547
22	8	754	5.8906
23	8	797	6.2266
24	8	841	6.5703
25	8	885	6.9141
26	8	916.5	7.1602
27	8	948	7.4063
28	2	reserved	
29	4	reserved	
30	6	reserved	
31	8	reserved	

5.1.3.2 Transport block size determination

For the PDSCH assigned by a PDCCH with DCI format 1_0 or format 1_1 with CRC scrambled by C-RNTI, TC-RNTI, CS-RNTI, SI-RNTI, RA-RNTI, or P-RNTI, if the higher layer parameter *MCS-Table-PDSCH* is set to '256QAM' and $0 \le I_{MCS} \le 27$, or the higher layer parameter *MCS-Table-PDSCH* is not set to '256QAM' and $0 \le I_{MCS} \le 28$, the UE shall first determine the TBS as specified below:

1) The UE shall first determine the number of REs (N_{RE}) within the slot.

   - A UE first determines the number of REs allocated for PDSCH within a PRB (N'_{RE}) by $N'_{RE} = N_{sc}^{RB} \cdot N_{symb}^{sh} - N_{DMRS}^{PRB} - N_{oh}^{PRB}$, where $N_{sc}^{RB} = 12$ is the number of subcarriers in a physical resource block, N_{symb}^{sh} is the number of symbols of the PDSCH allocation within the slot, N_{DMRS}^{PRB} is the number of REs for DM-RS per PRB in the scheduled duration including the overhead of the DM-RS CDM groups indicated by DCI format 1_0/1_1, and N_{oh}^{PRB} is the overhead configured by higher layer parameter *Xoh-PDSCH*. If the *Xoh-PDSCH* is not configured (a value from 0, 6, 12, or 18), the *Xoh-PDSCH* is set to 0.

   - A UE determines the total number of REs allocated for PDSCH (N_{RE}) by $N_{RE} = \overline{N}'_{RE} * n_{PRB}$, where n_{PRB} is the total number of allocated PRBs for the UE.

2) Intermediate number of information bits (N_{info}) is obtained by $N_{info} = N_{RE} * R * Q_m * \upsilon$.

   If $N_{info} \le 3824$

      Use step 3 as the next step of the TBS determination

   else

      Use step 4 as the next step of the TBS determination

   end if

3) When $N_{info} \le 3824$, TBS is determined as follows

   - quantized intermediate number of information bits $N'_{info} = \max\left(24, 2^n * \left\lfloor \frac{N_{info}}{2^n} \right\rfloor\right)$, where $n = \max(3, \lfloor \log_2(N_{info}) \rfloor - 6)$.

   - use Table 5.1.3.2-2 find the closest TBS that is not less than N'_{info}.

Table 5.1.3.2-2: TBS for $N_{info} \le 3824$

Index	TBS	Index	TBS	Index	TBS	Index	TBS
1	24	31	336	61	1288	91	3624
2	32	32	352	62	1320	92	3752
3	40	33	368	63	1352	93	3824
4	48	34	384	64	1416		
5	56	35	408	65	1480		
6	64	36	432	66	1544		
7	72	37	456	67	1608		
8	80	38	480	68	1672		
9	88	39	504	69	1736		
10	96	40	528	70	1800		
11	104	41	552	71	1864		
12	112	42	576	72	1928		
13	120	43	608	73	2024		
14	128	44	640	74	2088		
15	136	45	672	75	2152		
16	144	46	704	76	2216		
17	152	47	736	77	2280		
18	160	48	768	78	2408		
19	168	49	808	79	2472		
20	176	50	848	80	2536		
21	184	51	888	81	2600		
22	192	52	928	82	2664		
23	208	53	984	83	2728		
24	224	54	1032	84	2792		
25	240	55	1064	85	2856		
26	256	56	1128	86	2976		
27	272	57	1160	87	3104		
28	288	58	1192	88	3240		
29	304	59	1224	89	3368		
30	320	60	1256	90	3496		

4) When $N_{info} > 3824$, TBS is determined as follows.

- quantized intermediate number of information bits $N'_{info} = 2^n \times round\left(\frac{N_{info} - 24}{2^n}\right)$, where $n = \lfloor \log_2(N_{info} - 24) \rfloor - 5$ and ties in the round function are broken towards the next largest integer.
- if $R \le 1/4$

$TBS = 8 * C * \left\lceil \frac{N_{info}^{'} + 24}{8 * C} \right\rceil - 24$, where $C = \left\lceil \frac{N_{info}^{'} + 24}{3816} \right\rceil$

else

if $N_{info}^{'} > 8424$

$TBS = 8 * C * \left\lceil \frac{N_{info}^{'} + 24}{8 * C} \right\rceil - 24$, where $C = \left\lceil \frac{N_{info}^{'} + 24}{8424} \right\rceil$

else

$TBS = 8 * \left\lceil \frac{N_{info}^{'} + 24}{8} \right\rceil - 24$

end if

end if

else if the higher layer parameter *MCS-Table-PDSCH* is set to '256QAM' and $28 \le I_{MCS} \le 31$,

- the TBS is assumed to be as determined from the DCI transported in the latest PDCCH for the same transport block using $0 \le I_{MCS} \le 27$. If there is no PDCCH for the same transport block using $0 \le I_{MCS} \le 27$, and if the initial PDSCH for the same transport block is semi-persistently scheduled, the TBS shall be determined from the most recent semi-persistent scheduling assignment PDCCH.

else

- the TBS is assumed to be as determined from the DCI transported in the latest PDCCH for the same transport block using $0 \le I_{MCS} \le 28$. If there is no PDCCH for the same transport block using $0 \le I_{MCS} \le 28$, and if the initial PDSCH for the same transport block is semi-persistently scheduled, the TBS shall be determined from the most recent semi-persistent scheduling assignment PDCCH.

The NDI and HARQ process ID, as signalled on PDCCH, and the TBS, as determined above, shall be reported to higher layers.

5.1.4 PDSCH resource mapping

The REs corresponding to the union of configured or dynamically indicated resources in Subclauses 5.1.4.1, 5.1.4.2 and resources corresponding to SS/PBCH are declared as not available for PDSCH in Subclause 7.3.1.5 of [4, TS 38.211]. A UE is not expected to handle the case where PDSCH DM-RS REs are overlapping, even partially, with any RE(s) declared as not available for PDSCH.

5.1.4.1 PDSCH resource mapping with RB symbol level granularity

A UE may be configured with any of the higher layer parameters indicating REs declared as not available for PDSCH:

- *Resource-set-BWP* configuring up to [4] *rate-match-PDSCH-resource-set(s)* which may contain:
  - within a BWP, a pair of reserved resources in numerology of the BWP indicated by an RB level bitmap (higher layer parameter *rate-match-PDSCH-bitmap1*) with 1RB granularity and a symbol level bitmap spanning one or two slots (higher layer parameters *rate-match-PDSCH-bitmap2*) for which the reserved RBs apply. For each pair of RB and symbol level bitmaps, a UE may be configured with a time-domain pattern (higher layer parameter *rate-match-PDSCH-bitmap3*) corresponding to a unit equal to a duration of the symbol level bitmap, and indicating whether the pair is present in the unit or not. The *rate-match-PDSCH-bitmap3* can be {1, 2, 4, 5, 8, 10, 20 or 40} units long, but maximum 40ms. The pair configured as dynamic by higher layer can be included in one or two groups of resource sets (higher layer parameters Resource-set-group-1 and Resource-set-group-2). The Resource-set-cell configuration in numerology μ applies only to PDSCH of the same numerology μ.
  - within a BWP, a frequency domain resource of a CORESET with CORESET-ID and time domain resource determined by the higher layer parameters *monitoring-offset-PDCCH-slot* and *monitoring-periodicity-PDCCH-slot* and *monitoring-symbols-PDCCH-within-slot* of search-space-sets associated with the CORESET with a CORESET ID. This resource not available for PDSCH can be included in one or two groups of resource sets (higher layer parameters *Resource-set-group-1* and *Resource-set-group-2*).
- *Resource-set-cell* configuring up to 4 rate-match-PDSCH-resource-set(s) which may contain:
  - within a serving cell, a pair of reserved resources in numerology μ configured by higher layer parameter *resource-pattern-scs* is indicated by an RB level bitmap (higher layer parameter *rate-match-PDSCH-bitmap1*) with RB granularity and a symbol level bitmap spanning one or two slots (higher layer parameters *rate-match-PDSCH-bitmap2*) for which the reserved RBs apply. For each pair of RB and symbol level bitmaps, a UE may be configured with a time-domain pattern (higher layer parameter *rate-match-PDSCH-bitmap3*) corresponding to a unit equal to a duration of the symbol level bitmap, and indicating whether the pair is present in the unit or not. The *rate-match-PDSCH-bitmap3* can be {1, 2, 4, 5, 8, 10, 20 or 40} units long, but maximum 40ms. The pair configured as dynamic by higher layer can be included in one or two groups of resource sets (higher layer parameters Resource-set-group-1 and Resource-set-group-2).

A configured group *Resource-set-group-1* or *Resource-set-group-2* contains a list of RB symbol level resource set indices forming a union of resource-sets not available for PDSCH dynamically if corresponding bit in the PDCCH with a scheduling DCI. The REs corresponding to the union of configured RB-symbol level resource-sets that are not included in neither of two groups are not available for PDSCH.

For a bitmap pair included in one or two groups of resource sets and not configured with *rate-match-PDSCH-bitmap3*,

- if unit of *rate-match-PDSCH-bitmap2* is one slot, the bitmap-pair applies to each slot of PDSCH scheduled by detected PDCCH.
- if unit of *rate-match-PDSCH-bitmap2* is two slots, first slot of bitmap pair applies to all even-numbered slot(s) and second slot of bitmap pair applies to all odd-numbered slot(s) overlapping with slot(s) of PDSCH scheduled by detected PDCCH.

When monitored aggregation levels 8 and 16 PDCCH candidates in non-interleaved CORESET spanning one OFDM symbol are having the same CCE starting position, if the detected PDCCH scheduling the PDSCH has aggregation level 8, the resources corresponding to the aggregation level 16 are not available for PDSCH, otherwise the resources corresponding to detected PDCCH that scheduled the PDSCH are not available for PDSCH.

5.1.4.2 PDSCH resource mapping with RE level granularity

To decode PDSCH according to a decoded PDCCH, a UE may be configured with any of higher layer parameters:

- *LTE-carrier* configuring common RS, in 15 kHz subcarrier spacing applicable only to 15 kHz subcarrier spacing PDSCH, of one LTE carrier in a serving cell. The configuration contains *rate-match-resources-v-shift* consisting of LTE-CRS-vshift(s), *rate-match-resources-numb-LTE-CRS-antenna-port* consisting of LTE-CRS antenna ports 1, 2 or 4 ports, *rate-match-centre-subcarrier-location* representing the LTE carrier centre subcarrier location determined by offset from (reference) point A, *rate-match-LTE-CRS-BW* representing the LTE carrier bandwidth, and may also configure *rate-match-LTE-CRS-MBSFN-subframeconfig* representing MBSFN subframe configuration.
- within a BWP, the UE can be configured with one or more ZP CSI-RS resource set configuration(s) (higher layer parameter *ZP-CSI-RS-ResourceSetConfigList*), with each ZP-CSI-RS resource set consisting of at most [64] ZP CSI-RS resources (higher layer parameter *ZP-CSI-RS-ResourceConfig*) in numerology of the BWP. The following parameters are configured via higher layer signaling for each ZP CSI-RS resource configuration:
  - ZP-CSI-RS-ResourceConfigId determines ZP CSI-RS resource configuration identity.

- ZP-CSI-RS-Density defines the zero-power CSI-RS frequency density, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211].
- ZP-CSI-RS-FreqBand parameters enabling configuration of frequency occupancy of a ZP-CSI-RS resource within a BWP as defined in Subclause 7.4.1.5 of [4, TS 38.211].
- ZP-*CSI-RS-ResourceMapping* defines the OFDM symbol and subcarrier occupancy of the ZP-CSI-RS resource within a slot that are given in Subclause 7.4.1.5 of [4, TS 38.211].
- ZP-*CSI-RS-timeConfig* defines the ZP-CSI-RS periodicity and slot offset for periodic/semi-persistent ZP-CSI-RS.
- ZP-CSI-RS-ResourceConfigType defines the ZP-CSI-RS time domain behavior of ZP-CSI-RS resource configuration as described in Subclause 7.4.1.5 of [4, TS 38.211]. The *ZP-CSI-RS-ResourceConfigType* can be periodic, semi-persistent or aperiodic. All the resources in a ZP CSI-RS resource set are configured with the same ResourceConfigType (periodic, semi-persistent, aperiodic).

The UE may be configured with a DCI field for triggering the aperiodic ZP-CSI-RS. A list of ZP-CSI-RS resource set IDs, provided by higher layer parameter *Aperiodic-ZP-CSI-RS-Resource-List*, is configured for aperiodic triggering. The maximum number of aperiodic ZP CSI-RS resource sets configured per BWP is 3. The bit-length of DCI field *ZP CSI-RS trigger* depends on the number of aperiodic ZP CSI-RS resource sets configured (up to 2 bits). Each triggering state of *ZP CSI-RS trigger* in DCI is to trigger one ZP CSI-RS resource set. The first state is reserved for not triggering aperiodic ZP CSI-RS.

For a UE configured with the higher layer parameter *ZP-CSI-RS-ResourceType* set to semi-persistent', a list of ZP-CSI-RS resource set IDs, provided by higher layer parameter *SP-ZP-CSI-RS-Resource-List*, is configured

- when a UE receives an activation command [10, TS 38.321] for ZP CSI-RS resource(s) in slot n, the corresponding action in [10, TS 38.321] and the UE assumption on the PDSCH RE mapping corresponding to the activated ZP CSI-RS resource(s) shall be applied no later than the minimum requirement defined in [11, TS 38.133].
- when a UE receives a deactivation command [10, TS 38.321] for activated ZP CSI-RS resource(s) in slot n, the corresponding action in [10, TS 38.321] and the UE assumption on cessation of the PDSCH RE mapping corresponding to the de-activated ZP CSI-RS resource(s) shall be applied no later than the minimum requirement defined in [11, TS 38.133].

5.1.5 Antenna ports quasi co-location

The UE can be configured with up to M *TCI-States* by higher layer signalling to decode PDSCH according to a detected PDCCH with DCI intended for the UE and the given serving cell, where M depends on the UE capability. Each configured TCI state includes one RS set *TCI-RS-SetConfig*. Each *TCI-RS-SetConfig* contains parameters for configuring quasi co-location relationship between the reference signals in the RS set and the DM-RS port group of the PDSCH. The RS set contains a reference to either one or two DL RSs and an associated quasi co-location type (QCL-Type) for each one configured by the higher layer parameter QCL-Type. For the case of two DL RSs, the QCL types shall not be the same, regardless of whether the references are to the same DL RS or different DL RSs. The quasi co-location types indicated to the UE are based on the higher layer parameter *QCL-Type* and may take one or a combination of the following types:

- QCL-TypeA': {Doppler shift, Doppler spread, average delay, delay spread}
- QCL-TypeB': {Doppler shift, Doppler spread}
- QCL-TypeC': {average delay, Doppler shift}
- QCL-TypeD': {Spatial Rx parameter}

The UE receives an activation command [10, TS 38.321] used to map up to 8 TCI states to the codepoints of the DCI field Transmission Configuration Indication'. After a UE receives [initial] higher layer configuration of TCI states and before reception of the activation command, the UE may assume that the antenna ports of one DM-RS port group of PDSCH of a serving cell are spatially quasi co-located with the SSB determined in the initial access procedure with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial Rx parameters, where applicable.

If a UE is configured with the higher layer parameter *TCI-PresentInDCI* that is set as 'Enabled' for the CORESET scheduling the PDSCH, the UE assumes that the TCI field is present in the DL DCI of the PDCCH transmitted on the CORESET. If *TCI-PresentInDCI* is set as 'Disabled' for the CORESET scheduling the PDSCH or the PDSCH is scheduled by a DCI format 1_0, for determining PDSCH antenna port quasi co-location, the UE assumes that the TCI state for the PDSCH is identical to the TCI state applied for the CORESET used for the PDCCH transmission.

If the *TCI-PresentinDCI* is set as 'Enabled', the UE shall use the *TCI-States* according to the value of the '*Transmission Configuration Indication*' field in the detected PDCCH with DCI for determining PDSCH antenna port quasi co-location. The UE may assume that the antenna ports of one DM-RS port group of PDSCH of a serving cell are quasi co-located with the RS(s) in the RS set with respect to the QCL type parameter(s) given by the indicated TCI state if the time offset between the reception of the DL DCI and the corresponding PDSCH is equal to or greater than a threshold *Threshold-Sched-Offset*, where the threshold is based on UE capability. For both the cases when *TCI-PresentInDCI* = 'Enabled' and *TCI-PresentInDCI* = 'Disabled', if the offset between the reception of the DL DCI and the corresponding PDSCH is less than the threshold *Threshold-Sched-Offset*, the UE may assume that the antenna ports of one DM-RS port group of PDSCH of a serving cell are quasi co-located based on the TCI state used for PDCCH quasi co-location indication of the lowest *CORESET-ID* in the latest slot in which one or more CORESETs are configured for the UE. If all configured TCI states do not contain QCL-TypeD', the UE shall obtain the other QCL assumptions from the indicated TCI states for its scheduled PDSCH irrespective of the time offset between the reception of the DL DCI and the corresponding PDSCH.

A UE should expect only the following *QCL-Type* configurations in TCI-RS-Set:

- If a CSI-RS resource is in a CSI-RS resource set configured with higher layer parameter *TRS-Info*, the UE should only expect QCL-TypeC' or {QCL-TypeC' and QCL-TypeD'} configurations with SS/PBCH block or QCL-TypeD' with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *CSI-RS-ResourceRep*.
- If a CSI-RS resource is in a CSI-RS resource set configured without higher layer parameter *TRS-Info* and without *CSI-RS-ResourceRep*, the UE should only expect QCL-TypeA' or QCL-TypeB' configuration with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *TRS-Info* or QCL-TypeD' with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *CSI-RS-ResourceRep*.
- If a CSI-RS resource in a CSI-RS resource set is configured with higher layer parameter *CSI-RS-ResourceRep*, the UE should only expect QCL-TypeA' configuration with CSI-RS in a CSI-RS resource set configured with higher layer parameter *TRS-Info* or {QCL-TypeC' and QCL-TypeD'} configurations with SS/PBCH block or {QCL-TypeD} with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *CSI-RS-ResourceRep.*.
- For the DM-RS of CORESET scheduling the PDSCH, the UE should only expect QCL-TypeA' configuration with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *TRS-Info* or {QCL-TypeA' and QCL-TypeD'} configuration with SS/PBCH block if UE is not configured with CSI-RS in a CSI-RS resource set configured with higher layer parameter *TRS-Info* or QCL-TypeD' with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *CSI-RS-ResourceRep*.
- For the DM-RS of PDSCH, the UE should only expect QCL-TypeA' configuration with a CSI-RS resource in a CSI-RS resource set configured without higher layer parameter *TRS-Info* and without *CSI-RS-ResourceRep* or QCL-TypeA' configuration with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *TRS-Info* or {QCL-TypeA' and QCL-TypeD'} configuration with SS/PBCH block if UE is not configured with a CSI-RS resource in a CSI-RS resource set with higher layer parameter *TRS-Info* or QCL-TypeD' with a CSI-RS resource in a CSI-RS resource set configured with higher layer parameter *CSI-RS-ResourceRep* or {QCL-TypeA' and QCL-TypeD'} configuration with CSI-RS resource in a CSI-RS resource

set configured without higher layer parameter *TRS-Info* and without *CSI-RS-ResourceRep*.

5.1.6 UE procedure for receiving downlink reference signals

5.1.6.1 CSI-RS reception procedure

The CSI-RS defined in Subclause 7.4.1.5 of [4, TS 38.211], may be used for time/frequency tracking, CSI computation, L1-RSRP computation and mobility.

If the UE is configuredwith a CSI-RS resource and a CORESET in the same OFDM symbol(s), the UE may assume that a PDCCH DM-RS transmitted in the CORESET are quasi co-located with QCL-TypeD', if QCL-TypeD' is applicable. Furthermore, the UE shall not expect to be configured with the CSI-RS in PRBs that overlap those of the CORESET.

The UE is not expected to receive CSI-RS and [*SystemInformationBlockType1*] message in the overlapping PRBs.

5.1.6.1.1 CSI-RS for tracking

A UE in RRC connected mode is expected to receive the higher layer UE specific configuration of a CSI-RS resource set configured with higher layer parameter.

If a UE is configured with the higher layer parameter *TRS-Info*, the UE shall assume the antenna port with the same port index of the configured NZP CSI-RS resources in the CSI-RS resource set is same. For frequency range 1, the UE may be configured with a CSI-RS resource set of four periodic CSI-RS resources in two consecutive slots with two periodic CSI-RS resources in each slot. For frequency range 2 the UE may be configured with a CSI-RS resource set of two periodic CSI-RS resources in one slot or with a CSI-RS resource set of four periodic CSI-RS resources in two consecutive slots with two periodic CSI-RS resources in each slot.

The periodic CSI-RS resources in the CSI-RS resource set configured with higher layer parameter *TRS-Info* have the same periodicity, bandwidth and subcarrier location.

Each CSI-RS resource, defined in Subclause 7.4.1.5.3-1 of [4, TS 38.211], is configured by the higher layer parameter *NZP-CSI-RS-ResourceConfig* with the following restrictions:

- the time-domain locations of the two periodic CSI-RS resources in a slot, or of the four periodic CSI-RS resources in two consecutive slots, as defined by higher layer parameter *CSI-RS-resourceMapping*, is given by one of
  - $l \in \{4,8\}$, $l \in \{5,9\}$, or $l \in \{6,10\}$ for frequency range 1 and frequency range 2,
  - $l \in \{0,4\}$, $l \in \{1,5\}$, $l \in \{2,6\}$, $l \in \{3,7\}$, $l \in \{7,11\}$, $l \in \{8,12\}$ or $l \in \{9,13\}$ for frequency range 2.
- a single port CSI-RS resource with density $\rho = 3$ given by Table 7.4.1.5.3-1 and higher layer parameter *csi-RS-Density.*

- the bandwidth of the CSI-RS resource, as given by the higher layer parameter *csi-RS-FreqBand*, is the minimum of 52 and $N_{\mathrm{RB}}^{\mathrm{BWP},i}$ resource blocks, or is equal to $N_{\mathrm{RB}}^{\mathrm{BWP},i}$ resource blocks
- the UE is not expected to be configured with the periodicity of $2^{\mu} \times 10$ slots if the bandwidth of CSI-RS resource is larger than 52 resource blocks.
- the periodicity and slot offset, as given by the higher layer parameter *csi-RS-timeConfig*, is one of $2^{\mu} X_p$ slots where X_p =10, 20, 40, or 80 ms and where μ is defined in Subclause 4.3 of [4, TS 38.211].
- same *Pc* and *Pc_SS* value across all resources.

5.1.6.1.2 CSI-RS for L1-RSRP computation

If a UE is configured with the higher layer parameter *CSI-RS-ResourceRep* set to 'ON', the UE may assume that the CSI-RS resources, described in Subclause 5.2.2.3.1, within the resource set are transmitted with the same downlink spatial domain transmission filter, where the CSI-RS resources in the resource set are transmitted in different OFDM symbols. The UE is not expected to receive different periodicity in *CSI-RS-timeConfig* and *NrofPorts* in every CSI-RS resource within the set. If the CSI-RS-ResourceRep is set to 'OFF', the UE may not assume that the CSI-RS resources within the resource set are transmitted with the same downlink spatial domain transmission filter and with same NrofPorts in every symbol.

If the UE is configured with a *CSI-ReportConfig* with *reportQuantity* set to "CRI/RSRP", or "No Report" and if the Resource Setting for channel measurement contains a CSI-RS Resource Set that is configured with the higher layer parameter *CSI-RS-ResourceRep* and configured without the higher layer parameter *TRS-Info*, then the UE may be configured with the CSI-RS resource in the same OFDM symbol(s) as an SS/PBCH block, and the UE may assume that the CSI-RS and the SS/PBCH block are quasi co-located with QCL-TypeD' if QCL-TypeD is applicable. Furthermore, the UE shall not expect to be configured with the CSI-RS in PRBs that overlap those of the SS/PBCH block, and the UE shall expect that the same subcarrier spacing is used for both the CSI-RS and the SS/PBCH block.

A UE does not expect to be configured with a Reporting Setting, which is linked to a CSI-RS resource set for tracking, where the higher layer parameter *MeasRestrictionConfig-time-channel* for the Reporting Setting set to ON'.

5.1.6.1.3 CSI-RS for mobility

If a UE is configured with the higher layer parameter *CSI-RS-Resource-Mobility* and the higher layer parameter *associatedSSB* is not configured, the UE shall perform measurements based on *CSI-RS-Resource-Mobility* and the UE may base the timing of the CSI-RS resource on the timing of the serving cell.

If a UE is configured with the higher layer parameters *CSI-RS-Resource-Mobility* and *associatedSSB*, the UE may base the timing of the CSI-RS resource on the timing of the cell given by the *Cell_ID* of the CSI-RS resource configuration. Additionally, for a given CSI-RS resource, if the associated SS/PBCH block is configured but not detected by the UE, the UE is not required to monitor the corresponding CSI-RS resource. The higher layer parameter *isQuasiColocated* indicates whether the associated SS/PBCH block given by the *associatedSSB* and the CSI-RS resource(s) are quasi co-located with the associated SS/PBCH block with respect to [QCL-TypeD'].

5.1.6.2 DM-RS reception procedure

When receiving PDSCH scheduled by PDCCH with CRC scrambled by SI-RNTI, RA-RNTI, P-RNTI or TC-RNTI, or receiving PDSCH before dedicated higher layer configuration of any of the parameters *dmrs-AdditionalPosition*, *DL-DMRS-max-len* and *dmrs-Type,* the UE shall assume that the PDSCH is not present in any symbol carrying DM-RS except for PDSCH with allocation duration of 2 symbols with PDSCH mapping type B (described in subclause 7.4.1.1.2 of [4, TS 38.211]), and a single symbol front-loaded DM-RS of configuration type 1 on DM-RS port 1000 is transmitted, and that all the remaining orthogonal antenna ports are not associated with transmission of PDSCH to another UE and in addition

- For PDSCH with mapping type A, the UE shall assume *dmrs-AdditionalPosition*=2 and up to two additional single-symbol DM-RS present in a slot according to the PDSCH duration indicated in the DCI as defined in Subclause 7.4.1.1 of [4, TS 38.211], and
- For PDSCH with allocation duration of 7 symbols with mapping type B, the UE shall assume one additional single-symbol DM-RS present in the 5th or 6th symbol when the front-loaded DM-RS symbol is in the 1st or 2nd symbol respectively of the PDSCH allocation duration, otherwise the UE shall assume that the additional DM-RS symbol is not present, and
- For PDSCH with allocation duration of 4 symbols with mapping type B, the UE shall assume that no additional DM-RS are present, and
- For PDSCH with allocation duration of 2 symbols with mapping type B, the UE shall assume that no additional DM-RS are present, and the UE shall assume that the PDSCH is present in the symbol carrying DM-RS.

When receiving PDSCH scheduled by PDCCH with CRC scrambled by C-RNTI or CS-RNTI,

- the UE may be configured with the higher layer parameter *dmrs-Type*, and the configured DM-RS configuration type is used for receiving PDSCH in as defined in Subclause 7.4.1.1 of [4, TS 38.211].
- the UE may be configured with the maximum number of front-loaded DM-RS symbols for PDSCH by higher layer parameter *DL-DMRS-max-len.*

- if *DL-DMRS-max-len* is equal to 1, single-symbol DM-RS can be scheduled for the UE by DCI, and the UE can be configured with a number of additional DM-RS for PDSCH by higher layer parameter *dmrs-AdditionalPosition,* which can be 0, 1, 2 or 3.
- if *DL-DMRS-max-len* equal to 2, both single-symbol DM-RS and double symbol DM-RS can be scheduled for the UE by DCI, and the UE can be configured with a number of additional DM-RS for PDSCH by higher layer parameter *dmrs-AdditionalPosition,* which can be 0 or 1.
- and the UE shall assume to receive additional DM-RS as specified in Table 7.4.1.1.2-3 and Table 7.4.1.1.2-4 as described in Subclause 7.4.1.1.2 of [4, TS 38.211].

A UE may assume that the DM-RS ports configured with higher layer parameter [*-dmrs-group1] or [dmrs-group2]* are QCL (as defined in Subclause 4.3.1 of [4, TS 38.211]) with respect to {average gain and QCL-TypeA' and QCL-TypeD'}

A UE can be configured with one or two scrambling identity(s), $n_{\mathrm{ID}}^{\mathrm{DMRS},i}$, $i=0,1$ by higher layers for UE-specific reference signal generation as defined in Subclause 7.4.1.1 of [4, TS 38.211] to decode PDSCH.

For PDSCH scheduled by PDCCH with CRC scrambled by SI-RNTI, a UE shall assume that DM-RS sequence is started from the lowest PRB of CORESET signalled in PBCH, otherwise DM-RS sequence is started from the reference point A for the corresponding PDSCH.

A UE may be scheduled with a number of DM-RS ports by the antenna port index in DCI format 1_1 as described in Subclause 7.3.1.2 of [5, TS 38.212].

For DM-RS configuration type 1,

- if a UE is scheduled with one codeword and assigned with the antenna port mapping with indices of {2, 9, 10, 11 or 30} in Table 7.3.1.2.2-1 and Table 7.3.1.2.2-2 of Subclause 7.3.1.2 of [5, TS 38.212], or
- if a UE is scheduled with two codewords,

the UE may assume that all the remaining orthogonal antenna ports are not associated with transmission of PDSCH to another UE.

For DM-RS configuration type 2,

- if a UE is scheduled with one codeword and assigned with the antenna port mapping with indices of {2, 10 or 23} in Table 7.3.1.2.2-3 and Table 7.3.1.2.2-4 of Subclause 7.3.1.2 of [5, TS38.212], or
- if a UE is scheduled with two codewords,

the UE may assume that all the remaining orthogonal antenna ports are not associated with transmission of PDSCH to another UE.

If a UE receiving PDSCH is configured with the higher layer parameter *DL-PTRS-present*, the UE may assume that the following configurations are not occurring simultaneously for the received PDSCH:

- any DM-RS ports among 1004-1007 or 1006-1011 for DM-RS configurations type 1 and type 2, respectively are scheduled for the UE and the other UE(s) sharing the DM-RS REs on the same CDM group(s), and
- PT-RS is transmitted to the UE.

The UE is not expected to simultaneously be configured with the maximum number of front-loaded DM-RS symbols for PDSCH by higher layer parameter *DL-DMRS-max-len* equal to 2 and more than one additional DM-RS symbol as given by the higher layer parameter *dmrs-AdditionalPosition*.

The UE is not expected to assume co-scheduled UE(s) with different DM-RS configuration with respect to the actual number of front-loaded DM-RS symbol(s), the number of additional DM-RS, the DM--RS symbol location, and DM-RS configuration type as described in Subclause 7.4.1.1 of [4, TS 38.211].

A UE shall assume that the CDM groups indicated in the configured index from Table 7.3.1.2.2-1-4 of [5, TS. 38.212] contain potential co-scheduled downlink DM-RS and are not used for data transmission, where "1", "2" and "3" for the number of DM-RS CDM group(s) in Table 7.3.1.2.2-1-4 of [5, TS. 38.212] correspond to CDM group 0, {0,1}, {0,1,2}, respectively.

The UE is not expected to receive PDSCH scheduling DCI which indicates CDM group(s) with potential DM-RS ports which overlap with any configured CSI-RS resource(s) for that UE.

If the UE receives the DM-RS for PDSCH and an SS/PBCH block in the same OFDM symbol(s), then the UE may assume that the DM-RS and SS/PBCH block are quasi co-located with QCL-TypeD', if QCL-TypeD' is applicable. Furthermore, the UE shall not expect to receive DM-RS in resource elements that overlap those of the SS/PBCH block, and the UE can expect that the same or different subcarrier spacing is configured for the DM-RS and SS/PBCH block in a CC except for the case of 240 kHz where only different subcarrier spacing is supported.

5.1.6.3 PT-RS reception procedure

A UE shall report the preferred MCS and bandwidth thresholds based on the UE capability at a given carrier frequency, for each subcarrier spacing applicable to data channel at this carrier frequency, assuming the MCS table with the maximum ModOrder as it reported to support.

If a UE is configured with the higher layer parameter *Downlink-PTRS-Config,* set to 'ON',

- if either or both of the additional higher layer parameters *timeDensity* and *frequencyDensity* are configured, and the RNTI equals C-RNTI or CS-RNTI, the UE shall assume the PT-RS antenna ports' presence and pattern are a function of the corresponding scheduled MCS of the corresponding codeword and scheduled bandwidth in corresponding bandwidth part as shown in Table 5.1.6.3-1 and Table 5.1.6.3-2,

- if the higher layer parameter *timeDensity* is not configured, the UE may assume $L_{PT\text{-}RS} = 1$.
- if the higher layer parameter *frequencyDensity* is not configured, the UE may assume $K_{PT\text{-}RS} = 2$.

- otherwise, the UE shall assume the PT-RS is present with $L_{PT\text{-}RS} = 1$, $K_{PT\text{-}RS} = 2$ and the UE shall assume that PT-RS is not present when,
  - the scheduled MCS from Table 5.1.3.1-1 is smaller than 10, or
  - the scheduled MCS from Table 5.1.3.1-2 is smaller than 5, or
  - the number of scheduled RBs is smaller than 3, or
  - the RNTI equals RA-RNTI, SI-RNTI or P-RNTI.

Table 5.1.6.3-1: Time density of PT-RS as a function of scheduled MCS

Scheduled MCS	Time density (L_{PT-RS})
I_{MCS} < ptrs-MCS_1	PT-RS is not present
ptrs-MCS1 ≤ I_{MCS} < ptrs-MCS2	4
ptrs-MCS2 ≤ I_{MCS} < ptrs-MCS3	2
ptrs-MCS3 ≤ I_{MCS} < ptrs-MCS4	1

Table 5.1.6.3-2: Frequency density of PT-RS as a function of scheduled bandwidth

Scheduled bandwidth	Frequency density (K_{PT-RS})
$N_{RB} < N_{RB0}$	PT-RS is not present
$N_{RB0} \leq N_{RB} < N_{RB1}$	2
$N_{RB1} \leq N_{RB}$	4

If a UE is configured with the higher layer parameter *Downlink-PTRS-Config,* set to 'OFF', the UE assumes PT-RS is not present.

The higher layer parameter *PTRS-DownlinkConfig* provides the parameters *ptrs-MCS$_i$*, *i*=1,2,3 and with values in range 0-29 when MCS Table 5.1.3.1-1 is configured and 0-28 when MCS Table 5.1.3.1-2 is configured, respectively. *ptrs-MCS4* is not explicitly configured by higher layers but assumed 29 when MCS Table 5.1.3.1-1 is configured and 28 when MCS Table 5.1.3.1-2 is configured, respectively. The higher layer parameter *PTRS-DownlinkConfig* provides the parameters N_{RBi} i=0,1 with values in range 1-276.

If the higher layer parameter *PTRS-DownlinkConfig* indicates that the time density thresholds *ptrs-MCS(i) = ptrs-MCS(i+1)*, then the time density $L_{PT\text{-}RS}$ of the associated row where both these thresholds appear in Table 5.1.6.3-1 is disabled. If the higher layer parameter *PTRS-DownlinkConfig*indicates that the frequency density thresholds $N_{RB}(i) = N_{RB}(i+1)$, then the frequency density K_{PTRS} of the associated row where both these thresholds appear in Table 5.1.6.3-2 is disabled.

If either or both of the parameters PT-RS time density ($L_{PT\text{-}RS}$) and PT-RS frequency density ($K_{PT\text{-}RS}$), shown in Table 5.1.6.3-1 and Table 5.1.6.3-2, indicates that 'PT-RS not present', the UE shall assume that PT-RS is not present.

When a UE is scheduled PDSCH with two DL DM-RS port groups and each DM-RS port group is associated to one PT-RS port and one codeword respectively, the time density of the PT-RS port corresponding to the codeword with lower MCS should be set as the same as that of the PT-RS port corresponding to the codeword with higher MCS when two PT-RS ports are present.

When the UE is receiving a PDSCH with allocation duration of 2 symbols with mapping type B as defined in sub-clause 7.4.1.1.2 of [4, TS 38.211] and if $L_{PT\text{-}RS}$ is set to 2 or 4, the UE shall assume PT-RS is not transmitted.

When the UE is receiving a PDSCH with allocation duration of 4 symbols with mapping type B, and if $L_{PT\text{-}RS}$ is set to 4, the UE shall assume PT-RS is not transmitted.

When a UE is receiving PDSCH for retransmission, if the UE is scheduled with an MCS index greater than V, where V=28 for MCS Table 5.1.3.1-1 and V=27 for MCS Table 5.1.3.1-2 respectively, the MCS for the PT-RS time-density determination is obtained from the DCI received for the same transport block in the initial transmission, which is smaller than or equal to V.

If the higher layer parameter *TCI-PresentinDCI* is set as Enabled', the scheduled number of PT-RS ports for a UE is indicated by TCI in DCI.

If the higher layer parameter *TCI-PresentinDCI* is set as "Disabled", the scheduled number of PT-RS ports for a UE PDSCH transmission is indicated by the TCI state applied for the CORESET used for the PDCCH transmission that schedules the PDSCH when the scheduling offset is above the threshold indicated by the UE reported *ThresholdSched-Offset*. If the scheduling offset is less or equal than the threshold, the scheduled number of PT-RS ports for a UE PDSCH transmission is indicated by the TCI state applied for the CORESET with the lowest CORESET-ID in the latest slot in which one or more CORESETs are configured for the UE. If all configured TCI states do not contain QCL-TypeD', the UE shall obtain the number of PT-RS ports from the indicated TCI states for its scheduled PDSCH irrespective of the time offset between the reception of the DL DCI and the corresponding PDSCH.

A UE is configured by higher layer parameter *nrofPorts* with a number of DL PT-RS ports per *TCI-state* (as described in sub-clause 5.1.5) for PDSCH transmission*.*

- If the number of DL PT-RS ports associated to a *TCI-state* in DCI is set to 2, the scheduled number of PT-RS ports is 2, and each PT-RS port is associated with one DM-RS port within the corresponding DM-RS port group, and the UE does not expect to be scheduled with one DM-RS port group.
  - A DL PT-RS port and the DL DM-RS port(s) within the DL DM-RS port group containing the DM-RS port associated with the PT-RS port are assumed to be quasi co-located with respect to {QCL-TypeA' and QCL-TypeD'}.
  - The first PT-RS antenna port is associated with the lowest indexed DM-RS antenna port among the DM-RS antenna ports assigned for the first DM-RS port group. The second PT-RS antenna port is associated with the lowest indexed DM-RS antenna port among the DM-RS antenna ports assigned for the second DM-RS port group.
- If the number of DL PT-RS ports associated to a *TCI -state* in DCI is set to 1, the number of PT-RS ports is 1
  - If one PT-RS port is transmitted to a UE and the UE is scheduled with DM-RS ports from two DM-RS port groups, the UE may assume the PT-RS port is shared among the two DM-RS port groups.
  - If one DL PT-RS port is transmitted for two scheduled DL DM-RS port groups, the PT-RS port and the DM-RS port(s) within the DM-RS port group which does not contain the DM-RS port associated with the PT-RS port are assumed to be quasi co-located with respect to QCL-TypeB'. Otherwise, the PT-RS port and the DL DM-RS port(s) within the DL DM-RS port group which contains the DM-RS port associated with PT-RS port are assumed to be quasi co-located with respect to {QCL-TypeA' and QCL-TypeD'}.
  - If a UE is scheduled with one codeword, the PT-RS antenna port is associated with the lowest indexed DM-RS antenna port among the DM-RS antenna ports assigned for the PDSCH.
  - If a UE is scheduled with two codewords, the PT-RS antenna port is associated with the lowest indexed DM-RS antenna port among the DM-RS antenna ports assigned for the codeword with the higher MCS. If the MCS indices of the two codewords are the same, the PT-RS antenna port is associated with the lowest indexed DM-RS antenna port assigned for codeword 0.

5.1.7 Code block group based PDSCH transmission

5.1.7.1 UE procedure for grouping of code blocks to code block groups

If a UE is configured to receive code block group (CBG) based transmissions by receiving the higher layer parameter *codeBlockGroupTransmission* set to TRUE' for PDSCH, the UE shall determine the number of CBGs for a PDSCH transmission as

$$M = \min(N, C),$$

where *N* is the maximum number of CBGs per transport block as configured by *maxCodeBlockGroupsPerTransportBlock* for PDSCH, and *C* is the number of code blocks in the PDSCH according to the procedure defined in Subclause 7.2.3 of [5, TS 38.212].

Define $M_1 = \mathrm{mod}(C, M)$, $K_1 = \left\lceil \frac{C}{M} \right\rceil$, and $K_2 = \left\lfloor \frac{C}{M} \right\rfloor$.

If $M_1 > 0$, CBG m, $m = 0,1,...,M_1 - 1$, consists of code blocks with indices $m \cdot K_1 + k, k = 0,1,..., K_1 - 1$. CBG m, $m = M_1, M_1 + 1,..., M - 1$, consists of code blocks with indices $M_1 \cdot K_1 + (m - M_1) \cdot K_2 + k, k = 0,1,..., K_2 - 1$.

5.1.7.2 UE procedure for receiving code block group based transmissions

If a UE is configured to receive code block group based transmissions by receiving the higher layer parameter *codeBlockGroupTransmission* set to TRUE' for PDSCH,

- For initial transmission of a TB as indicated by the *New Data Indicator* field of the scheduling DCI, the UE may assume that all the code block groups are present.
- For a retransmission of a TB as indicated by the *New Data Indicator* field of the scheduling DCI, the UE may assume that
  - The *CBGTI* field of the scheduling DCI indicates which CBGs of the TB are present in the transmission. A bit value of 0' in the *CBGTI* field indicates that the corresponding CBG is not transmitted and 1' indicates that it is transmitted. The order of *CBGTI* field bits is such that the CBGs are mapped in order from CBG#0 onwards starting from the MSB.
  - If the *CBGFI* field of the scheduling DCI is present, *CBGFI* set to 0' indicates that the earlier received instances of the same CBGs being transmitted may be corrupted, and *CBGFI* set to 1' indicates that the CBGs being retransmitted are combinable with the earlier received instances of the same CBGs.

5.2 UE procedure for reporting channel state information (CSI)

5.2.1 Channel state information framework

The time and frequency resources that can be used by the UE to report CSI are controlled by the gNB. CSI may consist of Channel Quality Indicator (CQI), precoding matrix indicator (PMI), CSI-RS resource indicator (CRI), layer indication (LI), rank indication (RI) and/or and L1-RSRP.

For CQI, PMI, CRI, LI, RI, L1-RSRP, a UE is configured by higher layers with N≥1 *CSI-ReportConfig* Reporting Settings, M≥1 *CSI-ResourceConfig* Resource Settings, and a list of trigger states *ReportTriggerList* containing a list of associated CSI-ReportConfigs indicating the Resource Set IDs for channel and optionally for interference.

5.2.1.1 Reporting settings

Each Reporting Setting *CSI-ReportConfig* is associated with a single downlink BWP (indicated by higher layer parameter *bandwidthPartId*) and contains the reported parameter(s) for one CSI reporting band: CSI Type (I or II) if reported, codebook configuration including codebook subset restriction, time-domain behavior, frequency granularity for CQI and PMI, measurement restriction configurations, the layer indicator (LI), the reported L1-RSRP parameter(s), CRI, and SSBRI (SSB Resource Indicator).

The time domain behavior of the *CSI-ReportConfig* indicated by the higher layer parameter *reportConfigType* and can be set to aperiodic, semi-persistent, or periodic. For periodic and semi-persistent CSI reporting, the configured periodicity and slot offset applies in the numerology of the UL BWP in which the CSI report is configured to be transmitted on. The higher layer parameter *ReportQuantity* indicates the CSI-related or L1-RSRP-related quantities to report.The *ReportFreqConfiguration* indicates the reporting granularity in the frequency domain, including the CSI reporting band and if PMI/CQI reporting is wideband or sub-band. The *CSI-timeRestrictionForChannelMeasurements ReportConfig* can also contain enabling the configuration of time domain restriction for channel measurements and *timeRestrictionForInterferenceMeasurements* enabling the configuration of time domain restriction for interference measurements. The *CSI-ReportConfig* can also contain *CodebookConfig*, which contains configuration parameters for Type-I or Type II CSI including codebook subset restriction, and configurations of group based reporting.

5.2.1.2 Resource settings

Each CSI Resource Setting *CSI-ResourceConfig* contains a configuration of S≥1 CSI Resource Sets, with each CSI Resource Set consisting of CSI-RS resources (comprised of either NZP CSI-RS or CSI-IM) and SS/PBCH Block resources used for L1-RSRP computation. Each CSI Resource Setting is located in the DL BWP identified by the higher layer parameter *bwp-id*, and all CSI Resource Settings linked to a CSI Report Setting have the same DL BWP.

The time domain behavior of the CSI-RS resources within a CSI Resource Setting are indicated by the higher layer parameter *ResourceConfigType* and can be set to aperiodic, periodic, or semi-persistent. For periodic and semi-persistent CSI Resource Settings, the number of CSI-RS Resource Sets configured is limited to S=1. For periodic and semi-persistent CSI Resource Settings, the configured periodicity and slot offset is given in the numerology of its associated DL BWP, as given by *bwp-id.*

The following are configured via higher layer signaling for one or more CSI Resource Settings for channel and interference measurement:

- CSI-IM resource for interference measurement as described in Subclause 5.2.2.4.
- NZP CSI-RS resource for interference measurement as described in Subclause 5.2.2.3.1.
- NZP CSI-RS resource for channel measurement as described in Subclause 5.2.2.3.1.

The UE may assume that the CSI-RS resource(s) for channel measurement and the CSI-IM/NZP CSI-RS resource(s) for interference measurement configured for one CSI reporting are resource-wise QCL-TypeD'.

5.2.1.3 (void)

5.2.1.4 Reporting configurations

The UE shall calculate CSI parameters (if reported) assuming the following dependencies between CSI parameters (if reported)

- LI shall be calculated conditioned on the reported CQI, PMI, RI and CRI
- CQI shall be calculated conditioned on the reported PMI, RI and CRI
- PMI shall be calculated conditioned on the reported RI and CRI
- RI shall be calculated conditioned on the reported CRI.

The Reporting configuration for CSI can be aperiodic (using PUSCH), periodic (using PUCCH) or semi-persistent (using PUCCH, and DCI activated PUSCH). The CSI-RS Resources can be periodic, semi-persistent, or aperiodic. Table 5.2.1.4-1 shows the supported combinations of CSI Reporting configurations and CSI-RS Resource configurations and how the CSI Reporting is triggered for each CSI-RS Resource configuration. Periodic CSI-RS is configured by higher layers. Semi-persistent CSI-RS is activated and deactivated as described in Subclause 5.2.1.5.2. Aperiodic CSI-RS is configured and triggered/activated as described in Subclause 5.2.1.5.1.

Table 5.2.1.4-1: Triggering/Activation of CSI Reporting for the possible CSI-RS Configurations.

CSI-RS Configuration	Periodic CSI Reporting	Semi-Persistent CSI Reporting	Aperiodic CSI Reporting
Periodic CSI-RS	No dynamic triggering/activation	For reporting on PUCCH, the UE receives an activation command [10, TS 38.321]; for reporting on PUSCH, the UE receives triggering on DCI	Triggered by DCI; additionally, activation command [10, TS 38.321] possible as defined in Subclause 5.2.1.5.1.
Semi-Persistent CSI-RS	Not Supported	For reporting on PUCCH, the UE receives an activation command [10, TS 38.321]; for reporting on PUSCH, the UE receives triggering on DCI	Triggered by DCI; additionally, activation command [10, TS 38.321] possible as defined in Subclause 5.2.1.5.1.
Aperiodic CSI-RS	Not Supported	Not Supported	Triggered by DCI; additionally, activation command [10, TS 38.321] possible as defined in Subclause 5.2.1.5.1.

When the UE is configured with the higher layer configured parameter *Number-CQI* set to '1', a single CQI is reported for one codeword per CSI report. When the UE is configured with the higher layer configured parameter *Number-CQI* set to '2', one CQI for each codeword is reported per CSI report.

When the UE is configured with higher layer parameter *ResourceSetConfig* and when the higher layer parameter *CSI-RS-ResourceRep* is set to 'OFF', the UE shall determine a CRI from the supported set of CRI values as defined in Subclause 6.3.1.1.2 of [5, TS 38.212] and report the number in each CRI report. When the higher layer parameter *CSI-RS-ResourceRep* is set to 'ON', CRI is not reported. CRI reporting is not supported when the higher layer parameter *CodebookType* is set to TypeII' or to TypeII-PortSelection'.

For a periodic or semi-persistent CSI report on PUCCH, the periodicity (measured in slots) is configured by the higher layer parameter *reportSlotConfig*.

For a semi-persistent or aperiodic CSI report on PUSCH, the allowed slot offsets are configured by the higher layer parameter *reportSlotOffset*. The offset is selected in the activating/triggering DCI.

For CSI reporting, a UE can be configured via higher layer signaling with one out of two possible subband sizes, where a subband is defined as $N_{\mathrm{PRB}}^{\mathrm{SB}}$ contiguous PRBs and depends on the total number of PRBs in the carrier bandwidth part according to Table 5.2.1.4-2.

Table 5.2.1.4-2: Configurable subband sizes

Carrier bandwidth part (PRBs)	Subband size (PRBs)
< 24	N/A
24 – 72	4, 8
73 – 144	8, 16
145 – 275	16, 32

The *ReportFreqConfiguration* contained in a *CSI-ReportConfig* indicates the frequency granularity of the CSI Report. A CSI reporting setting configuration defines a CSI reporting band as a subset of subbands of the bandwidth part, where the *ReportFreqConfiguration* indicates:

- the *CSI-ReportingBand* as a contiguous or non-contiguous subset of subbands in the bandwidth part for which CSI shall be reported. The UE is not expected to be configured with a CSI reporting band which contains subbands where reference signals for channel and interference are not present.

- single CQI or multiple CQI reporting, as configured by the higher layer parameter *CQI-FormatIndicator*. When single CQI reporting is configured, a single CQI is reported for each codeword for the entire CSI reporting band. When multiple CQI reporting is configured, one CQI for each codeword is reported for each subband in the CSI reporting band.

- single PMI or multiple PMI reporting as configured by the higher layer parameter *PMI-FormatIndicator*. When single PMI reporting is configured, a single PMI is reported for the entire CSI reporting band. When multiple PMI reporting is configured, except with 2 antenna ports, a single wideband indication (i_1 in Subclause 5.2.2.2) is reported for the entire CSI reporting band and one subband indication (i_2 in subclause 5.2.2.2) is reported for each subband in the CSI reporting band. When multiple PMIs are configured with 2 antenna ports, a PMI is reported for each subband in the CSI reporting band.

A CSI Reporting Setting is said to have a wideband frequency-granularity if either

- *ReportQuantity* is set to CRI/RI/PMI/CQI', CRI/RI/i1/CQI' or 'CRI/RI/LI/PMI/CQI', *CQI-FormatIndicator* indicates single CQI reporting and *PMI-FormatIndicator* indicates single PMI reporting, or
- *ReportQuantity* is set to CRI/RI/i1' or
- *ReportQuantity* is set to CRI/RI/CQI' and *CQI-FormatIndicator* indicates single CQI reporting, or
- *ReportQuantity* is set to CRI/RSRP'

otherwise, the CSI Reporting Setting is said to have a subband frequency-granularity.

The first subband size is given by $N_{PRB}^{SB} - \left(N_{BWP,i}^{start} \bmod N_{PRB}^{SB}\right)$ and the last subband size given by $\left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod N_{PRB}^{SB}$ if $\left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod N_{PRB}^{SB} \neq 0$ and N_{PRB}^{SB} if $\left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod N_{PRB}^{SB} = 0$

When a UE is configured with higher layer parameter *CodebookType* set to 'TypeI-SinglePanel' and *PMI-FormatIndicator* is configured for single PMI reporting, the UE may be configured with *ReportQuantity* to report:

- RI (if reported), CRI (if reported), and a PMI consisting of a single wideband indication (i_1 in Subclause 5.2.2.2.1) for the entire CSI reporting band, or
- RI (if reported), CRI (if reported), CQI, and a PMI consisting of a single wideband indication (i_1 in Subclause 5.2.2.2.1) for the entire CSI reporting band. The CQI is calculated conditioned on the reported i_1 assuming PDSCH transmission with $N_p \geq 1$ precoders (corresponding to the same i_1 but different i_2 in sub-clause 5.2.2.2.1), where the UE assumes that one precoder is randomly selected from the set of N_p precoders for each PRG on PDSCH, where the PRG size for CQI calculation is configured by the higher layer parameter *PDSCH-bundle-size-for-CSI*

If a UE is configured with semi-persistent CSI reporting, the UE shall report CSI when both CSI-IM and NZP CSI-RS resources are configured as periodic or semi-persistent. If a UE is configured with aperiodic CSI reporting, the UE shall report CSI when both CSI-IM and NZP CSI-RS resources are configured as periodic, semi-persistent or aperiodic.

5.2.1.4.1 Resource Setting configuration

For aperiodic CSI, each trigger state configured using the higher layer parameter *ReportTrigger* is associated one or multiple *CSI-ReportConfig* where each *CSI-ReportConfig* is linked to periodic, or semi-persistent, or aperiodic resource setting(s):

- When one Resource Setting is configured, the Resource Setting is for channel measurement for L1-RSRP computation.

- When two Resource Settings are configured, the first one Resource Setting is for channel measurement and the second one is for interference measurement performed on CSI-IM or on NZP CSI-RS.
- When three Resource Settings are configured, the first one resource setting is for channel measurement, the second one is for CSI-IM based interference measurement and the third one is for NZP CSI-RS based interference measurement.

For semi-persistent or periodic CSI, each *CSI-ReportConfig* is linked to periodic or semi-persistent Resource Setting(s):

- When one Resource Setting is configured, the Resource Setting is for channel measurement for L1-RSRP computation.
- When two Resource Settings are configured, the first one Resource Setting is for channel measurement and the second one is used for interference measurement performed on CSI-IM.

If interference measurement is performed on CSI-IM, each CSI-RS resource for channel measurement is resource-wise associated with a CSI-IM resource by the ordering of the CSI-RS resource and CSI-IM resource in the corresponding resource sets. The number of CSI-RS resources for channel measurement equals to the number of CSI-IM resources.

If interference measurement is performed on NZP CSI-RS, a UE does not expect to be configured with more than one NZP CSI-RS resource in the associated resource set within the resource setting for channel measurement.

For CSI measurement(s), a UE assumes:

- each NZP CSI-RS port configured for interference measurement corresponds to an interference transmission layer.
- all interference transmission layers on NZP CSI-RS ports for interference measurement take into account the associated EPRE ratios configured in 5.2.2.3.1;
- other interference signal on REs of NZP CSI-RS resource for channel measurement, NZP CSI-RS resource for interference measurement, or CSI-IM resource for interference measurement.

5.2.1.4.2 Report Quantity Configurations

If the UE is configured with a *CSI-ReportConfig* with the higher layer parameter *ReportQuantity* set to CRI/RI/PMI/CQI', CRI/RI/i1', CRI/RI/i1/CQI', CRI/RI/CQI' or CRI/RI/LI/PMI/CQI', and multiple resources are configured in the corresponding resource set for channel measurement, then the UE shall derive the CSI parameters other than CRI conditioned on the reported CRI.

If the UE is configured with a *CSI-ReportConfig* with the higher layer parameter *ReportQuantity* set to 'CRI/RSRP' or SSBRI/RSRP'

- if the UE is configured with the higher layer parameter *group-based-beam-reporting* set to 'OFF', the UE is not required to update measurements for more than 64 [CSI-RS and or SSB] resources, and the UE shall report in a single report *nrofReportedRS* (higher layer configured) different [CRI or SSBRI (SSB Resource Indicator)] for each report setting.
- if the UE is configured with the higher layer parameter *group-based-beam-reporting* set to 'ON', the UE is not required to update measurements for more than 64 [CSI-RS and or SSB] resources, and the UE shall report in a single reporting instance two different [CRI or SSBRI] for each report setting, where [CSI-RS and or SSB] resources can be received simultaneously by the UE either with a single spatial domain receive filter, or with multiple simultaneous spatial domain receive filters.

If the UE is configured with a *CSI-ReportConfig* with the higher layer parameter *ReportQuantity* set to CRI/RI/PMI/CQI', CRI/RI/i1', CRI/RI/i1/CQI', CRI/RI/CQI' or CRI/RI/LI/PMI/CQI', then the UE is not expected to be configured with more than 8 CSI-RS resources in a CSI-RS resource set contained within a resource setting that is linked to the *CSI-ReportConfig*.

If the UE is configured with a *CSI-ReportConfig* with higher layer parameter *ReportQuantity* set to 'CRI/RSRP' or No Report' and the *CSI-ReportConfig* is linked to a resource setting configured with the higher layer parameter *ResourceConfigType* set to 'aperiodic', then the UE is not expected to be configured with more than 16 CSI-RS resources in a CSI-RS resource set contained within the resource setting.

If the UE is configured with a *CSI-ReportConfig* with the higher layer parameter *ReportQuantity* set to 'CRI/RI/CQI':

- the UE is configured with higher layer parameter *Non-PMI-PortIndication* contained in a *CSI-ReportConfig,* where *r* ports are indicated in the order of layer ordering for rank *r* and each CSI-RS resource in the CSI resource setting is linked to the *CSI-ReportConfig* based on the order of the associated *NZP-CSI-RS-ResourceConfigID* in the linked CSI resource setting linked for channel measurement. The higher layer parameter *Non-PMI-PortIndication* contains a sequence $p_0^{(1)}, p_0^{(2)}, p_1^{(2)}, p_0^{(3)}, p_1^{(3)}, p_2^{(3)},..., p_0^{(R)}, p_1^{(R)},..., p_{R-1}^{(R)}$ of port indices, where $p_0^{(\nu)},..., p_{\nu-1}^{(\nu)}$ are the CSI-RS port indices associated with rank ν and $R \in \{1,2,...,\min(8,P)\}$ where $P \in \{1,2,4,8\}$ is the number of ports in the CSI-RS resource.
- When calculating the CQI for a rank, the UE shall use the ports indicated for that rank for the selected CSI-RS resource. The precoder for the indicated ports shall be assumed to be the identity matrix.

If the UE is configured with a CSI-RS resource is configured with the higher layer parameter *ReportQuantity* set to 'No Report', then the UE shall not report any quantity for the *CSI-ReportConfig* associated with the *ReportQuantity*. Otherwise, the UE shall report the quantity for the *CSI-ReportConfig* as configured by the associated *ReportQuantity.*

5.2.1.4.3 L1-RSRP Reporting

For L1-RSRP computation

- the UE may be configured with CSI-RS resources, SS/PBCH Block resources or both CSI-RS and SS/PBCH Block resource.
- the UE may be configured with CSI-RS resource setting up to 16 CSI-RS resource sets having up to 64 resources within each set. The total number of different CSI-RS resources over all resource sets is no more than 128.

For L1-RSRP reporting, if the higher layer parameter *nrofReportedRS* is configured to be one, the reported L1-RSRP value is defined by a 7-bit value in the range [-140, -44] dBm with 1dB step size, if the higher layer parameter *nrofReportedRS* is configured to be larger than one, or if the higher layer parameter group-based-beam-reporting is configured as ON', the UE shall use differential L1-RSRP based reporting, where the largest value of L1-RSRP uses a 7-bit value in the range [-140, -44] dBm with 1dB step size, and the differential L1-RSRP uses a 4-bit value. The differential L1-RSRP value is computed with 2 dB step size with a reference to the largest L1-RSRP value which is part of the same L1-RSRP reporting instance. The mapping between the reported L1-RSRP value and the measured quantity is described in [11, TS 38.133].

5.2.1.5 Triggering/activation of CSI Reports and CSI-RS

5.2.1.5.1 Aperiodic CSI Reporting/Aperiodic CSI-RS

For CSI-RS resource sets associated with Resource Settings configured with the higher layer parameter *ResourceConfigType* set to 'aperiodic', periodic', or semi-persistent', trigger states for Reporting Setting(s) and/or Resource Setting for channel and/or interference measurement on one or more component carriers are configured using the higher layer parameter *AperiodicReportTrigger*. For aperiodic CSI report triggering, a single set of CSI triggering states are higher layer configured, wherein the CSI triggering states can be associated with any candidate DL BWP. A UE is not expected to receive more than one aperiodic CSI report request for a given slot. A UE is not expected to be triggered with a CSI report for a non-active DL BWP. A trigger state is initiated using the *CSI request* field in DCI.

- When all the bits of *CSI request* field in DCI are set to zero, no CSI is requested.
- When the number of configured CSI triggering states in *AperiodicReportTrigger* is greater than $2^{N_{\mathrm{TS}}}-1$, where N_{TS} is the number of bits in the DCI *CSI request* field, the UE receives a selection command [10, TS 38.321] used to map up to $2^{N_{\mathrm{TS}}}-1$ trigger states to the codepoints of the *CSI request* field in DCI. N_{TS} is configured by the higher layer parameter *ReportTriggerSize* where $N_{TS} \in \{0,1,2,3,4,5,6\}$.

- When the number of CSI triggering states in *AperiodicReportTrigger* is less than or equal to $2^{N_{TS}}-1$, the *CSI request* field in DCI directly indicates the triggering state and the UE's quasi co-location assumption.
- For each aperiodic CSI-RS resource associated with each CSI triggering state, the UE is indicated the quasi co-location configuration of quasi co-location RS source(s) and quasi co-location type(s), as described in Subclause 5.1.5, through higher layer signaling of *QCL-Info-AperiodicReportingTrigger* which contains a list of references to *TCI-RS-SetConfig*'s for the aperiodic CSI-RS resources associated with the CSI triggering state. If a *TCI-RS-SetConfig* in the list is configured with a reference to an RS associated with *QCL-TypeD*', that RS may be an SS/PBCH block located in the same or different CC/DL BWP or a CSI-RS resource configured as periodic or semi-persistent located in the same or different CC/DL BWP.

For a UE configured with the higher layer parameter *AperiodicReportTrigger*, if a Resource Setting linked to a *CSI-ReportConfig* has multiple aperiodic resource sets and only one of the aperiodic CSI-RS resource sets is associated with the trigger state, a higher layer configured bitmap *ResourceSetBitmap* is configured per trigger state per Resource Setting to select the CSI-IM/NZP CSI-RS resource set(s) from the Resource Setting.

When aperiodic CSI-RS is used with aperiodic reporting, the CSI-RS offset is configured per resource set by the higher layer parameter *AperiodicNZP-CSI-RS-TriggeringOffset*. The CSI-RS triggering offset has the range of 0 to 4 slots. If all the associated trigger states do not contain QCL-TypeD' parameter in the corresponding TCI states, the CSI-RS triggering offset is fixed to zero. The UE does not expect that aperiodic CSI-RS is transmitted before the OFDM symbol(s) carrying its triggering DCI.

If the UE is configured with a single carrier, the UE is not expected to transmit more than one aperiodic CSI report triggered by different DCIs on overlapping OFDM symbols.

5.2.1.5.2 Semi-persistent CSI/Semi-persistent CSI-RS

For semi-persistent reporting on PUSCH, a set of semi-persistent Reporting settings are higher layer configured by *Semi-persistent-on-PUSCHReportTrigger,* the CSI request field in DCI scrambled with SP-CSI C-RNTI activates one of the semi-persistent CSI reports and the PUCCH resource used for transmitting the CSI report are configured by *reportConfigType*.

Semi-persistent reporting on PUCCH is activated by an activation command [10, TS 38.321], which selects one of the semi-persistent Reporting Settings for use by the UE on the PUCCH. If the field r*eportConfigType* is not present, the UE shall report the CSI on PUSCH.

For a UE configured with the higher layer parameter *ResourceConfigType* set to 'semi-persistent'.

- when a UE receives an activation command [10, TS 38.321] for CSI-RS resource(s) for channel measurement and CSI-IM/NZP CSI-RS resource(s) for interference measurement associated with configured CSI resource setting(s) in slot n, the corresponding actions in [10, TS 38.321] and the UE assumptions (including QCL assumptions provided by a list of references to *TCI-RS-SetConfig's,* one per activated resource) on CSI-RS/CSI-IM transmission corresponding to the configured CSI-RS/CSI-IM resource configuration(s) shall be applied no later than the minimum requirement defined in [10, TS 38.133]. If a *TCI-RS-SetConfig* in the list is configured with a reference to an RS associated with QCL-TypeD', that RS can be an SS/PBCH block, periodic or semi-persistent CSI-RS located in same or different CC/DL BWP.

- when a UE receives a deactivation command [10, TS 38.321] for activated CSI-RS/CSI-IM resource(s) associated with configured CSI resource setting(s) in slot n, the corresponding actions in [10, TS 38.321] and UE assumption on cessation of CSI-RS/CSI-IM transmission corresponding to the deactivated CSI-RS/CSI-IM resource(s) shall apply no later than the minimum requirement defined in [10, TS 38.133]. If a *TCI-RS-SetConfig* in the list is configured with a reference to an RS associated with QCL-TypeD', that RS can be an SS/PBCH block, periodic or semi-persistent CSI-RS located in same or different CC/DL BWP.

5.2.2 Channel state information

5.2.2.1 Channel quality indicator (CQI)

The CQI indices and their interpretations are given in Table 5.2.2.1-2 for reporting CQI based on QPSK, 16QAM and 64QAM. The CQI indices and their interpretations are given in Table 5.2.2.1-3 for reporting CQI based on QPSK, 16QAM, 64QAM and 256QAM.

Based on an unrestricted observation interval in time unless specified otherwise in this Subclause, [and an unrestricted observation interval in frequency-TBD], the UE shall derive for each CQI value reported in uplink slot *n* the highest CQI index which satisfies the following condition:

- A single PDSCH transport block with a combination of modulation scheme, target code rate 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, if the higher layer parameter *CQI-table* configures Table 5.2.2.1-2, or Table 5.2.2.1-3, or
  - a higher layer configured *BLER-target*, if the higher layer parameter *CQI-table* configures Table 5.2.2.1-4.

If a UE is not configured with higher layer parameter *MeasRestrictionConfig-time-channel*, the UE shall derive the channel measurements for computing CQI value reported in uplink slot n based on only the NZP CSI-RS, no later than the CSI reference resource, (defined in TS 38.211[4]) associated with the CSI resource setting.

If a UE is configured with higher layer parameter *MeasRestrictionConfig-time-channel*, the UE shall derive the channel measurements for computing CSI reported in uplink slot n based on only the most recent, no later than the CSI reference resource, occasion of NZP CSI-RS (defined in [4, TS 38.211]) associated with the CSI resource setting.

If a UE is not configured with higher layer parameter *MeasRestrictionConfig-time-interference*, the UE shall derive the interference measurements for computing CQI value reported in uplink slot n based on only the CSI-IM and/or NZP CSI-RS for interference measurement no later than the CSI reference resource associated with the CSI resource setting.

If a UE is configured with higher layer parameter *MeasRestrictionConfig-time-interference* the UE shall derive the interference measurements for computing the CQI value reported in uplink slot n based on the most recent, no later than the CSI reference resource, occasion of CSI-IM and/or NZP CSI-RS for interference measurement (defined in [4, TS 38.211]) associated with the CSI resource setting.

For each sub-band index *s*, a 2-bit sub-band differential CQI is defined as:

- Sub-band Offset level (*s*) = wideband CQI index – sub-band CQI index (*s*)

The mapping from the 2-bit sub-band differential CQI values to the offset level is shown in Table 5.2.2.1-1

Table 5.2.2.1-1: Mapping sub-band differential CQI value to offset level

Sub-band differential CQI value	Offset level
0	0
1	1
2	≥ 2
3	≤-1

A combination of modulation scheme and transport block size corresponds to a CQI index if:

- the combination could be signaled for transmission on the PDSCH in the CSI reference resource according to the Transport Block Size determination described in Subclause 5.1.3.2, 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.

Table 5.2.2.1-2: 4-bit CQI Table

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Table 5.2.2.1-3: 4-bit CQI Table 2

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063

Table 5.2.2.1-3: [TBD]-bit CQI Table 3

5.2.2.1.1 CSI reference resource definition

The CSI reference resource for a serving cell is defined as follows:

- In the frequency domain, the CSI reference resource is defined by the group of downlink physical resource blocks corresponding to the band to which the derived CQI value relates.
- In the time domain, for a UE configured with a single CSI resource set for the serving cell, the CSI reference resource for a CSI reporting in uplink slot n is defined by a single downlink slot n-n_{CQI_ref},
  - where for periodic and semi-persistent CSI reporting n_{CQI_ref} is the smallest value greater than or equal to [TBD], such that it corresponds to a valid downlink slot.
  - where for aperiodic CSI reporting, if the UE is indicated by the DCI to report CSI in the same slot as the CSI request, n_{CQI_ref} is such that the reference resource is in the same valid downlink slot as the corresponding CSI request, otherwise n_{CQI_ref} is the smallest value greater than or equal to $\lfloor Z' / N_{symb}^{slot} \rfloor$, such that slot n-n_{CQI_ref} corresponds to a valid downlink slot, where Z' corresponds to the delay requirement as defined in Subclause 5.4.
  - when periodic or semi-persistent CSI-RS/CSI-IM is used for channel/interference measurements, the UE is not expected to measure channel/interference on the CSI-RS/CSI-IM whose last OFDM symbol is received up to Z' symbols before transmission time of the first OFDM symbol of the aperiodic CSI reporting.

A slot in a serving cell shall be considered to be a valid downlink slot if:

- it is configured as a downlink slot for that UE, and
- it does not fall within a configured measurement gap for that UE, and
- the active DL BWP in the slot is the same as the DL BWP for which the CSI reporting is performed, and
- there is at least one CSI-RS transmission occasion for channel measurement and CSI-RS and/or CSI-IM occasion for interference measurement no later than CSI reference resource for which the CSI reporting is performed.

If there is no valid downlink slot for the CSI reference resource corresponding to a CSI Report Setting in a serving cell, CSI reporting is omitted for the serving cell in uplink slot n.

When deriving CSI feedback, the UE is not expected that a NZP CSI -RS resource for channel measurement overlaps with CSI-IM resource for interference measurement or NZP CSI -RS resource for interference measurement.

In the CSI reference resource, the UE shall assume the following for the purpose of deriving the CQI index, and if also configured, for deriving PMI and RI:

- The first 2 OFDM symbols are occupied by control signaling.
- The number of PDSCH and DM-RS symbols is equal to 12.
- The same bandwidth part subcarrier spacing configured as for the PDSCH reception
- The bandwidth as configured for the corresponding CQI report.
- The reference resource uses the CP length and subcarrier spacing configured for PDSCH reception
- No resource elements used by primary or secondary synchronization signals or PBCH.
- Redundancy Version 0.
- The ratio of PDSCH EPRE to CSI-RS EPRE is as given in Subclause 4.1.
- Assume no REs allocated for NZP CSI-RS and ZP CSI-RS.
- Assume the same number of front loaded DM-RS symbols as the maximum front-loaded symbols configured by the higher layer parameter *DL-DMRS-max-len.*
- Assume the same number of additional DM-RS symbols as the additional symbols configured by the higher layer parameter *DL-DMRS-add-pos*.
- Assume the PDSCH symbols are not containing DM-RS.
- Assume PRB bundling size of 2 PRBs.
- The PDSCH transmission scheme where the UE may assume that PDSCH transmission would be performed with up to 8 transmission layers as defined in Subclause 7.3.1.4 of [4, TS 38.211]. For CQI calculation, the UE should assume that PDSCH signals on antenna ports in the set [1000 1008+ν-1] for ν layers would result in signals equivalent to corresponding symbols transmitted on antenna ports [3000 3000+*P*-1], as given by

$$\begin{bmatrix} y^{(3000)}(i) \\ M \\ y^{(3000+P-1)}(i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)}(i) \\ M \\ x^{(\nu-1)}(i) \end{bmatrix}$$

where $x(i) = \left[x^{(0)}(i) \ldots x^{(\nu-1)}(i)\right]^T$ is a vector of PDSCH symbols from the layer mapping defined in Subclause 7.3.1.4 of [4, TS 38.211], $P \in [1,2,4,8,12,16,24,32]$ is the number of CSI-RS ports. If only one CSI-RS port is configured, *W(i)* is 1, otherwise *W(i)* is the precoding matrix corresponding to the reported PMI applicable to *x(i)*. The corresponding PDSCH signals transmitted on antenna ports [3000,3000 + *P* - 1] would have a ratio of EPRE to CSI-RS EPRE equal to the ratio given in Subclause 4.1.

5.2.2.2 Precoding matrix indicator (PMI)

5.2.2.2.1 Type I Single-Panel Codebook

For 2 antenna ports {3000, 3001} and the UE configured with higher layer parameter *CodebookType* set to 'TypeI-SinglePanel' each PMI value corresponds to a codebook index given in Table 5.2.2.2.1-1. The UE is configured with the higher layer parameter *TypeI-SinglePanel-2Tx-CodebookSubsetRestriction*. The bitmap parameter *TypeI-SinglePanel-2Tx-CodebookSubsetRestriction* forms the bit sequence $a_5,...,a_1,a_0$ where a_0 is the LSB and a_5 is the MSB and where a bit value of zero indicates that PMI reporting is not allowed to correspond to the precoder associated with the bit. Bits 0 to 3 are associated respectively with the codebook indices 0 to 3 for $\upsilon=1$ layer, and bits 4 and 5 are associated respectively with the codebook indices 0 and 1 for $\upsilon=2$ layers.

Table 5.2.2.2.1-1: Codebooks for 1-layer and 2-layer CSI reporting using antenna ports 3000 to 3001

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

For 4 antenna ports {3000, 3001, 3002, 3003}, 8 antenna ports {3000, 3001, …, 3007}, 12 antenna ports {3000, 3001, …, 3011}, 16 antenna ports {3000, 3001, …, 3015}, 24 antenna ports {3000, 3001, …, 3023}, and 32 antenna ports {3000, 3001, …, 3031}, and the UE configured with higher layer parameter *CodebookType* set to 'TypeI-SinglePanel', except when the number of layers $\upsilon\in\{2,3,4\}$ (where υ is the associated RI value), each PMI value corresponds to three codebook indices $i_{1,1}, i_{1,2}, i_2$. When the number of layers $\upsilon\in\{2,3,4\}$, each PMI value corresponds to four codebook indices $i_{1,1}, i_{1,2}, i_{1,3}, i_2$. The composite codebook index i_1 is defined by

$$i_1=\begin{cases}\begin{bmatrix}i_{1,1} & i_{1,2}\end{bmatrix} & \upsilon\notin\{2,3,4\}\\ \begin{bmatrix}i_{1,1} & i_{1,2} & i_{1,3}\end{bmatrix} & \upsilon\in\{2,3,4\}\end{cases}$$

The codebooks for 1-8 layers are given respectively in Tables 5.2.2.2.1-5, 5.2.2.2.1-6, 5.2.2.2.1-7, 5.2.2.2.1-8, 5.2.2.2.1-9, 5.2.2.2.1-10, 5.2.2.2.1-11, and 5.2.2.2.1-12. The mapping from $i_{1,3}$ to k_1 and k_2 for 2-layer reporting is given in Table 5.2.2.2.1-3. The mapping from

$i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer reporting when $P_{\text{CSI-RS}} < 16$ is given in Table 5.2.2.2.1-4. The quantities φ_n, θ_p, u_m, $v_{l,m}$, and $\tilde{v}_{l,m}$ are given by

$$\varphi_n = e^{j\pi n/2}$$
$$\theta_p = e^{j\pi p/4}$$
$$u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$$
$$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \cdots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$$
$$\tilde{v}_{l,m} = \begin{bmatrix} u_m & e^{j\frac{4\pi l}{O_1 N_1}} u_m & \cdots & e^{j\frac{4\pi l(N_1/2-1)}{O_1 N_1}} u_m \end{bmatrix}^T$$

- The values of N_1 and N_2 are configured with the higher layer parameters *CodebookConfig-N1* and *CodebookConfig-N2*, respectively. The supported configurations of (N_1, N_2) for a given number of CSI-RS ports and the corresponding values of (O_1, O_2) are given in Table 5.2.2.2.1-2. The number of CSI-RS ports, $P_{\text{CSI-RS}}$, is $2N_1N_2$.
- UE shall only use $i_{1,2} = 0$ and shall not report $i_{1,2}$ if the value of *CodebookConfig-N2* is set to 1.

The UE is also configured with the higher layer parameters *TypeI-SinglePanel-CodebookSubsetRestriction,* and *TypeI-SinglePanel-RI-Restriction*. The bitmap parameter *TypeI-SinglePanel-CodebookSubsetRestriction* forms the bit sequence $a_{A_c-1}, \ldots, a_1, a_0$ where a_0 is the LSB and a_{A_c-1} is the MSB and where a bit value of zero indicates that PMI reporting is not allowed to correspond to any precoder associated with the bit. The number of bits is given by $A_c = N_1O_1N_2O_2$. Except when the number of layers $\upsilon \in \{3,4\}$ and the number of antenna ports is 16, 24, or 32, bit $a_{N_2O_2l+m}$ is associated with all precoders based on the quantity $v_{l,m}$, $l = 0, \ldots, N_1O_1 - 1$, $m = 0, \ldots, N_2O_2 - 1$. When the number of layers $\upsilon \in \{3,4\}$ and the number of antenna ports is 16, 24, or 32,

- bits $a_{(N_2O_2(2l-1)+m) \bmod N_1O_1N_2O_2}$, $a_{N_2O_2(2l)+m}$, and $a_{N_2O_2(2l+1)+m}$ are each associated with all precoders based on the quantity $\tilde{v}_{l,m}$, $l = 0, \ldots, N_1O_1/2 - 1$, $m = 0, \ldots, N_2O_2 - 1$;
- if one or more of the associated bits is zero, then PMI reporting is not allowed to correspond to any precoder based on $\tilde{v}_{l,m}$.

The bitmap parameter *TypeI-SinglePanel-RI-Restriction* forms the bit sequence $r_7, \ldots, r_1, r_0$ where r_0 is the LSB and r_7 is the MSB. When r_i is zero, $i \in \{0,1,\ldots,7\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $\upsilon = i + 1$ layers.

Table 5.2.2.2.1-2: Supported configurations of (N_1,N_2) and (O_1,O_2)

Number of CSI-RS antenna ports, $P_{\text{CSI-RS}}$	(N_1,N_2)	(O_1,O_2)
4	(2,1)	(4,1)
8	(2,2)	(4,4)
	(4,1)	(4,1)
12	(3,2)	(4,4)
	(6,1)	(4,1)
16	(4,2)	(4,4)
	(8,1)	(4,1)
24	(4,3)	(4,4)
	(6,2)	(4,4)
	(12,1)	(4,1)
32	(4,4)	(4,4)
	(8,2)	(4,4)
	(16,1)	(4,1)

Table 5.2.2.2.1-3: Mapping of $i_{1,3}$ to k_1 and k_2 for 2-layer CSI reporting

$i_{1,3}$	$N_1 > N_2 > 1$		$N_1 = N_2$		$N_1 = 2, N_2 = 1$		$N_1 > 2, N_2 = 1$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	0	0	0	0	0	0	0	0
1	O_1	0	O_1	0	O_1	0	O_1	0
2	0	O_2	0	O_2			$2O_1$	0
3	$2O_1$	0	O_1	O_2			$3O_1$	0

Table 5.2.2.2.1-4: Mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer CSI reporting when $P_{\text{CSI-RS}} < 16$

$i_{1,3}$	$N_1 = 2, N_2 = 1$		$N_1 = 4, N_2 = 1$		$N_1 = 6, N_2 = 1$		$N_1 = 2, N_2 = 2$		$N_1 = 3, N_2 = 2$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	O_1	0	O_1	0	O_1	0	O_1	0	O_1	0
1			$2O_1$	0	$2O_1$	0	0	O_2	0	O_2
2			$3O_1$	0	$3O_1$	0	O_1	O_2	O_1	O_2
3					$4O_1$	0			$2O_1$	0

Table 5.2.2.2.1-5: Codebook for 1-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode = 1			
$i_{1,1}$	$i_{1,2}$	i_2	
$0,1,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$W^{(1)}_{i_{1,1},i_{1,2},i_2}$
where $W^{(1)}_{l,m,n}=\frac{1}{\sqrt{P_{\text{CSI-RS}}}}\begin{bmatrix}v_{l,m}\\ \varphi_n v_{l,m}\end{bmatrix}$.			

CodebookMode = 2, $N_2>1$					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	1	2	3
$0,1,\ldots,\frac{N_1O_1}{2}-1$	$0,1,\ldots,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1},2i_{1,2},0}$	$W^{(1)}_{2i_{1,1},2i_{1,2},1}$	$W^{(1)}_{2i_{1,1},2i_{1,2},2}$	$W^{(1)}_{2i_{1,1},2i_{1,2},3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	5	6	7
$0,1,\ldots,\frac{N_1O_1}{2}-1$	$0,1,\ldots,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},0}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},1}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},2}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	9	10	11
$0,1,\ldots,\frac{N_1O_1}{2}-1$	$0,1,\ldots,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,0}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,1}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,2}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	13	14	15
$0,1,\ldots,\frac{N_1O_1}{2}-1$	$0,1,\ldots,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,0}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,1}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,2}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,3}$
where $W^{(1)}_{l,m,n}=\frac{1}{\sqrt{P_{\text{CSI-RS}}}}\begin{bmatrix}v_{l,m}\\ \varphi_n v_{l,m}\end{bmatrix}$.					

***CodebookMode* = 2,** $N_2=1$					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	**1**	**2**	**3**
$0,1,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(1)}_{2i_{1,1},0,0}$	$W^{(1)}_{2i_{1,1},0,1}$	$W^{(1)}_{2i_{1,1},0,2}$	$W^{(1)}_{2i_{1,1},0,3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	**5**	**6**	**7**
$0,1,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(1)}_{2i_{1,1}+1,0,0}$	$W^{(1)}_{2i_{1,1}+1,0,1}$	$W^{(1)}_{2i_{1,1}+1,0,2}$	$W^{(1)}_{2i_{1,1}+1,0,3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	**9**	**10**	**11**
$0,1,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(1)}_{2i_{1,1}+2,0,0}$	$W^{(1)}_{2i_{1,1}+2,0,1}$	$W^{(1)}_{2i_{1,1}+2,0,2}$	$W^{(1)}_{2i_{1,1}+2,0,3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	**13**	**14**	**15**
$0,1,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(1)}_{2i_{1,1}+3,0,0}$	$W^{(1)}_{2i_{1,1}+3,0,1}$	$W^{(1)}_{2i_{1,1}+3,0,2}$	$W^{(1)}_{2i_{1,1}+3,0,3}$
where $W^{(1)}_{l,m,n}=\frac{1}{\sqrt{P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m}\end{bmatrix}$.					

Table 5.2.2.2.1-6: Codebook for 2-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***CodebookMode* = 1**			
$i_{1,1}$	$i_{1,2}$	i_2	
$0,1,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	0,1	$W^{(2)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_2}$
where $W^{(2)}_{l,l',m,m',n}=\frac{1}{\sqrt{2P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & -\varphi_n v_{l',m'}\end{bmatrix}$. and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.			

***CodebookMode* = 2, $N_2>1$**			
$i_{1,1}$	$i_{1,2}$	i_2	
		0	**1**
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,2i_{1,2},2i_{1,2}+k_2,0}$	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,2i_{1,2},2i_{1,2}+k_2,1}$
$i_{1,1}$	$i_{1,2}$	i_2	
		2	**3**
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,2i_{1,2},2i_{1,2}+k_2,0}$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,2i_{1,2},2i_{1,2}+k_2,1}$
$i_{1,1}$	$i_{1,2}$	i_2	
		4	**5**
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,2i_{1,2}+1,2i_{1,2}+1+k_2,0}$	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,2i_{1,2}+1,2i_{1,2}+1+k_2,1}$
$i_{1,1}$	$i_{1,2}$	i_2	
		6	**7**
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,2i_{1,2}+1,2i_{1,2}+1+k_2,0}$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,2i_{1,2}+1,2i_{1,2}+1+k_2,1}$
where $W^{(2)}_{l,l',m,m',n}=\frac{1}{\sqrt{2P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & -\varphi_n v_{l',m'}\end{bmatrix}$. and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.			

***CodebookMode* = 2, $N_2=1$**					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	**1**	**2**	**3**
$0,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,0,0,0}$	$W^{(2)}_{2i_{1,1},2i_{1,1}+k_1,0,0,1}$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,0,0,0}$	$W^{(2)}_{2i_{1,1}+1,2i_{1,1}+1+k_1,0,0,1}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	**5**	**6**	**7**
$0,\ldots,\frac{N_1O_1}{2}-1$	0	$W^{(2)}_{2i_{1,1}+2,2i_{1,1}+2+k_1,0,0,0}$	$W^{(2)}_{2i_{1,1}+2,2i_{1,1}+2+k_1,0,0,1}$	$W^{(2)}_{2i_{1,1}+3,2i_{1,1}+3+k_1,0,0,0}$	$W^{(2)}_{2i_{1,1}+3,2i_{1,1}+3+k_1,0,0,1}$
where $W^{(2)}_{l,l',m,m',n}=\frac{1}{\sqrt{2P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & -\varphi_n v_{l',m'}\end{bmatrix}$. and the mapping from $i_{1,3}$ to k_1 is given in Table 5.2.2.2.1-3.					

Table 5.2.2.2.1-7: Codebook for 3-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***CodebookMode* = 1-2, $P_{\text{CSI-RS}}<16$**			
$i_{1,1}$	$i_{1,2}$	i_2	
$0,\ldots,N_1O_1-1$	$0,1,\ldots,N_2O_2-1$	0,1	$W^{(3)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_2}$
where $W^{(3)}_{l,l',m,m'.n}=\frac{1}{\sqrt{3P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l,m} \\ \varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l,m}\end{bmatrix}$.			

and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-4.

***CodebookMode* = 1-2,** $P_{\text{CSI-RS}} \geq 16$				
$i_{1,1}$	$i_{1,2}$	$i_{1,3}$	i_2	
$0,\ldots,\frac{N_1 O_1}{2}-1$	$0,\ldots,N_2 O_2 -1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,2},i_{1,3},i_2}$
where $W^{(3)}_{l,m,p,n} = \frac{1}{\sqrt{3P_{\text{CSI-RS}}}}\begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} & \theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} & -\varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_n \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}$.				

Table 5.2.2.2.1-8: Codebook for 4-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***CodebookMode* = 1-2,** $P_{\text{CSI-RS}} < 16$			
$i_{1,1}$	$i_{1,2}$	i_2	
$0,\ldots,N_1 O_1 -1$	$0,1,\ldots,N_2 O_2 -1$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_2}$
where $W^{(4)}_{l,l',m,m'.n} = \frac{1}{\sqrt{4P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l,m} & -\varphi_n v_{l',m'} \end{bmatrix}$. and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-4.			

***CodebookMode* = 1-2,** $P_{\text{CSI-RS}} \geq 16$				
$i_{1,1}$	$i_{1,2}$	$i_{1,3}$	i_2	
$0,\ldots,\frac{N_1 O_1}{2}-1$	$0,\ldots,N_2 O_2 -1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,2},i_{1,3},i_2}$
where $W^{(4)}_{l,m,p,n} = \frac{1}{\sqrt{4P_{\text{CSI-RS}}}}\begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} & \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} & \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} & -\varphi_n \tilde{v}_{l,m} & -\varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} & \varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}$.				

Table 5.2.2.2.1-9: Codebook for 5-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***CodebookMode* = 1-2**				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_2 > 1$	$0,\ldots,N_1 O_1 -1$	$0,\ldots,N_2 O_2 -1$	$0,1$	$W^{(5)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 = 1$	$0,\ldots,N_1 O_1 -1$	0	$0,1$	$W^{(5)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,0,0,0,i_2}$
where $W^{(5)}_{l,l',l'',m,m'.m'',n} = \frac{1}{\sqrt{5P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & v_{l',m'} & -v_{l',m'} & v_{l'',m''} \end{bmatrix}$.				

Table 5.2.2.2.1-10: Codebook for 6-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode = 1-2				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_2 > 1$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(6)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 = 1$	$0,\ldots,N_1O_1-1$	0	$0,1$	$W^{(6)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,0,0,0,i_2}$
where $W^{(6)}_{l,l',l'',m,m'.m'',n} = \frac{1}{\sqrt{6P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} \end{bmatrix}$.				

Table 5.2.2.2.1-11: Codebook for 7-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode = 1-2				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_1 = 4, N_2 = 1$	$0,\ldots,\frac{N_1O_1}{2}-1$	0	$0,1$	$W^{(7)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,i_{1,1}+3O_1,0,0,0,0,i_2}$
$N_1 > 4, N_2 = 1$	$0,\ldots,N_1O_1-1$	0	$0,1$	$W^{(7)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,i_{1,1}+3O_1,0,0,0,0,i_2}$
$N_1 = 2, N_2 = 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(7)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 = 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$0,1$	$W^{(7)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 > 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(7)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
where $W^{(7)}_{l,l',l'',l''',m,m'.m'',m''',n} = \frac{1}{\sqrt{7P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l'',m''} & v_{l'',m''} & v_{l''',m'''} & v_{l''',m'''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} & v_{l''',m'''} & -v_{l''',m'''} \end{bmatrix}$.				

Table 5.2.2.2.1-12: Codebook for 8-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode = 1-2				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_1 = 4, N_2 = 1$	$0,\ldots,\frac{N_1O_1}{2}-1$	0	$0,1$	$W^{(8)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,i_{1,1}+3O_1,0,0,0,0,i_2}$
$N_1 > 4, N_2 = 1$	$0,\ldots,N_1O_1-1$	0	$0,1$	$W^{(8)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+2O_1,i_{1,1}+3O_1,0,0,0,0,i_2}$
$N_1 = 2, N_2 = 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(8)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 = 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,\frac{N_2O_2}{2}-1$	$0,1$	$W^{(8)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 > 2$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(8)}_{i_{1,1},i_{1,1}+O_1,i_{1,1},i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_{1,2}+O_2,i_2}$
where $W^{(8)}_{l,l',l'',l''',m,m'.m'',m''',n} = \frac{1}{\sqrt{8P_{\text{CSI-RS}}}}\begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} & v_{l'',m''} & v_{l''',m'''} & v_{l''',m'''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} & v_{l''',m'''} & -v_{l''',m'''} \end{bmatrix}$.				

5.2.2.2.2 Type I Multi-Panel Codebook

For 8 antenna ports {3000, 3001, …, 3007}, 16 antenna ports {3000, 3001, …, 3015}, and 32 antenna ports {3000, 3001, …, 3031}, and the UE configured with higher layer parameter *CodebookType* set to 'TypeI-MultiPanel',

- The values of N_g, $N_1$and N_2 are configured with the higher layer parameters *NumberOfPanels*, *CodebookConfig-N1*, and *CodebookConfig-N2*, respectively. The supported configurations of (N_g, N_1, N_2) for a given number of CSI-RS ports and the corresponding values of (O_1, O_2) are given in Table 5.2.2.2.2-1. The number of CSI-RS ports, $P_{\text{CSI-RS}}$, is $2N_g N_1 N_2$.
- When $N_g = 2$, *CodebookMode* shall be set to either '1' or '2'. When $N_g = 4$, *CodebookMode* shall be set to '1'.

The UE is also configured with the higher layer parameters *TypeI-MultiPanel-CodebookSubsetRestriction* and *TypeI-MultiPanel-RI-Restriction*. The bitmap parameter *TypeI-MultiPanel-CodebookSubsetRestriction* forms the bit sequence $a_{A_c-1},...,a_1,a_0$ where a_0 is the LSB and a_{A_c-1} is the MSB and where a bit value of zero indicates that PMI reporting is not allowed to correspond to any precoder associated with the bit. The number of bits is given by $A_c = N_1 O_1 N_2 O_2$. Bit $a_{N_2 O_2 l+m}$ is associated with all precoders based on the quantity $v_{l,m}$, $l = 0,\ldots,N_1 O_1 - 1$, $m = 0,\ldots,N_2 O_2 - 1$, as defined below. The bitmap parameter *TypeI-MultiPanel-RI-Restriction* forms the bit sequence $r_3,...,r_1,r_0$ where r_0 is the LSB and r_3 is the MSB. When r_i is zero, $i \in \{0,1,\ldots,3\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $\upsilon = i+1$ layers.

Table 5.2.2.2.2-1: Supported configurations of (N_g, N_1, N_2) and (O_1, O_2)

Number of CSI-RS antenna ports, $P_{\text{CSI-RS}}$	(N_g, N_1, N_2)	(O_1, O_2)
8	(2,2,1)	(4,1)
16	(2,4,1)	(4,1)
	(4,2,1)	(4,1)
	(2,2,2)	(4,4)
32	(2,8,1)	(4,1)
	(4,4,1)	(4,1)
	(2,4,2)	(4,4)
	(4,2,2)	(4,4)

Each PMI value corresponds to the codebook indices i_1 and i_2, where i_1 is the vector

$$i_1 = \begin{cases} \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,4} \end{bmatrix} & \upsilon = 1 \\ \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,3} & i_{1,4} \end{bmatrix} & \upsilon \in \{2,3,4\} \end{cases}$$

and υ is the associated RI value. When *CodebookMode* is set to '1', $i_{1,4}$ is

$$i_{1,4} = \begin{cases} i_{1,4,1} & N_g = 2 \\ \begin{bmatrix} i_{1,4,1} & i_{1,4,2} & i_{1,4,3} \end{bmatrix} & N_g = 4 \end{cases}.$$

When *CodebookMode* is set to '2', $i_{1,4}$ and i_2 are

$$\begin{aligned} i_{1,4} &= \begin{bmatrix} i_{1,4,1} & i_{1,4,2} \end{bmatrix} \\ i_2 &= \begin{bmatrix} i_{2,0} & i_{2,1} & i_{2,2} \end{bmatrix} \end{aligned}.$$

The mapping from $i_{1,3}$ to k_1 and k_2 for 2-layer reporting is given in Table 5.2.2.2.1-3. The mapping from $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer reporting is given in Table 5.2.2.2.2-2.

- UE shall only use $i_{1,2} = 0$ and shall not report $i_{1,2}$ if the value of *CodebookConfig-N2* is set to 1.

Table 5.2.2.2.2-2: Mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer CSI reporting

$i_{1,3}$	$N_1=2, N_2=1$		$N_1=4, N_2=1$		$N_1=8, N_2=1$		$N_1=2, N_2=2$		$N_1=4, N_2=2$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	O_1	0	O_1	0	O_1	0	O_1	0	O_1	0
1			$2O_1$	0	$2O_1$	0	0	O_2	0	O_2
2			$3O_1$	0	$3O_1$	0	O_1	O_2	O_1	O_2
3					$4O_1$	0			$2O_1$	0

Several quantities are used to define the codebook elements. The quantities φ_n, a_p, b_n, u_m, and $v_{l,m}$ are given by

$$\begin{aligned} \varphi_n &= e^{j\pi n/2} \\ a_p &= e^{j\pi/4} e^{j\pi p/2} \\ b_n &= e^{-j\pi/4} e^{j\pi n/2} \\ u_m &= \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases} \\ v_{l,m} &= \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \cdots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T \end{aligned}$$

Furthermore, the quantities $W_{l,m,p,n}^{1,N_g,1}$ and $W_{l,m,p,n}^{2,N_g,1}$ ($N_g \in \{2,4\}$) are given by

$$W_{l,m,p,n}^{1,2,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \end{bmatrix} \quad W_{l,m,p,n}^{2,2,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \end{bmatrix}$$

$$W_{l,m,p,n}^{1,4,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \\ \varphi_{p_3} v_{l,m} \\ \varphi_n \varphi_{p_3} v_{l,m} \end{bmatrix} \quad W_{l,m,p,n}^{2,4,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \\ \varphi_{p_3} v_{l,m} \\ -\varphi_n \varphi_{p_3} v_{l,m} \end{bmatrix}$$

where

$$p = \begin{cases} p_1 & N_g = 2 \\ [p_1 \quad p_2 \quad p_3] & N_g = 4 \end{cases},$$

and the quantities $W_{l,m,p,n}^{1,N_g,2}$ and $W_{l,m,p,n}^{2,N_g,2}$ ($N_g = 2$) are given by

$$W_{l,m,p,n}^{1,2,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \end{bmatrix} \quad W_{l,m,p,n}^{2,2,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_2} b_{n_2} v_{l,m} \end{bmatrix}$$

where

$$\begin{aligned} p &= [p_1 \quad p_2] \\ n &= [n_0 \quad n_1 \quad n_2] \end{aligned}.$$

The codebooks for 1-4 layers are given respectively in Tables 5.2.2.2.2-3, 5.2.2.2.2-4, 5.2.2.2.2-5, and 5.2.2.2.2-6.

Table 5.2.2.2.2-3: Codebook for 1-layer CSI reporting using antenna ports 3000 to 2999+P$_{\text{CSI-RS}}$

***CodebookMode*='1',** $N_g \in \{2,4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q = 1,\ldots,N_g - 1$	i_2	
$0,\ldots,N_1O_1 - 1$	$0,\ldots,N_2O_2 - 1$	$0,1,2,3$	$0,1,2,3$	$W_{i_{1,1},i_{1,2},i_{1,4},i_2}^{(1)}$
where $W_{l,m,p,n}^{(1)} = W_{l,m,p,n}^{1,N_g,1}$.				

CodebookMode **='2',** $N_g = 2$					
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1,2$	$i_{2,0}$	$i_{2,q}, q = 1,2$	
$0,\ldots,N_1O_1 - 1$	$0,\ldots,N_2O_2 - 1$	$0,1,2,3$	$0,1,2,3$	$0,1$	$W^{(1)}_{i_{1,1},i_{1,2},i_{1,4},i_2}$
where $W^{(1)}_{l,m,p,n} = W^{1,N_g,2}_{l,m,p,n}$.					

Table 5.2.2.2.2-4: Codebook for 2-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode **='1',** $N_g \in \{2,4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q = 1,\ldots,N_g - 1$	i_2	
$0,\ldots,N_1O_1 - 1$	$0,\ldots,N_2O_2 - 1$	$0,1,2,3$	$0,1$	$W^{(2)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(2)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{2}}\begin{bmatrix} W^{1,N_g,1}_{l,m,p,n} & W^{2,N_g,1}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.				

CodebookMode **='2',** $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1,2$	$i_{2,q}, q = 0,1,2$	
$0,\ldots,N_1O_1 - 1$	$0,\ldots,N_2O_2 - 1$	$0,1,2,3$	$0,1$	$W^{(2)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(2)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{2}}\begin{bmatrix} W^{1,N_g,2}_{l,m,p,n} & W^{2,N_g,2}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.				

Table 5.2.2.2.2-5: Codebook for 3-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

CodebookMode **='1',** $N_g \in \{2,4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q = 1,\ldots,N_g - 1$	i_2	
$0,\ldots,N_1O_1 - 1$	$0,\ldots,N_2O_2 - 1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(3)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{3}}\begin{bmatrix} W^{1,N_g,1}_{l,m,p,n} & W^{1,N_g,1}_{l',m',p,n} & W^{2,N_g,1}_{l,m,p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

***CodebookMode*='2',** $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q=1,2$	$i_{2,q}, q=0,1,2$	
$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(3)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{3}}\begin{bmatrix} W^{1,N_g,2}_{l,m,p,n} & W^{1,N_g,2}_{l',m',p,n} & W^{2,N_g,2}_{l,m,p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

Table 5.2.2.2.2-6: Codebook for 4-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***CodebookMode*='1',** $N_g \in \{2,4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q=1,\ldots,N_g-1$	i_2	
$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(4)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{4}}\begin{bmatrix} W^{1,N_g,1}_{l,m,p,n} & W^{1,N_g,1}_{l',m',p,n} & W^{2,N_g,1}_{l,m,p,n} & W^{2,N_g,1}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

***CodebookMode*='2',** $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q=1,2$	$i_{2,q}, q=0,1,2$	
$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(4)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{4}}\begin{bmatrix} W^{1,N_g,2}_{l,m,p,n} & W^{1,N_g,2}_{l',m',p,n} & W^{2,N_g,2}_{l,m,p,n} & W^{2,N_g,2}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

5.2.2.2.3 Type II Codebook

For 4 antenna ports {3000, 3001, …, 3003}, 8 antenna ports {3000, 3001, …, 3007}, 12 antenna ports {3000, 3001, …, 3011}, 16 antenna ports {3000, 3001, …, 3015}, 24 antenna ports {3000, 3001, …, 3023}, and 32 antenna ports {3000, 3001, …, 3031}, and the UE configured with higher layer parameter *CodebookType* set to 'TypeII'

- The values of N_1 and N_2 are configured with the higher layer parameters *CodebookConfig-N1* and *CodebookConfig-N2*, respectively. The supported configurations of (N_1, N_2) for a given number of CSI-RS ports and the corresponding values of (O_1, O_2) are given in Table 5.2.2.2.1-2. The number of CSI-RS ports, $P_{\text{CSI-RS}}$, is $2N_1N_2$.
- The value of L is configured with the higher layer parameter *NumberOfBeams*, where $L=2$ when $P_{\text{CSI-RS}}=4$ and $L \in \{2,3,4\}$ when $P_{\text{CSI-RS}}>4$.

- The value of N_{PSK} is configured with the higher layer parameter *PhaseAlphabetSize*, where $N_{\text{PSK}} \in \{4,8\}$.
- The UE is configured with the higher layer parameter *SubbandAmplitude* set to 'ON' or 'OFF'.
- The UE shall not report RI > 2.

When $\upsilon \leq 2$, where υ is the associated RI value, each PMI value corresponds to the codebook indices i_1 and i_2 where

$$i_1 = \begin{cases} \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,3,1} & i_{1,4,1} \end{bmatrix} & \upsilon = 1 \\ \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,3,1} & i_{1,4,1} & i_{1,3,2} & i_{1,4,2} \end{bmatrix} & \upsilon = 2 \end{cases}$$

$$i_2 = \begin{cases} \begin{bmatrix} i_{2,1,1} \end{bmatrix} & \textit{SubbandAmplitude} = \text{'OFF'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,1,2} \end{bmatrix} & \textit{SubbandAmplitude} = \text{'OFF'},\ \upsilon = 2 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} \end{bmatrix} & \textit{SubbandAmplitude} = \text{'ON'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} & i_{2,1,2} & i_{2,2,2} \end{bmatrix} & \textit{SubbandAmplitude} = \text{'ON'},\ \upsilon = 2 \end{cases}$$

The L vectors combined by the codebook are identified by the indices $i_{1,1}$ and $i_{1,2}$, where

$$\begin{aligned} i_{1,1} &= \begin{bmatrix} q_1 & q_2 \end{bmatrix} \\ q_1 &\in \{0,1,\ldots,O_1-1\} \\ q_2 &\in \{0,1,\ldots,O_2-1\} \end{aligned}$$

$$i_{1,2} \in \left\{0,1,\ldots,\binom{N_1 N_2}{L}-1\right\}.$$

Let

$$\begin{aligned} n_1 &= \left[n_1^{(0)},\ldots,n_1^{(L-1)} \right] \\ n_2 &= \left[n_2^{(0)},\ldots,n_2^{(L-1)} \right] \\ n_1^{(i)} &\in \{0,1,\ldots,N_1-1\} \\ n_2^{(i)} &\in \{0,1,\ldots,N_2-1\} \end{aligned}$$

and

$$C(x,y) = \begin{cases} \binom{x}{y} & x \geq y \\ 0 & x < y \end{cases}.$$

where the values of $C(x,y)$ are given in Table 5.2.2.2.3-1.

Then the elements of n_1 and n_2 are found from $i_{1,2}$ using the algorithm:

$s_{-1} = 0$
for $i = 0,\ldots,L-1$

Find the largest $x^* \in \{L-1-i,\ldots,N_1N_2-1-i\}$ in Table 5.2.2.2.3-1 such that

$i_{1,2} - s_{i-1} \geq C\left(x^*, L-i\right)$

$e_i = C\left(x^*, L-i\right)$

$s_i = s_{i-1} + e_i$

$n^{(i)} = N_1N_2 - 1 - x^*$

$n_1^{(i)} = n^{(i)} \bmod N_1$

$n_2^{(i)} = \frac{\left(n^{(i)} - n_1^{(i)}\right)}{N_1}$

When n_1 and n_2 are known, $i_{1,2}$ is found using:

$n^{(i)} = N_1n_2^{(i)} + n_1^{(i)}$ where the indices $i = 0,1,\ldots,L-1$ are assigned such that $n^{(i)}$ increases as i increases

$i_{1,2} = \sum_{i=0}^{L-1} C\left(N_1N_2 - 1 - n^{(i)}, L-i\right)$, where $C(x,y)$ is given in Table 5.2.2.2.3-1.

- If $N_2 = 1$, $q_2 = 0$ and $n_2^{(i)} = 0$ for $i = 0,1,\ldots,L-1$, and q_2 is not reported.
- When $(N_1, N_2) = (2,1)$, $n_1 = [0,1]$ and $n_2 = [0,0]$, and $i_{1,2}$ is not reported.
- When $(N_1, N_2) = (4,1)$ and $L = 4$, $n_1 = [0,1,2,3]$ and $n_2 = [0,0,0,0]$, and $i_{1,2}$ is not reported.
- When $(N_1, N_2) = (2,2)$ and $L = 4$, $n_1 = [0,1,0,1]$ and $n_2 = [0,0,1,1]$, and $i_{1,2}$ is not reported.

Table 5.2.2.2.3-1: Combinatorial coefficients $C(x,y)$

x \ y	1	2	3	4

0	0	0	0	0
1	1	0	0	0
2	2	1	0	0
3	3	3	1	0
4	4	6	4	1
5	5	10	10	5
6	6	15	20	15
7	7	21	35	35
8	8	28	56	70
9	9	36	84	126
10	10	45	120	210
11	11	55	165	330
12	12	66	220	495
13	13	78	286	715
14	14	91	364	1001
15	15	105	455	1365

The strongest coefficient on layer $l, l=1,\ldots,\upsilon$ is identified by $i_{1,3,l} \in \{0,1,\ldots,2L-1\}$.

The amplitude coefficient indicators $i_{1,4,l}$ and $i_{2,2,l}$ are

$$
\begin{aligned}
i_{1,4,l} &= \left[k_{l,0}^{(1)}, k_{l,1}^{(1)}, \ldots, k_{l,2L-1}^{(1)}\right] \\
i_{2,2,l} &= \left[k_{l,0}^{(2)}, k_{l,1}^{(2)}, \ldots, k_{l,2L-1}^{(2)}\right] \\
k_{l,i}^{(1)} &\in \{0,1,\ldots,7\} \\
k_{l,i}^{(2)} &\in \{0,1\}
\end{aligned}
$$

for $l=1,\ldots,\upsilon$. The mapping from $k_{l,i}^{(1)}$ to the amplitude coefficient $p_{l,i}^{(1)}$ is given in Table 5.2.2.2.3-2 and the mapping from $k_{l,i}^{(2)}$ to the amplitude coefficient $p_{l,i}^{(2)}$ is given in Table 5.2.2.2.3-3. The amplitude coefficients are represented by

$$
\begin{aligned}
p_l^{(1)} &= \left[p_{l,0}^{(1)}, p_{l,1}^{(1)}, \ldots, p_{l,2L-1}^{(1)}\right] \\
p_l^{(2)} &= \left[p_{l,0}^{(2)}, p_{l,1}^{(2)}, \ldots, p_{l,2L-1}^{(2)}\right]
\end{aligned}
$$

for $l=1,\ldots,\upsilon$.

Table 5.2.2.2.3-2: Mapping of elements of $i_{1,4,l}$: $k_{l,i}^{(1)}$ to $p_{l,i}^{(1)}$

$k_{l,i}^{(1)}$	$p_{l,i}^{(1)}$
0	0
1	$\sqrt{1/64}$
2	$\sqrt{1/32}$
3	$\sqrt{1/16}$
4	$\sqrt{1/8}$
5	$\sqrt{1/4}$
6	$\sqrt{1/2}$
7	1

Table 5.2.2.2.3-3: Mapping of elements of $i_{2,2,l}$: $k_{l,i}^{(2)}$ to $p_{l,i}^{(2)}$

$k_{l,i}^{(2)}$	$p_{l,i}^{(2)}$
0	$\sqrt{1/2}$
1	1

The phase coefficient indicators are

$$i_{2,1,l} = \left[c_{l,0}, c_{l,1}, \ldots, c_{l,2L-1}\right]$$

for $l = 1, \ldots, \upsilon$.

The amplitude and phase coefficient indicators are reported as follows:

- The indicators $k_{l,i_{1,3,l}}^{(1)} = 7$, $k_{l,i_{1,3,l}}^{(2)} = 1$, and $c_{l,i_{1,3,l}} = 0$ ($l = 1, \ldots, \upsilon$). $k_{l,i_{1,3,l}}^{(1)}$, $k_{l,i_{1,3,l}}^{(2)}$, and $c_{l,i_{1,3,l}}$ are not reported for $l = 1, \ldots, \upsilon$.
- The remaining $2L-1$ elements of $i_{1,4,l}$ ($l = 1, \ldots, \upsilon$) are reported, where $k_{l,i}^{(1)} \in \{0,1,\ldots,7\}$. Let M_l ($l = 1, \ldots, \upsilon$) be the number of elements of $i_{1,4,l}$ that satisfy $k_{l,i}^{(1)} > 0$.
- The remaining $2L-1$ elements of $i_{2,1,l}$ and $i_{2,2,l}$ ($l = 1, \ldots, \upsilon$) are reported as follows:
  - When *SubbandAmplitude* is set to 'OFF',
    - $k_{l,i}^{(2)} = 1$ for $l = 1, \ldots, \upsilon$, and $i = 0,1,\ldots,2L-1$. $i_{2,2,l}$ is not reported for $l = 1, \ldots, \upsilon$.
    - For $l = 1, \ldots, \upsilon$, the elements of $i_{2,1,l}$ corresponding to the coefficients that satisfy $k_{l,i}^{(1)} > 0$, $i \neq i_{1,3,l}$, as determined by the reported elements of $i_{1,4,l}$, are reported, where $c_{l,i} \in \{0,1,\ldots,N_{\mathrm{PSK}}-1\}$ and the remaining $2L - M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i} = 0$.

- When *SubbandAmplitude* is set to 'ON',
  - For $l=1,\ldots,\upsilon$, the elements of $i_{2,2,l}$ and $i_{2,1,l}$ corresponding to the $\min\left(M_l,K^{(2)}\right)-1$ strongest coefficients (excluding the strongest coefficient indicated by $i_{1,3,l}$), as determined by the corresponding reported elements of $i_{1,4,l}$, are reported, where $k_{l,i}^{(2)}\in\{0,1\}$ and $c_{l,i}\in\{0,1,\ldots,N_{\mathrm{PSK}}-1\}$. The values of $K^{(2)}$ are given in Table 5.2.2.2.3-4. The remaining $2L-\min\left(M_l,K^{(2)}\right)$ elements of $i_{2,2,l}$ are not reported and are set to $k_{l,i}^{(2)}=1$. The elements of $i_{2,1,l}$ corresponding to the $M_l-\min\left(M_l,K^{(2)}\right)$ weakest non-zero coefficients are reported, where $c_{l,i}\in\{0,1,2,3\}$. The remaining $2L-M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i}=0$.
  - When two elements, $k_{l,x}^{(1)}$ and $k_{l,y}^{(1)}$, of the reported elements of $i_{1,4,l}$ are identical ($k_{l,x}^{(1)}=k_{l,y}^{(1)}$), then element $\min(x,y)$ is prioritized to be included in the set of the $\min\left(M_l,K^{(2)}\right)-1$ strongest coefficients for $i_{2,1,l}$ and $i_{2,2,l}$ ($l=1,\ldots,\upsilon$) reporting.

Table 5.2.2.2.3-4: Full resolution subband coefficients when *SubbandAmplitude* is set to 'ON'

L	$K^{(2)}$
2	4
3	4
4	6

The codebooks for 1-2 layers are given in Table 5.2.2.2.3-5, where the indices $m_1^{(i)}$ and $m_2^{(i)}$ are given by

$$m_1^{(i)}=O_1n_1^{(i)}+q_1$$
$$m_2^{(i)}=O_2n_2^{(i)}+q_2$$

for $i=0,1,\ldots,L-1$, and the quantities $\varphi_{l,i}$, u_m, and $v_{l,m}$ are given by

$$\varphi_{l,i}=\begin{cases} e^{j2\pi c_{l,i}/N_{\text{PSK}}} & SubbandAmplitude=\text{'OFF'} \\ e^{j2\pi c_{l,i}/N_{\text{PSK}}} & SubbandAmplitude=\text{'ON'},\ \min\left(M_l,K^{(2)}\right)\text{ strongest coefficients (including } i_{1,3,l}\text{) with } k_{l,i}^{(1)}>0 \\ e^{j2\pi c_{l,i}/4} & SubbandAmplitude=\text{'ON'},\ M_l-\min\left(M_l,K^{(2)}\right)\text{ weakest coefficients with } k_{l,i}^{(1)}>0 \\ 1 & SubbandAmplitude=\text{'ON'},\ 2L-M_l\text{ coefficients with } k_{l,i}^{(1)}=0 \end{cases}$$

$$u_m=\begin{cases}\begin{bmatrix}1 & e^{j\frac{2\pi m}{O_2N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2N_2}}\end{bmatrix} & N_2>1 \\ 1 & N_2=1\end{cases}.$$

$$v_{l,m}=\begin{bmatrix}u_m & e^{j\frac{2\pi l}{O_1N_1}}u_m & \cdots & e^{j\frac{2\pi l(N_1-1)}{O_1N_1}}u_m\end{bmatrix}^T$$

Table 5.2.2.2.3-5: Codebook for 1-layer and 2-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

Layers	
$\upsilon=1$	$W^{(1)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}}=W^1_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}}$
$\upsilon=2$	$W^{(2)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}}=\frac{1}{\sqrt{2}}\begin{bmatrix}W^1_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}} & W^2_{q_1,q_2,n_1,n_2,p_2^{(1)},p_2^{(2)},i_{2,1,2}}\end{bmatrix}$
where $W^l_{q_1,q_2,n_1,n_2,p_l^{(1)},p_l^{(2)},c_l}=\frac{1}{\sqrt{N_1N_2\sum_{i=0}^{2L-1}\left(p_{l,i}^{(1)}p_{l,i}^{(2)}\right)^2}}\begin{bmatrix}\sum_{i=0}^{L-1}v_{m_1^{(i)},m_2^{(i)}}p_{l,i}^{(1)}p_{l,i}^{(2)}\varphi_{l,i} \\ \sum_{i=0}^{L-1}v_{m_1^{(i)},m_2^{(i)}}p_{l,i+L}^{(1)}p_{l,i+L}^{(2)}\varphi_{l,i+L}\end{bmatrix}$, $l=1,2$, and the mappings from i_1 to q_1, q_2, n_1, n_2, $p_1^{(1)}$, and $p_2^{(1)}$, and from i_2 to $i_{2,1,1}$, $i_{2,1,2}$, $p_1^{(2)}$ and $p_2^{(2)}$ are as described above, including the ranges of the constituent indices of i_1 and i_2.	

When the UE is configured with higher layer parameter *CodebookType* set to 'TypeII', the UE is also configured with the higher layer parameters *TypeII-CodebookSubsetRestriction* and *TypeII-RI-Restriction*. The bitmap parameter *TypeII -RI-Restriction* forms the bit sequence r_1,r_0 where r_0 is the LSB and r_1 is the MSB. When r_i is zero, $i\in\{0,1\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $\upsilon=i+1$ layers. The bitmap parameter *TypeII-CodebookSubsetRestriction* forms the bit sequence $B=B_1B_2$ where bit sequences B_1, and B_2 are concatenated to form B. To define B_1 and B_2, first define the O_1O_2 vector groups $G(r_1,r_2)$ as

$$G(r_1,r_2)=\left\{v_{N_1r_1+x_1,N_2r_2+x_2}:x_1=0,1,\ldots,N_1-1;x_2=0,1,\ldots,N_2-1\right\}$$

for

$$r_1 \in \{0,1,\ldots,O_1-1\}$$
$$r_2 \in \{0,1,\ldots,O_2-1\}.$$

The UE shall be configured with restrictions for 4 vector groups indicated by $\left(r_1^{(k)}, r_2^{(k)}\right)$ for $k=0,1,2,3$ and identified by the group indices

$$g^{(k)} = O_1 r_2^{(k)} + r_1^{(k)}$$

for $k=0,1,\ldots,3$, where the indices are assigned such that $g^{(k)}$ increases as k increases. The remaining vector groups are not restricted.

- If $N_2 = 1$, $g^{(k)} = k$ for $k=0,1,\ldots,3$, and B_1 is empty.
- If $N_2 > 1$, $B_1 = b_1^{(10)} \cdots b_1^{(0)}$ is the binary representation of the integer β_1 where $b_1^{(10)}$ is the MSB and $b_1^{(0)}$ is the LSB. β_1 is found using:

  $$\beta_1 = \sum_{k=0}^{3} C\left(O_1 O_2 - 1 - g^{(k)}, 4-k\right),$$

  where $C(x,y)$ is defined in Table 5.2.2.2.3-1. The group indices $g^{(k)}$ and indicators $\left(r_1^{(k)}, r_2^{(k)}\right)$ for $k=0,1,2,3$ may be found from β_1 using the algorithm:

  $s_{-1} = 0$
  for $k = 0,\ldots,3$
  Find the largest $x^* \in \{3-k,\ldots,O_1 O_2 - 1 - k\}$ such that $\beta_1 - s_{k-1} \ge C\left(x^*, 4-k\right)$
  $e_k = C\left(x^*, 4-k\right)$
  $s_k = s_{k-1} + e_k$
  $g^{(k)} = O_1 O_2 - 1 - x^*$
  $r_1^{(k)} = g^{(k)} \bmod O_1$
  $r_2^{(k)} = \frac{\left(g^{(k)} - r_1^{(k)}\right)}{O_1}$

The bit sequence $B_2 = B_2^{(0)} B_2^{(1)} B_2^{(2)} B_2^{(3)}$ is the concatenation of the bit sequences $B_2^{(k)}$ for $k=0,1,\ldots,3$, corresponding to the group indices $g^{(k)}$. The bit sequence $B_2^{(k)}$ is defined as

$$B_2^{(k)} = b_2^{(k,2N_1N_2-1)} \cdots b_2^{(k,0)}$$

Bits $b_2^{(k,2(N_1x_2+x_1)+1)} b_2^{(k,2(N_1x_2+x_1))}$ indicate the maximum allowed amplitude coefficient $p_{l,i}^{(1)}$ for the vector in group $g^{(k)}$ indexed by x_1, x_2, where the maximum amplitude coefficients are given in Table 5.2.2.2.3-6.

Table 5.2.2.2.3-6: Maximum allowed amplitude coefficients for restricted vectors

Bits $b_2^{(k,2(N_1x_2+x_1)+1)}b_2^{(k,2(N_1x_2+x_1))}$	Maximum Amplitude Coefficient $p_{l,i}^{(1)}$
00	0
01	$\sqrt{1/4}$
10	$\sqrt{1/2}$
11	1

5.2.2.2.4 Type II Port Selection Codebook

For 4 antenna ports {3000, 3001, …, 3003}, 8 antenna ports {3000, 3001, …, 3007}, 12 antenna ports {3000, 3001, …, 3007}, 16 antenna ports {3000, 3001, …, 3015}, 24 antenna ports {3000, 3001, …, 3023}, and 32 antenna ports {3000, 3001, …, 3031}, and the UE configured with higher layer parameter *CodebookType* set to 'TypeII-PortSelection'

- The number of CSI-RS ports is given by $P_{\text{CSI-RS}} \in \{4,8,12,16,24,32\}$ as configured by higher layer parameter *NrofPorts*.
- The value of L is configured with the higher layer parameter *NumberOfBeams* , where $L=2$ when $P_{\text{CSI-RS}}=4$ and $L\in\{2,3,4\}$ when $P_{\text{CSI-RS}}>4$.
- The value of d is configured with the higher layer parameter *PortSelectionSamplingSize*, where $d\in\{1,2,3,4\}$ and $d \le \min\left(\frac{P_{\text{CSI-RS}}}{2}, L\right)$.
- The value of N_{PSK} is configured with the higher layer parameter *PhaseAlphabetSize*, where $N_{\text{PSK}}\in\{4,8\}$.
- The UE is configured with the higher layer parameter *SubbandAmplitude* set to 'ON' or 'OFF'.
- The UE shall not report RI > 2.

The UE is also configured with the higher layer parameter *TypeII-PortSelection-RI-Restriction*. The bitmap parameter *TypeII-PortSelection-RI-Restriction* forms the bit sequence r_1, r_0 where r_0 is the LSB and r_1 is the MSB. When r_i is zero, $i\in\{0,1\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $\upsilon = i+1$ layers.

When $\upsilon \le 2$, where υ is the associated RI value, each PMI value corresponds to the codebook indices i_1 and i_2 where

$$i_1 = \begin{cases} \begin{bmatrix} i_{1,1} & i_{1,3,1} & i_{1,4,1} \end{bmatrix} & \upsilon = 1 \\ \begin{bmatrix} i_{1,1} & i_{1,3,1} & i_{1,4,1} & i_{1,3,2} & i_{1,4,2} \end{bmatrix} & \upsilon = 2 \end{cases}$$

$$i_2 = \begin{cases} \begin{bmatrix} i_{2,1,1} \end{bmatrix} & SubbandAmplitude = \text{'OFF'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,1,2} \end{bmatrix} & SubbandAmplitude = \text{'OFF'},\ \upsilon = 2 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} \end{bmatrix} & SubbandAmplitude = \text{'ON'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} & i_{2,1,2} & i_{2,2,2} \end{bmatrix} & SubbandAmplitude = \text{'ON'},\ \upsilon = 2 \end{cases}.$$

The L antenna ports per polarization are selected by the index $i_{1,1}$, where

$$i_{1,1} \in \left\{ 0,1,\ldots,\left\lceil \frac{P_{\text{CSI-RS}}}{2d} \right\rceil - 1 \right\}.$$

The strongest coefficient on layer $l,\ l = 1,\ldots,\upsilon$ is identified by $i_{1,3,l} \in \{0,1,\ldots,2L-1\}$.

The amplitude coefficient indicators $i_{1,4,l}$ and $i_{2,2,l}$ are

$$\begin{aligned} i_{1,4,l} &= \left[k_{l,0}^{(1)}, k_{l,1}^{(1)}, \ldots, k_{l,2L-1}^{(1)} \right] \\ i_{2,2,l} &= \left[k_{l,0}^{(2)}, k_{l,1}^{(2)}, \ldots, k_{l,2L-1}^{(2)} \right] \\ k_{l,i}^{(1)} &\in \{0,1,\ldots,7\} \\ k_{l,i}^{(2)} &\in \{0,1\} \end{aligned}$$

for $l = 1,\ldots,\upsilon$. The mapping from $k_{l,i}^{(1)}$ to the amplitude coefficient $p_{l,i}^{(1)}$ is given in Table 5.2.2.2.3-2 and the mapping from $k_{l,i}^{(2)}$ to the amplitude coefficient $p_{l,i}^{(2)}$ is given in Table 5.2.2.2.3-3. The amplitude coefficients are represented by

$$\begin{aligned} p_l^{(1)} &= \left[p_{l,0}^{(1)}, p_{l,1}^{(1)}, \ldots, p_{l,2L-1}^{(1)} \right] \\ p_l^{(2)} &= \left[p_{l,0}^{(2)}, p_{l,1}^{(2)}, \ldots, p_{l,2L-1}^{(2)} \right] \end{aligned}$$

for $l = 1,\ldots,\upsilon$.

The phase coefficient indicators are

$$i_{2,1,l} = \left[c_{l,0}, c_{l,1}, \ldots, c_{l,2L-1} \right]$$

for $l = 1,\ldots,\upsilon$.

The amplitude and phase coefficient indicators are reported as follows:

- The indicators $k_{l,i_{1,3,l}}^{(1)} = 7$, $k_{l,i_{1,3,l}}^{(2)} = 1$, and $c_{l,i_{1,3,l}} = 0$ ($l = 1,\ldots,\upsilon$). $k_{l,i_{1,3,l}}^{(1)}$, $k_{l,i_{1,3,l}}^{(2)}$, and $c_{l,i_{1,3,l}}$ are not reported for $l = 1,\ldots,\upsilon$.
- The remaining $2L-1$ elements of $i_{1,4,l}$ ($l = 1,\ldots,\upsilon$) are reported, where $k_{l,i}^{(1)} \in \{0,1,\ldots,7\}$. Let M_l ($l = 1,\ldots,\upsilon$) be the number of elements of $i_{1,4,l}$ that satisfy $k_{l,i}^{(1)} > 0$.
- The remaining $2L-1$ elements of $i_{2,1,l}$ and $i_{2,2,l}$ ($l = 1,\ldots,\upsilon$) are reported as follows:

- When *SubbandAmplitude* is set to 'OFF',
  - $k_{l,i}^{(2)}=1$ for $l=1,\ldots,\upsilon$, and $i=0,1,\ldots,2L-1$. $i_{2,2,l}$ is not reported for $l=1,\ldots,\upsilon$.
  - For $l=1,\ldots,\upsilon$, the M_l-1 elements of $i_{2,1,l}$ corresponding to the coefficients that satisfy $k_{l,i}^{(1)}>0$, $i\neq i_{1,3,l}$, as determined by the reported elements of $i_{1,4,l}$, are reported, where $c_{l,i}\in\{0,1,\ldots,N_{\text{PSK}}-1\}$ and the remaining $2L-M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i}=0$.
- When *SubbandAmplitude* is set to 'ON',
  - For $l=1,\ldots,\upsilon$, the elements of $i_{2,2,l}$ and $i_{2,1,l}$ corresponding to the $\min\left(M_l,K^{(2)}\right)-1$ strongest coefficients (excluding the strongest coefficient indicated by $i_{1,3,l}$), as determined by the corresponding reported elements of $i_{1,4,l}$, are reported, where $k_{l,i}^{(2)}\in\{0,1\}$ and $c_{l,i}\in\{0,1,\ldots,N_{\text{PSK}}-1\}$. The values of $K^{(2)}$ are given in Table 5.2.2.2.3-4. The remaining $2L-\min\left(M_l,K^{(2)}\right)$ elements of $i_{2,2,l}$ are not reported and are set to $k_{l,i}^{(2)}=1$. The elements of $i_{2,1,l}$ corresponding to the $M_l-\min\left(M_l,K^{(2)}\right)$ weakest non-zero coefficients are reported, where $c_{l,i}\in\{0,1,2,3\}$. The remaining $2L-M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i}=0$.
  - When two elements, $k_{l,x}^{(1)}$ and $k_{l,y}^{(1)}$, of the reported elements of $i_{1,4,l}$ are identical ($k_{l,x}^{(1)}=k_{l,y}^{(1)}$), then element $\min(x,y)$ is prioritized to be included in the set of the $\min\left(M_l,K^{(2)}\right)-1$ strongest coefficients for $i_{2,1,l}$ and $i_{2,2,l}$ ($l=1,\ldots,\upsilon$) reporting.

The codebooks for 1-2 layers are given in Table 5.2.2.2.4-1, where the quantity $\varphi_{l,i}$ is given by

$$\varphi_{l,i}=\begin{cases} e^{j2\pi c_{l,i}/N_{\text{PSK}}} & \textit{SubbandAmplitude}=\text{'OFF'} \\ e^{j2\pi c_{l,i}/N_{\text{PSK}}} & \textit{SubbandAmplitude}=\text{'ON', } \min\left(M_l,K^{(2)}\right) \text{ strongest coefficients (including } i_{1,3,l}\text{) with } k_{l,i}^{(1)}>0 \\ e^{j2\pi c_{l,i}/4} & \textit{SubbandAmplitude}=\text{'ON', } M_l-\min\left(M_l,K^{(2)}\right) \text{ weakest coefficients with } k_{l,i}^{(1)}>0 \\ 1 & \textit{SubbandAmplitude}=\text{'ON', } 2L-M_l \text{ coefficients with } k_{l,i}^{(1)}=0 \end{cases}$$

and v_m is a $P_{\text{CSI-RS}}/2$-element column vector containing a value of 1 in element $(m \bmod P_{\text{CSI-RS}}/2)$ and zeros elsewhere (where the first element is element 0).

Table 5.2.2.2.4-1: Codebook for 1-layer and 2-layer CSI reporting using antenna ports 3000 to 2999+P_{CSI-RS}

Layers	
$\upsilon = 1$	$W^{(1)}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}} = W^{1}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}}$
$\upsilon = 2$	$W^{(2)}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}} = \frac{1}{\sqrt{2}}\left[W^{1}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}} \quad W^{2}_{i_{1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}}\right]$
where $W^{l}_{i_{1,1},p_l^{(1)},p_l^{(2)},i_{2,1,l}} = \frac{1}{\sqrt{\sum_{i=0}^{2L-1}\left(p_{l,i}^{(1)}p_{l,i}^{(2)}\right)^2}}\begin{bmatrix}\sum_{i=0}^{L-1} v_{i_{1,1}d+i}\, p_{l,i}^{(1)} p_{l,i}^{(2)} \varphi_{l,i} \\ \sum_{i=0}^{L-1} v_{i_{1,1}d+i}\, p_{l,i+L}^{(1)} p_{l,i+L}^{(2)} \varphi_{l,i}\end{bmatrix}$, $l = 1,2$, and the mappings from i_1 to $i_{1,1}$, $p_1^{(1)}$, and $p_2^{(1)}$ and from i_2 to $i_{2,1,1}$, $i_{2,1,2}$, $p_1^{(2)}$, and $p_2^{(2)}$ are as described above, including the ranges of the constituent indices of i_1 and i_2.	

5.2.2.3 Reference signal (CSI-RS)

5.2.2.3.1 NZP CSI-RS

The UE can be configured with one or more NZP CSI-RS resource set configuration(s) as indicated by the higher layer parameter *NZP-CSI-RS-ResourceSetConfig.* Each NZP CSI-RS resource set consists of K≥1 NZP CSI-RS resource(s).

The following parameters for which the UE shall assume non-zero transmission power for CSI-RS resource are configured via higher layer parameter *NZP-CSI-RS-ResourceConfig* for each CSI-RS resource configuration:

- *NZP-CSI-RS-ResourceConfigId* determines CSI-RS resource configuration identity.
- *NrofPorts* defines the number of CSI-RS ports, where the allowable values are given inSubclause 7.4.1.5 of [4, TS 38.211].
- *CSI-RS-timeConfig* defines the CSI-RS periodicity and slot offset for periodic/semi-persistent CSI-RS.
- *CSI-RS-ResourceMapping* defines the OFDM symbol and subcarrier occupancy of the CSI-RS resource within a slot that are given in Subclause 7.4.1.5 of [4, TS 38.211].
- *CSI-RS-Density* defines CSI-RS frequency density of each CSI-RS port per PRB, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211].
- *CDMType* defines CDM values and pattern, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211].
- *CSI-RS-FreqBand* parameters configure the bandwidth and the initial RB index in the frequency domain, both in units of 4RBs, of a CSI-RS resource within a BWP as defined in Subclause 7.4.1.5 of [4, TS 38.211].

- *Pc*: which is the assumed ratio of PDSCH EPRE to NZP CSI-RS EPRE when UE derives CSI feedback and takes values in the range of [-8, 15] dB with 1 dB step size.
- *Pc_SS*: which is the assumed ratio of SS/PBCH block EPRE to NZP CSI-RS EPRE.
- *ScramblingID*: defines scrambling ID of CSI-RS with length of 10 bits.
- *CC_Info* defines which component carrier the configured CSI-RS is located in.
- *CSI-RS-ResourceRep* parameter associated with a CSI-RS resource set defines whether a repetition in conjunction with spatial domain transmission filter is ON/OFF at gNB-side as described in Subclause 5.1.6.1.2. and can be configured only when the higher layer parameter *ReportQuantity* associated with all the reporting settings linked with the CSI-RS resource set is set to 'CRI/RSRP' or No Report'.
- QCL-InfoPeriodicCSI-RS contains a reference to a TCI-RS-SetConfig indicating QCL source RS(s). If the TCI-RS-SetConfig is configured with a reference to an RS with QCL-TypeD' association, that RS may be an SS/PBCH block located in the same or different CC/DL BWP or a CSI-RS resource configured as periodic located in the same or different CC/DL BWP.

5.2.2.4 Channel State Information – Interference Measurement (CSI-IM)

The UE can be configured with one or more CSI-IM resource set configuration(s) as indicated by the higher layer parameter *CSI-IM-ResourceSetConfig*. Each CSI-IM resource set consists of *K*≥1 CSI-IM resource(s).

The following parameters are configured via higher layer parameter *CSI-IM-ResourceConfig* for each CSI-IM resource configuration:

- *CSI-IM-ResourceId* determines CSI-IM resource configuration identity
- *CSI-IM-ResourceMapping* defines subcarrier and symbol occupancy of the CSI-IM resource within a slot.
- *CSI-IM-RE-Pattern* is configured by *csi-IM-ResourceElementPattern* as given in Subclause 7.4.1.5.3 of [4, TS 38.211].
- *CSI-IM-timeConfig* defines the CSI-IM periodicity and slot offset for periodic/semi-persistent CSI-IM.
- *CSI-IM-FreqBand* includes parameters to enable configuration of frequency-occupancy of CSI-IM

In each of the PRBs configured by *CSI-IM-FreqBand,* the UE shall assume each CSI-IM resource is located in,

- resource elements (k_{CSI-IM}, l_{CSI-IM}), $(k_{CSI-IM}, l_{CSI-IM}+1)$, $(k_{CSI-IM}+1, l_{CSI-IM})$ and $(k_{CSI-IM}+1, l_{CSI-IM}+1)$, if *CSI-IM-RE-Pattern* is set to Pattern0',

- resource elements (k_{CSI-IM}, l_{CSI-IM}), $(k_{CSI-IM}+1, l_{CSI-IM})$, $(k_{CSI-IM}+2, l_{CSI-IM})$ and $(k_{CSI-IM}+3, l_{CSI-IM})$ if *CSI-IM-RE-Pattern* is set to Pattern1',

where k_{CSI-IM} and l_{CSI-IM} are the configured frequency-domain location and time-domain location, respectively, by higher layer parameter *CSI-IM-ResourceMapping*..

5.2.3 CSI reporting using PUSCH

A UE shall perform aperiodic CSI reporting using PUSCH on serving cell c upon successful decoding .
An aperiodic CSI report carried on the PUSCH supports wideband, and sub-band frequency granularities. An aperiodic CSI report carried on the PUSCH supports Type I and Type II CSI.

A UE shall perform semi-persistent CSI reporting on the PUSCH upon successful decoding of a DCI format 0_1 which activates a semi-persistent CSI trigger state. DCI format 0_1 contains a CSI request field which indicates the semi-persistent CSI trigger state to activate or deactivate. Semi-persistent CSI reporting on the PUSCH supports Type I and Type II CSI with wideband, and sub-band frequency granularities. The PUSCH resources and MCS shall be allocated semi-persistently by an uplink DCI.

CSI reporting on PUSCH can be multiplexed with uplink data on PUSCH. CSI reporting on PUSCH can also be performed without any multiplexing with uplink data from the UE.

Type I CSI feedback is supported for CSI Reporting on PUSCH. Type I sub-band CSI is supported for CSI Reporting on the PUSCH. Type II CSI is supported for CSI Reporting on the PUSCH.

For Type I and Type II CSI feedback on PUSCH, a CSI report comprises of two parts. Part 1 is used to identify the number of information bits in Part 2. Part 1 shall be transmitted in its entirety before Part 2 and may be used to identify the number of information bits in Part 2.

- For Type I CSI feedback, Part 1 contains RI (if reported), CRI (if reported), CQI for the first codeword. Part 2 contains PMI and contains the CQI for the second codeword when RI>4.
- For Type II CSI feedback , Part 1 has a fixed payload size and contains RI, CQI, and an indication of the number of non-zero wideband amplitude coefficients per layer for the Type II CSI (see sub-clause 5.2.2). The fields of Part 1 – RI, CQI, and the indication of the number of non-zero wideband amplitude coefficients for each layer – are separately encoded. Part 2 contains the PMI of the Type II CSI. Part 1 and 2 are separately encoded.

A Type II CSI report that is carried on the PUSCH shall be computed independently from any Type II CSI report that is carried on the PUCCH formats 1, 3, or 4 (see sub-clause 5.2.4 and 5.2.2).

When the higher layer parameter *ReportQuantity* is configured with one of the values 'CRI/RSRP' or 'SSBRI/RSRP', the CSI feedback consists of a single part.

For both Type I and Type II reports configured for PUCCH but transmitted on PUSCH, the encoding scheme follows that of PUCCH as described in Subclause 5.2.4.

When CSI reporting on PUSCH comprises two parts, the UE may omit a portion of the Part 2 CSI. Omission of Part 2 CSI is according to the priority order shown in Table 5.2.3-1, where N_{Rep} is the number of CSI reports in one slot. Priority 0 is the highest priority and priority $2N_{\text{Rep}}$ is the lowest priority and the CSI report numbers correspond to the order of the associated *ReportConfigID*. When omitting Part 2 CSI information for a particular priority level, the UE shall omit all of the information at that priority level.

Table 5.2.3-1: Priority reporting levels for Part 2 CSI

Priority 0: Part 2 wideband CSI for CSI reports 1 to N_{Rep}
Priority 1: Part 2 subband CSI of even subbands for CSI report 1
Priority 2: Part 2 subband CSI of odd subbands for CSI report 1
Priority 3: Part 2 subband CSI of even subbands for CSI report 2
Priority 4: Part 2 subband CSI of odd subbands for CSI report 2
⋮
Priority $2N_{\text{Rep}}-1$: Part 2 subband CSI of even subbands for CSI report N_{Rep}
Priority $2N_{\text{Rep}}$: Part 2 subband CSI of odd subbands for CSI report N_{Rep}

When the UE is scheduled to transmit a transport block on PUSCH multiplexed with a CSI report, Part 2 CSI is omitted only when the UCI code rate for transmitting all of Part 2 would be greater than a threshold code rate c_{T}, where

$$c_{\text{T}} = \frac{c_{\text{MCS}}}{\beta_{\text{offset}}^{\text{CSI-2}}}$$

- c_{MCS} is the target PUSCH code rate from Table 6.1.4.1-1.
- $\beta_{\text{offset}}^{\text{CSI-2}}$ is the CSI offset value from Table 9.3-2 of [6, TS 38.213].

Part 2 CSI is omitted level by level, beginning with the lowest priority level until the lowest priority level is reached which causes the UCI code rate to be less than or equal to c_{T}.

When part 2 CSI is transmitted on PUSCH with no transport block, lower priority bits are omitted until Part 2 CSI code rate is below a threshold code rate c_{T} lower than one, where

$$c_T = \frac{\beta_{\mathrm{offset}}^{\mathrm{CSI-part1}}}{\beta_{\mathrm{offset}}^{\mathrm{CSI-part2}}} \cdot r_{\mathrm{CSI-1}}$$

- $\beta_{\mathrm{offset}}^{\mathrm{CSI-part1}}$ and $\beta_{\mathrm{offset}}^{\mathrm{CSI-part2}}$ are the CSI offset value from Table 9.3-2 of [6, TS 38.213].
- [$r_{\mathrm{CSI-1}}$ is based on the code rate calculated at UE or signaled in DCI.]

5.2.4 CSI reporting using PUCCH

A UE is semi-statically configured by higher layers to perform periodic CSI Reporting on the PUCCH. A UE can be configured by higher layers for multiple periodic CSI Reports corresponding to one or more higher layer configured CSI Reporting Setting Indications, where the associated CSI Measurement Links and CSI Resource Settings are higher layer configured. Periodic CSI reporting on PUCCH formats 2, 3, 4 supports Type I CSI with wideband granularity.

A UE shall perform semi-persistent CSI reporting on the PUCCH upon successfully decoding a selection command [10, TS 38.321]. The selection command will contain one or more Reporting Setting Indications where the associated CSI Measurement Links and CSI Resource Settings are configured. Semi-persistent CSI reporting on the PUCCH supports Type I CSI. Semi-persistent CSI reporting on the PUCCH format 2 supports Type I CSI with wideband frequency granularity. Semi-persistent CSI reporting on PUCCH formats 3 or 4 supports Type I Sub-band CSI and Type II CSI with wideband frequency granularity.

When the PUCCH carry Type I CSI with wideband frequency granularity, the CSI payload carried by the PUCCH format 2 and PUCCH formats 3, or 4 are identical and the same irrespective of RI (if reported), CRI (if reported). For type I CSI sub-band reporting on PUCCH formats 3, or 4, the payload is split into two parts. The first part contains RI (if reported), CRI (if reported), CQI for the first codeword. The second part contains PMI and contains the CQI for the second codeword when RI > 4.

A semi-persistent report carried on the PUCCH formats 3 or 4 supports Type II CSI feedback, but only Part 1 of Type II CSI feedback (See sub-clause 5.2.2 and 5.2.3). Supporting Type II CSI reporting on the PUCCH formats 3 or 4 is a UE capability. A Type II CSI report (Part 1 only) carried on PUCCH formats 3 or 4 shall be calculated independently of any Type II CSI reports carried on the PUSCH (see sub-clause 5.2.3).

When the UE is configured with CSI Reporting on PUCCH formats 2, 3 or 4, each PUCCH resource is configured for each candidate UL BWP.

A UE is not expected to report CSI with a payload size larger than 115 bits when configured with PUCCH format 4.

5.2.5 Priority rules for CSI reports

CSI reports are associated with a priority value $\mathrm{Pri}_{iCSI}(y,k,c,s) = 2 \cdot 16 \cdot M_s \cdot y + 16 \cdot M_s \cdot k + M_s \cdot c + s$ where

- $y = 0$ for aperiodic CSI reports to be carried on PUSCH $y = 1$ for semi-persistent CSI reports to be carried on PUSCH, $y = 2$ for semi-persistent CSI reports to be carried on PUCCH and $y = 3$ for periodic CSI reports to be carried on PUSCH
- $k = 0$ for CSI reports carrying L1-RSRP and $k = 1$ for CSI reports not carrying L1-RSRP
- c is the serving cell index
- s is the ReportConfigID*D* and M_s is the value of the higher layer parameter *maxNrofCSI-Reports.*

A first CSI report is said to have priority over second CSI report if the associated $\mathrm{Pri}_{iCSI}(y,k,c,s)$ value is lower for the first report than for the second report.

Two CSI reports are said to collide if the time occupancy of the physical channels scheduled to carry the CSI reports overlap in at least one OFDM symbol and are transmitted on the same carrier. When a UE is configured to transmit two colliding CSI reports, the following rules apply (for CSI reports transmitted on PUSCH, as described in Subclause 5.2.3; for CSI reports transmitted on PUCCH, as described in Subclause 5.2.4):

- The CSI report with higher $\mathrm{Pri}_{iCSI}(y,k,c,s)$ value shall not be sent by the UE

If a semi-persistent CSI report to be carried on PUSCH collides with PUSCH data transmission, the CSI report shall not be transmitted by the UE.

5.3 UE PDSCH processing procedure time

If the first uplink symbol to carry the HARQ-ACK information, as defined by the assigned HARQ-ACK timing K_1 and the PUCCH resource to be used and including the effect of the timing advance, starts no earlier than at symbol L_1 then the UE shall provide a valid HARQ-ACK message, where L_1 is defined as the next uplink symbol with its CP starting after $T_{proc,1} = \left((N_1 + d_{1,1} + d_{1,2} + d_{1,3})(2048+144) \cdot \kappa 2^{-\mu_{DL}}\right) \cdot T_C$ after the end of the last symbol of the PDSCH carrying the TB being acknowledged.

- N_1 is based on μ of table 5.3-1 that corresponds to the min (μ_{DL}, μ_{UL}) where theμ_{DL} corresponds to the subcarrier spacing of the downlink with which the PDSCH was transmitted and μ_{UL} corresponds to the subcarrier spacing of the uplink channel with which the HARQ-ACK is to be transmitted
- If HARQ-ACK is transmitted on PUCCH, then $d_{1,1} = 0$,
- If HARQ-ACK is transmitted on PUSCH, then $d_{1,1} = 1$.

- If the UE is configured with multiple active component carriers, the value of $d_{1,2}$ is equal to maximum timing difference between component carriers as given in [11, TS 38.133], otherwise $d_{1,2}$ = 0.
- If the PDSCH is mapping type A as given in subclause 7.4.1.1 of [4, TS 38.211], and the last symbol of PDSCH is on the *i*th symbol of the slot where *i*<7, then $d_{1,3} = 7 - i$.
- otherwise $d_{1,2}$ = 0.

Otherwise the UE may not provide a valid HARQ-ACK corresponding to the scheduled PDSCH. The value of $T_{proc,1}$ is used both in the case of normal and extended cyclic prefix.

Table 5.3-1: PDSCH processing time for PDSCH processing capability 1

μ	PDSCH decoding time N_1 [symbols]	
	No additional PDSCH DM-RS configured	**Additional PDSCH DM-RS configured**
0	8	13
1	10	13
2	17	20
3	20	24

5.4 UE CSI computation time

When the *CSI request* field on a DCI triggers a CSI report on PUSCH not multiplexed with HARQ-ACK or transport block, the UE shall provide a valid CSI report,

- if the first uplink symbol to carry the corresponding CSI report including the effect of the timing advance, starts no earlier than at symbol Z_{ref}, where Z_{ref} is defined as the next uplink symbol with its CP starting after $\left(Z \cdot (2048+144) \cdot \kappa 2^{-\mu}\right) \cdot T_C$ after the end of the last symbol of the PDCCH triggering the CSI report., and
- if the first uplink symbol to carry the corresponding CSI report including the effect of the timing advance, starts no earlier than at symbol Z'_{ref}, where Z'_{ref} is defined as the next uplink symbol with its CP starting after $\left(Z \cdot (2048+144) \cdot \kappa 2^{-\mu}\right) \cdot T_C$ after the end of the last symbol in time of: the last symbol of aperiodic CSI-RS resource for channel measurements, the last symbol of aperiodic CSI-IM used for interference measurements, and the last symbol of aperiodic NZP CSI-RS for interference measurement, when aperiodic CSI-RS is used for channel measurement.

otherwise the UE may ignore the scheduling DCI.

If the CSI to be transmitted corresponds to wideband frequency-granularity where the CSI corresponds to at most 4 CSI-RS ports and where *CodebookType* is set to 'TypeI-SinglePanel' or where *ReportQuantity* is set to CRI/RI/CQI' (Z,Z') is defined as (Z_1, Z'_1) of the table 5.4-1, otherwise (Z,Z') is defined as the (Z_2, $Z'_{2.}$) of the table 5.4-1.

- μ of table 5.4-1 corresponds to the min (μ_{DL}, μ_{UL}) where the μ_{DL} corresponds to the subcarrier spacing of the PDCCH with which the DCI was transmitted and μ_{UL} corresponds to the subcarrier spacing of the PUSCH with which the CSI report is to be transmitted

Table 5.4-1: CSI computation delay

μ	Z_1 [symbols]		Z_2 [symbols]	
	Z_1	Z'_1	Z_2	Z'_2
0	[TBD]	[TBD]	[TBD]	[TBD]
1	[TBD]	[TBD]	[TBD]	[TBD]
2	[TBD]	[TBD]	[TBD]	[TBD]
3	[TBD]	[TBD]	[TBD]	[TBD]

6 Physical uplink shared channel related procedure

If a UE is configured by higher layers to decode PDCCH with the CRC scrambled by the C-RNTI, the UE shall decode the PDCCH and transmit the corresponding PUSCH.

6.1 UE procedure for transmitting the physical uplink shared channel

PUSCH transmission(s) can be dynamically scheduled by an UL grant in a DCI, or semi-statically configured to operate according to Subclause 6.1.2.3 and according to Subclause 5.8.2 of [10, TS 38.321] upon the reception of higher layer parameter of *UL-TWG-type1* without the detection of an UL grant in a DCI, or semi-persistently scheduled by an UL grant in a DCI after the reception of higher layer parameter of *UL-TWG-type2*.

For uplink, a maximum of 16 HARQ processes per cell is supported by the UE. The number of processes the UE may assume will at most be used for the uplink is configured to the UE for each cell separately by higher layer parameter [*nrofHARQ-processesForPUSCH*].

6.1.1 Transmission schemes

Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission. The UE is configured with codebook based transmission when the higher layer parameter *ulTxConfig* is set to 'Codebook', the UE is configured non-codebook based transmission when the higher layer parameter *ulTxConfig* is set to 'NonCodebook'. If the higher layer parameter *ulTxConfig* is not configured, the PUSCH transmission is based on one PUSCH antenna port, which is triggered by DCI format 0_0.

6.1.1.1 Codebook based UL transmission

For codebook based transmission, the UE determines its PUSCH transmission precoder based on SRI, TRI and TPMI fields from the DCI, where the TPMI is used to indicate the preferred precoder over the SRS ports in the selected SRS resource by the SRI when multiple SRS resources are configured, or if a single SRS resource is configured TPMI is used to indicate the preferred precoder over the SRS ports. The transmission precoder is selected from the uplink codebook, as defined in Subclause 6.3.1.5 of [4, TS 38.211]. When the UE is configured with the higher layer parameter *ulTxConfig* set to Codebook', the UE is configured with at least one SRS resource. The indicated SRI in slot *n* is associated with the most recent transmission of SRS resource identified by the SRI, where the SRS resource is prior to the PDCCH carrying the SRI before slot *n*.

For codebook based transmission, the UE determines its codebook subsets based on TPMI and upon the reception of higher layer parameter *ULCodebookSubset* which may be configured with fullAndPartialAndNonCoherent', or partialAndNonCoherent' , or 'Non-Coherent' depending on the UE capability. The maximum transmission rank may be configured by the higher parameter *ULmaxRank.*

A UE reporting its UE capability of partialAndNonCoherent' transmission shall not expect to be configured by ULCodebookSubset with fullAndPartialAndNonCoherent'.

A UE reporting its UE capability of 'Non-Coherent' transmission shall not expect to be configured by ULCodebookSubset with fullAndPartialAndNonCoherent' or with partialAndNonCoherent-'.

A UE shall not expect to be configured with the higher layer parameter *ULCodebookSubset* set to partialAndNonCoherent' when two [SRS] antenna ports are configured.

For codebook based transmission, the UE may be configured with a single SRS resource set and only one SRS resource can be indicated based on the SRI from within the SRS resource set. The maximum number of configured SRS resources for codebook based transmission is 2.

When multiple SRS resources are configured, the UE shall expect that higher layer parameter *NrofSRS-Ports* shall be configured with the same value in all SRS resources, and the higher layer parameter *SRS-ResourceConfigType* shall be configured with the same value in all SRS resources.

6.1.1.2 Non-Codebook based UL transmission

For non-codebook based transmission, the UE can determine its PUSCH precoder and transmission rank based on the wideband SRI field from the DCI. The UE shall use one or multiple SRS resources for SRS transmission, where the number of SRS resources which can be configured to the UE for simultaneously transmission in the same RBs is being part of UE capability signalling Only one SRS port for each SRS resource is configured. Only one SRS resource set can be configured with higher layer parameter *srsSetUse* set to nonCodebook'. The maximum number of SRS resources that can be configured for non-codebook based uplink transmission is 4. The indicated SRI in slot *n* is associated with the most recent transmission of SRS resource identified by the SRI, where the SRS resource is prior to the PDCCH carrying the SRI before slot *n*.

For non-codebook based transmission, the UE can measure NZP CSI-RS resource to calculate the precoder used for the transmission of precoded SRS. A UE can be configured with only one NZP CSI-RS resource for the SRS resource set.

- If aperiodic SRS resource is configured, the [CSI-RS information in the same slot TBD] for UL channel measurement is indicated via DCI, where the association among aperiodic SRS triggering state, triggered SRS resource(s) *SRS-ResourceConfigId*, CSI-RS resource ID *NZP-CSI-RS-ResourceConfigID* are higher layer configured by *AperiodicSRS-ResourceTrigger*. A UE may receive the dynamic SRS transmission request for aperiodic SRS transmission in the same slot as the reception of the DL CSI-RS resource A UE is not expected to update the SRS precoding information if the gap from the last symbol of the reception of the AP-CSI-RS resource and the first symbol of the AP-SRS transmission is less than 42 OFDM symbols. A UE may receive the SRI which shall be associated with the most recent SRS transmission.
- If periodic or semi-persistent SRS resource set is configured, the NZP-CSI-RS-ResourceConfigID for measurement is indicated via higher layer parameter SRS-AssocCSIRS per set.

The UE shall perform one-to-one mapping from the indicated SRI(s) to the indicated DM-RS ports(s) in the DCI format 0_1 increasing order.

For non-codebook based transmission, the UE does not expect to be configured with both *SRS-SpatialRelationInfo* for SRS resource and *SRS-AssocCSIRS* for SRS resource set.

For non-codebook based UL transmission, a UE can be scheduled with DCI format 0_1 when at least one SRS resource is configured.

6.1.2 Resource allocation

6.1.2.1 Resource allocation in time domain

When the UE is scheduled to transmit a transport block and no CSI report, or the UE is scheduled to transmit a transport block and a CSI report on PUSCH by a DCI, the *Time domain resource assignment* field of the DCI provides a row index of a higher layer configured table *pusch-symbolAllocation*, where the indexed row defines the slot offset K_2, the start and length indicator *SLIV*, and the PUSCH mapping type to be applied in the PUSCH transmission.

When the UE is scheduled to transmit a PUSCH with no transport block and with a CSI report by a *CSI request* field on a DCI, the *Time-domain PUSCH resources* field of the DCI provides a row index of a higher layer configured table *pusch-symbolAllocation*, where the indexed row defines the start and length indicator SLIV, and the PUSCH mapping type to be applied in the PUSCH transmission and K_2 is determined based on the corresponding list entries $Y_j, j = 0,...,N_{\mathrm{Rep}} - 1$ of the higher layer parameter *reportSlotOffset* for the N_{Rep}

triggered CSI Reporting Settings. The *i*th codepoint of K_2 s determined as $K_2 = \max_j Y_j$ where $Y_j(i)$ is the *i*th codepoint of Y_j.

- The slot where the UE shall transmit the PUSCH is determined by K_2 as $\left\lfloor n \cdot \frac{2^{\mu_{PUSCH}}}{2^{\mu_{PDCCH}}} \right\rfloor + K_2$ where *n* is the slot with the scheduling DCI, K_2 is based on the numerology of PUSCH, and
- The starting symbol *S* relative to the start of the slot, and the number of consecutive symbols *L* counting from the symbol *S* allocated for the PUSCH are determined from the start and length indicator *SLIV* of the indexed row:

  if $(L-1) \leq 7$ then

  $$SLIV = 14 \cdot (L-1) + S$$

  else

  $$SLIV = 14 \cdot (14 - L + 1) + (14 - 1 - S)$$

  where $0 < L \leq 14 - S$, and
- The PUSCH mapping type is set to Type A or Type B as defined in Subclause 6.4.1.1.3 of [4, TS 38.211] as given by the indexed row.

The UE shall consider the *S* and *L* combinations defined in table 6.1.2.1-1 as valid PUSCH allocations

Table 6.1.2.1-1: Valid *S* and *L* combinations

PUSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	***L***	***S+L***	***S***	***L***	***S+L***
Type A	0	{4,…,14}	{4,…,14}	0	{4,…,12}	{4,…,12}
Type B	{0,…,13}	{1,…,14}	{1,…,14}	{0,…,12}	{1,…,12}	{1,…,12}

When the UE is configured with *aggregationFactorUL* > 1, the same symbol allocation is applied across the *aggregationFactorUL* consecutive slots and the PUSCH is limited to a single transmission layer. The UE shall repeat the TB across the *aggregationFactorUL* consecutive slots applying the same symbol allocation in each slot.

If the UE procedure for determining slot configuration, as defined in subclause 11.1 of [6, TS 38.213], determines symbols of a slot allocated for PUSCH as downlink symbols, the transmission on that slot is omitted for multi-slot PUSCH transmission.

6.1.2.2 Resource allocation in frequency domain

The UE shall determine the resource block assignment in frequency domain using the resource allocation field in the detected PDCCH DCI. Two uplink resource allocation schemes type 0 and type 1 are supported. Uplink resource allocation scheme type 0 is supported for OFDM-based PUSCH. Uplink resource allocation scheme type 1 is supported for PUSCH for both cases when transform precoding is enabled or disabled.

If the scheduling DCI is configured to indicate the downlink resource allocation type as part of the *Frequency domain resource* assignment field, the UE shall use uplink resource allocation type 0 or type 1 as defined by this field. Otherwise the UE shall use the uplink frequency resource allocation type as defined by the higher layer parameter *Resource-allocation-config* for PUSCH.

The UE may assume that when the scheduling PDCCH is received with DCI format 0_0, then uplink resource allocation type 1 is used.

If a bandwidth part indicator field is not configured in the scheduling DCI, the RB indexing for uplink type 0 and type 1 resource allocation is determined within the UE's active carrier bandwidth part. If a bandwidth part indicator field is configured in the scheduling DCI, the RB indexing for uplink type 0 and type 1 resource allocation is determined within the UE's carrier bandwidth part indicated by bandwidth part indicator field value in the DCI, except for the case when DCI format 0_0 is decoded in the common search space in CORESET 0 in which case the initial bandwidth part shall be used. The UE shall upon detection of PDCCH intended for the UE determine first the uplink carrier bandwidth part and then the resource allocation within the carrier bandwidth part.

6.1.2.2.1 Uplink resource allocation type 0

In uplink resource allocation of type 0, the resource block assignment information includes a bitmap indicating the Resource Block Groups (RBGs) that are allocated to the scheduled UE where a RBG is a set of consecutive virtual resource blocks defined by higher layer parameter *rbg-Size*configured for PUSCH and the size of the carrier bandwidth part as defined in Table 6.1.2.2.1-1.

Table 6.1.2.2.1-1: Nominal RBG size *P*

Carrier Bandwidth Part Size	Configuration 1	Configuration 2
1 – 36	2	4
37 – 72	4	8
73 – 144	8	16
145 – 275	16	16

The total number of RBGs (N_{RBG}) for a uplink carrier bandwidth part *i* of size $N_{\mathrm{BWP,i}}^{size}$ PRBs is given by $N_{RBG} = \left\lceil \left(N_{BWP,i}^{size} + \left(N_{BWP,i}^{start} \bmod P\right)\right) / P \right\rceil$ where

- the size of the first RBG is $RBG_0^{size} = P - N_{BWP,i}^{start} \bmod P$,
- the size of the last RBG is $RBG_{last}^{size} = \left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod P$ if $\left(N_{BWP,i}^{start} + N_{BWP,i}^{size}\right) \bmod P > 0$ and *P* otherwise.
- the size of all other RBG is *P*.

The bitmap is of size N_{RBG} bits with one bitmap bit per RBG such that each RBG is addressable. The RBGs shall be indexed in the order of increasing frequency of the carrier bandwidth part and starting at the lowest frequency. The order of RBG bitmap is such that RBG 0 to RBG $N_{\mathrm{RBG}} - 1$ are mapped from MSB to LSB of the bitmap. The RBG is allocated to the UE if the corresponding bit value in the bitmap is 1, the RBG is not allocated to the UE otherwise.

6.1.2.2.2 Uplink resource allocation type 1

In uplink resource allocation of type 1, the resource block assignment information indicates to a scheduled UE a set of contiguously allocated localized virtual resource blocks within the active carrier bandwidth part of size N_{BWP}^{size} PRBs except for the case when DCI format 0_0 is decoded in the common search space in CORESET 0 in which case the initial bandwidth part of size N_{BWP}^{size} shall be used.

An uplink type 1 resource allocation field consists of a resource indication value (*RIV*) corresponding to a starting virtual resource block (RB_{start}) and a length in terms of contiguously allocated resource blocks L_{RBs}. The resource indication value is defined by

if $(L_{RBs} - 1) \le \left\lfloor N_{BWP}^{size} / 2 \right\rfloor$ then

$$RIV = N_{BWP}^{size}(L_{RBs} - 1) + RB_{start}$$

else

$$RIV = N_{BWP}^{size}(N_{BWP}^{size} - L_{RBs} + 1) + (N_{BWP}^{size} - 1 - RB_{start})$$

where $L_{RBs} \geq 1$ and shall not exceed $N_{BWP}^{size} - RB_{start}$.

6.1.2.3 Resource allocation for uplink transmission with configured grant

When PUSCH resource allocation is semi-statically configured by higher layer parameter *ConfiguredGrantConfig*, and the PUSCH transmission corresponding to the configured grant triggered, the following higher layer parameters are applied in the transmission:

- For both Type 1 and Type 2 PUSCH transmissions with a configured grant: [RRC IE name]
- For Type 1 PUSCH transmissions with a configured grant:

- The row index of an RRC configured table *pusch-symbolAllocation* is determined by the higher layer parameter *timeDomainAllocation*, indicating a combination of start symbol and length and PUSCH mapping type;
- Frequency domain resource allocation is determined by the higher layer parameter *frequencyDomainAllocation* according to the procedure in Subclause 6.1.2.2 for a given resource allocation type indicated by *resourceAllocation;*
- The I_{MCS} is provided by higher layer parameter *mcsAndTBS;*
- Number of DM-RS CDM groups, DM-RS ports, SRS resource indication and DM-RS sequence initialization are determined as in Subclause 7.3.1.1 of [5, TS 38.212], and the antenna port value, the bit value for DM-RS sequence initialization, precoding information and number of layers, SRS resource indicator are provided by *UL-TWG-DMRS*;
- When frequency hopping is enabled, the frequency offset between two frequency hops can be configured by higher layer parameter *Frequency-hopping-offset.*

- For Type 2 PUSCH transmissions with a configured grant: the resource allocation follows the higher layer configuration and UL grant received on the DCI according to [10, TS 38.321].

The UE shall not transmit anything on the resources configured by *ConfiguredGrantConfig* if the higher layers did not deliver a transport block to transmit on the resources allocated for uplink transmission without grant.

A set of allowed periodicities *P* are defined in [12, TS 38.331].

6.1.2.3.1 Transport Block repetition for uplink transmissions with a configured grant

The RRC-configured parameter *repK* and *repK-RV* define the *K* repetitions to be applied to the transmitted transport block, and the redundancy version pattern to be applied to the repetitions. For the n^{th} transmission occasion among *K* repetitions, *n*=1, 2, … , *K*, it is associated with $(mod(n\text{-}1,4)+1)^{th}$ value in the configured RV sequence. The initial transmission of a transport block may start at

- the first transmission occasion of the *K* repetitions if the configured RV sequence is {0,2,3,1},
- any of the transmission occasions of the *K* repetitions that are associated with RV=0 if the configured RV sequence is {0,3,0,3},
- any of the transmission occasions of the *K* repetitions if the configured RV sequence is {0,0,0,0}, except the last transmission occasion when K=8.

For any RV sequence, the repetitions shall be terminated after transmitting *K* repetitions, or at the last transmission occasion among the *K* repetitions within the period *P*, or when a UL grant for scheduling the same TB is received within the period *P*, whichever is reached first.

For both Type 1 and Type 2 PUSCH transmissions with a configured grant, when a UE is configured with data mapping Type A and *K> 1,* the same symbol allocation is applied across the *K* consecutive slots and the PUSCH is limited to a single transmission layer. The UE shall repeat the TB across the *K* consecutive slots applying the same symbol allocation in each slot.

6.1.3 UE procedure for applying transform precoding on PUSCH

For Msg3 PUSCH transmission, the UE shall consider the transform precoding either enabled or disabled according to the higher layer configured parameter *msg3-tp.*

For PUSCH transmission scheduled with a DCI:

- If the DCI with the scheduling grant was received with DCI format 0_0, the UE shall, for this PUSCH transmission, consider the transform precoding either enabled or disabled according to the higher layer configured parameter *msg3-tp*.
- If the DCI with the scheduling grant was not received with DCI format 0_0
    - If the UE is configured with the higher layer parameter [*transform-precoding-scheduled*], the UE shall, for this PUSCH transmission, consider the transform precoding either enabled or disabled according to this parameter.
    - If the UE is not configured with the higher layer parameter [*transform-precoding-scheduled*], the UE shall, for this PUSCH transmission, consider the transform precoding either enabled or disabled according to the higher layer configured parameter *msg3-tp*.

For PUSCH transmission without grant

- If the UE is configured with the higher layer parameter [transform-precoding-TWG], the UE shall, for this PUSCH transmission, consider the transform precoding either enabled or disabled according to this parameter.
- If the UE is not configured with the higher layer parameter [transform-precoding-TWG], the UE shall, for this PUSCH transmission, consider the transform precoding either enabled or disabled according to the higher layer configured parameter msg3-tp.

6.1.4 Modulation order, redundancy version and transport block size determination

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

- read the 5-bit modulation and coding scheme field (I_{MCS})in the DCI to determine the modulation order (Q_m) and target code rate (*R*) based on the procedure defined in Subclause 6.1.4.1
- read redundancy version field (*rv*) in the DCI to determine the redundancy version, and
- [check the "CSI request" bit field]

and second

- the UE shall use the number of layers (υ), the total number of allocated PRBs (n_{PRB}) to determine the transport block size based on the procedure defined in Subclause 6.1.4.2.

6.1.4.1 Modulation order and target code rate determination

For the PUSCH assigned by a DCI format 0_0/0_1 with CRC scrambled by C-RNTI, TC-RNTI, or CS-RNTI,if transform precoding is disabled and *MCS-Table-PUSCH* is not set to '256QAM',

- the UE shall use I_{MCS} and Table 5.1.3.1-1 to determine the modulation order (Q_m) and Target code rate (*R*) used in the physical downlink shared channel.

elseif transform precoding is disabled and *MCS-Table-PUSCH* is set to '256QAM',

- the UE shall use I_{MCS} and Table 5.1.3.1-2 to determine the modulation order (Q_m) and Target code rate (*R*) used in the physical downlink shared channel.

elseif transform precoding is enabled and *MCS-Table-PUSCH-transform-precoding* is not set to '256QAM',

- the UE shall use I_{MCS} and Table 6.1.4.1-1 to determine the modulation order (Q_m) and Target code rate (*R*) used in the physical uplink shared channel.
- for MCS index 0 and 1, *q*=1 if UE has reported to support pi/2 BPSK modulation; and *q*=2 in other cases

else

- the UE shall use I_{MCS} and Table 5.1.3.1-2 to determine the modulation order (Q_m) and Target code rate (*R*) used in the physical downlink shared channel.

end

Table 6.1.4.1-1: MCS index table for PUSCH with transform precoding and 64QAM

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x 1024	Spectral efficiency
0	q	240/ q	0.2344
1	q	314/ q	0.3066
2	2	193	0.3770
3	2	251	0.4902
4	2	308	0.6016
5	2	379	0.7402
6	2	449	0.8770
7	2	526	1.0273
8	2	602	1.1758
9	2	679	1.3262
10	4	340	1.3281
11	4	378	1.4766
12	4	434	1.6953
13	4	490	1.9141
14	4	553	2.1602
15	4	616	2.4063
16	4	658	2.5703
17	6	466	2.7305
18	6	517	3.0293
19	6	567	3.3223
20	6	616	3.6094
21	6	666	3.9023
22	6	719	4.2129
23	6	772	4.5234
24	6	822	4.8164
25	6	873	5.1152
26	6	910	5.3320
27	6	948	5.5547
28	1	reserved	
29	2	reserved	
30	4	reserved	
31	6	reserved	

6.1.4.2 Transport block size determination

For the PUSCH assigned by a DCI format 0_0/0_1 with CRC scrambled by C-RNTI, TC-RNTI, or CS-RNTI, if

- $0 \le I_{MCS} \le 27$ and transform precoding is disabled and *MCS-Table-PUSCH* is set to '256QAM', or
- $0 \le I_{MCS} \le 27$ and transform precoding is enabled and *MCS-Table-PUSCH- transform-precoding* is set to '256QAM', or
- $0 \le I_{MCS} \le 28$ and transform precoding is disabled and *MCS-Table-PUSCH* is not set to '256QAM', or
- $0 \le I_{MCS} \le 27$ and transform precoding is enabled and *MCS-Table-PUSCH-transform-precoding* is not set to '256QAM', the UE shall first determine the TBS as specified below:

  The UE shall first determine the number of REs (N_{RE}) within the slot:

  - A UE first determines the number of REs allocated for PUSCH within a PRB $\left(N'_{RE}\right)$ by
  - $N'_{RE} = N_{sc}^{RB} * N_{symb}^{sh} - N_{DMRS}^{PRB} - N_{oh}^{PRB}$, where $N_{sc}^{RB} = 12$ is the number of subcarriers in the frequency domain in a physical resource block, N_{symb}^{sh} is the number of symbols of the PUSCH allocation within the slot, N_{DMRS}^{PRB} is the number of REs for DM-RS per PRB in the scheduled duration including the overhead of the DM-RS CDM groups indicated by DCI format 0_0/0_1, and N_{oh}^{PRB} is the overhead configured by higher layer parameter Xoh-PUSCH. If the Xoh-PUSCH is not configured (a value from 0, 6, 12, or 18), the Xoh-PDSCH is set to 0.
  - A UE determines the total number of REs allocated for PUSCH $\left(N_{RE}\right)$ by $N_{RE} = \overline{N}'_{RE} * n_{PRB}$ where n_{PRB} is the total number of allocated PRBs for the UE.
  - Next, proceed with steps 2-5 as defined in Subclause 5.1.3.2

else if

- $28 \le I_{MCS} \le 31$ and transform precoding is disabled and MCS-Table-PUSCH is set to '256QAM', or
- $28 \le I_{MCS} \le 31$ and transform precoding is enabled and *MCS-Table-PUSCH-transform-precoding* is set to '256QAM', or
- $28 \le I_{MCS} \le 31$ and transform precoding is enabled and MCS-Table-PUSCH-transform-precoding is not set to '256QAM', or
- the TBS is assumed to be as determined from the DCI transported in the latest PDCCH for the same transport block using $0 \le I_{MCS} \le 27$. If there is no PDCCH for the same transport block using $0 \le I_{MCS} \le 27$, and if the initial PUSCH for the same

transport block is semi-persistently scheduled, the TBS shall be determined from the most recent configured scheduling PDCCH.

else

- the TBS is assumed to be as determined from the DCI transported in the latest PDCCH for the same transport block using $0 \le I_{MCS} \le 28$. If there is no PDCCH for the same transport block using $0 \le I_{MCS} \le 28$, and if the initial PUSCH for the same transport block is transmitted with configured grant, the TBS shall be determined from the most recent configured scheduling PDCCH.

6.1.5 Code block group based PUSCH transmission

6.1.5.1 UE procedure for grouping of code blocks to code block groups

If a UE is configured to receive code block group (CBG) based transmissions by receiving the higher layer parameter *codeBlockGroupTransmission* set to TRUE' for PUSCH, the UE shall determine the number of CBGs for a PUSCH transmission as

$$M = \min(N, C),$$

where *N* is the maximum number of CBGs per transport block as configured by *maxCodeBlockGroupsPerTransportBlock* for PUSCH, and C is the number of code blocks in the PUSCH according to the procedure defined in Subclause 6.2.3 of [5, TS 38.212].

Define $M_1 = \mathrm{mod}(C, M)$, $K_1 = \left\lceil \frac{C}{M} \right\rceil$, and $K_2 = \left\lfloor \frac{C}{M} \right\rfloor$.

If $M_1 > 0$, CBG *m*, $m = 0,1,\ldots,M_1 - 1$, consists of code blocks with indices $m \cdot K_1 + k, k = 0,1,\ldots,K_1 - 1$. CBG *m*, $m = M_1, M_1 + 1,\ldots,M - 1$, consists of code blocks with indices $M_1 \cdot K_1 + (m - M_1) \cdot K_2 + k, k = 0,1,\ldots,K_2 - 1$.

6.1.5.2 UE procedure for transmitting code block group based transmissions

If a UE is configured to transmit code block group based transmissions by receiving the higher layer parameter *codeBlockGroupTransmission* to TRUE' for PUSCH,

- For an initial transmission of a TB as indicated by the *New Data Indicator* field of the scheduling DCI, the UE may expect that the *CBGTI* field indicates all the CBGs of the TB are to be transmitted, and the UE shall include all the code block groups of the TB.

- For a retransmission of a TB as indicated by the *New Data Indicator* field of the scheduling DCI, the UE shall include only the CBGs indicated by the *CBGTI* field of the scheduling DCI.

A bit value of 0' in the *CBGTI* field indicates that the corresponding CBG is not to be transmitted and 1' indicates that it is to be transmitted. The order of *CBGTI* field bits is such that the CBGs are mapped in order from CBG#0 onwards starting from the MSB.

6.2 UE reference symbol (RS) procedure

6.2.1 UE sounding procedure

The UE can be configured with one or more Sounding Reference Symbol (SRS) resource sets as configured by the higher layer parameter *SRS-ResourceSetConfig*. For each SRS resource set, a UE may be configured with $K \geq 1$ SRS resources (higher later parameter *SRS-ResourceConfig*), where the maximum value of K is indicated by [*SRS_capability* [13, 38.306]]. The SRS resource set applicability is configured by the higher layer parameter *SRS-SetUse.* When the higher layer parameter *SRS-SetUse* is set to 'BeamManagement', only one SRS resource in each of multiple SRS sets can be transmitted at a given time instant. The SRS resources in different SRS resource sets can be transmitted simultaneously.

For aperiodic SRSt least one state of the DCI field is used to select at least one out of the configured SRS resource set.

The following SRS parameters are semi-statically configurable by higher layer parameter *SRS-ResourceConfig*.

- *SRS-ResourceConfigId* determines SRS resource configuration identify.
- Number of SRS ports as defined by the higher layer parameter *NrofSRS-Ports* in Subclause 6.4.1.4 of [4, TS 38.211].
- Time domain behaviour of SRS resource configuration as indicated by the higher layer parameter *SRS-ResourceConfigType*, which can be periodic, semi-persistent, aperiodic SRS transmission as defined in Subclause 6.4.1.4 of [4, TS 38.211].
- Slot level periodicity and slot level offset as defined by the higher layer parameter *SRS-SlotConfig* for an SRS resource of type periodic or semi-persistent.
- Number of OFDM symbols in the SRS resource, starting OFDM symbol of the SRS resource within a slot including repetition factor R as defined by the higher layer parameter *SRS-ResourceMapping* in Subclause 6.4.1.4 of [4, TS 38.211].
- SRS bandwidth B_{SRS} and C_{SRS}, as defined by the higher layer parameter *SRS-FreqHopping* in Subclause 6.4.1.4 of [4, TS 38.211].
- Frequency hopping bandwidth, b_{hop}, as defined by the higher layer parameter *SRS-FreqHopping* in Subclause 6.4.1.4 of [4, TS 38.211].
- Defining frequency domain position and configurable shift to align SRS allocation to 4 PRB grid, as defined by the higher layer parameter *SRS-FreqDomainPosition* in Subclause 6.4.1.4 of [4, TS 38.211].
- Cyclic shift, as defined by the higher layer parameter *SRS-CyclicShiftConfig* in Subclause 6.4.1.4 of [4, TS 38.211].

- Transmission comb value and comb offset as defined by the higher layer parameter *SRS-TransmissionComb* in Subclause 6.4.1.4 of [4].
- SRS sequence ID as defined by the higher layer parameter *SRS-SequenceId* in Subclause 6.4.1.4 of [4].
- The configuration of the spatial relation between a reference RS which can be an SSB/PBCH, CSI-RS or an SRS and the target SRS is indicated by the higher layer parameter *SRS-SpatialRelationInfo*.

The UE may be configured by the higher layer parameter *SRS-ResourceMapping* with an SRS resource occupying a location within the last 6 symbols of the slot.

When PUSCH and SRS are transmitted in the same slot, the UE may be configured to transmit SRS after the transmission of the PUSCH and the corresponding DM-RS.

For a UE configured with one or more SRS resource configuration(s), and when the higher layer parameter *SRS-ResourceConfigType* is set to 'periodic':

- if the UE is configured with the higher layer parameter *SRS-SpatialRelationInfo* set to 'SSB/PBCH', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the reception of the SSB/PBCH, if the higher layer parameter *SRS-SpatialRelationInfo* is set to 'CSI-RS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the reception of the periodic CSI-RS or of the semi-persistent CSI-RS, if the higher layer parameter SRS-SpatialRelationInfo is set to 'SRS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the transmission of the periodic SRS.

For a UE configured with one or more SRS resource configuration(s), and when the higher layer parameter *SRS-ResourceConfigType* is set to 'semi-persistent':

- when a UE receives an activation command [10, TS 38.321] for SRS resource set in slot n, the corresponding actions in [10, TS 38.321] and the UE assumptions on SRS transmission corresponding to the configured SRS resource set shall be applied no later than the minimum requirement defined in [11, TS 38.133]. The activation command also contains spatial relation assumptions provided by a list of references to reference signal resources, one per element in the activated SRS resource set. Each entry in the list refers to either an SS/PBCH, NZP CSI-RS resource, or SRS resource.
- when a UE receives a deactivation command [10, TS 38.321] for activated SRS resource set in slot n, the corresponding actions in [10, TS 38.321] and UE assumption on cessation of SRS transmission corresponding to the deactivated SRS resource set shall apply no later than the minimum requirement defined in [11, TS 38.133].
- if the UE is configured with the higher layer parameter *SRS-SpatialRelationInfo* set to 'SSB/PBCH', the UE shall transmit the SRS resource with the same spatial

domain transmission filter used for the reception of the SSB/PBCH, if the higher layer parameter *SRS-SpatialRelationInfo* is set to 'CSI-RS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the reception of the periodic CSI-RS or of the semi-persistent CSI-RS, if the higher layer parameter *SRS-SpatialRelationInfo* is set to 'SRS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the transmission of the periodic SRS or of the semi-persistent SRS.

- if an SRS resource in the activated resource set is configured with the higher layer parameter *SRS-SpatialRelationInfo*, the UE shall assume that the reference in the activation command to the reference signal resource overrides the one configured in *SRS-SpatialRelationInfo.*

For a UE configured with one or more SRS resource configuration(s), and when the higher layer parameter *SRS-ResourceConfigType* is set to 'aperiodic':

- the UE receives a configuration of SRS resource sets,
- the UE receives a downlink DCI, a group common DCI, or an uplink DCI based activation command where a codepoint of the DCI may activate one or more SRS resource set(s).
- if the UE is configured with the higher layer parameter *SRS-SpatialRelationInfo* set to 'SSB/PBCH', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the reception of the SSB/PBCH, if the higher layer parameter *SRS-SpatialRelationInfo* is set to 'CSI-RS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the reception of the periodic CSI-RS or of the semi-persistent CSI-RS, or of the aperiodidc CSI-RS. If the higher layer parameter SRS-*SpatialRelationInfo* is set to 'SRS', the UE shall transmit the SRS resource with the same spatial domain transmission filter used for the transmission of the periodic SRS or of the semi-persistent SRS or of the aperiodic SRS.

The 2-bit SRS request field [5 TS38.212] in DCI format 0_1, 1_1 indicates the triggered SRS resource set given in Table 6.2.1-1. The 2-bit SRS request field [5, TS38.212] in DCI format 2_3 indicates the triggered SRS resource set given in Subclause 11.4 of [6, TS 38.213].

Table 6.2.1-1: SRS request value for aperiodic SRS

Value of SRS request field	Description
'00'	No aperiodic SRS trigger
'01'	The 1st SRS resource set(s) configured by higher layers
'10'	The 2nd SRS resource set(s) configured by higher layers
'11'	The 3rd SRS resource set(s) configured by higher layers

If a UE is configured with the higher layer parameter *SRS-AssocCSIRS* and with the higher layer parameter *ulTxConfig* set to 'NonCodebook', the UE may be configured with a NZP

CSI-RS resource where a *NZP-CSI-RS-ResourceConfigId* is associated with an SRS resource set.

For PUCCH formats 0 and 2, a UE shall not transmit SRS when semi-persistent and periodic SRS are configured in the same symbol(s) with PUCCH carrying only CSI report(s), or only L1-RSRP report(s) or if aperiodic SRS is configured and PUCCH consists of beam failure request. In the case that SRS is not transmitted due to overlap with PUCCH, only the SRS symbol(s) that overlap with PUCCH symbol(s) are dropped. PUCCH shall not be transmitted when aperiodic SRS happens to overlap in the same symbol with semi-persistent or periodic PUCCH carrying semi-persistent/periodic CSI report(s) or semi-persistent/periodic L1-RSRP report(s) only.

A UE is not expected to be configured with aperiodic SRS and PUCCH formats 0 or 2 with aperiodic CSI report in the same symbol.

A UE is not expected to be configured with SRS and PUSCH/UL DM-RS/UL PT-RS/PUCCH formats 1, 3 or 4 in the same symbol.

A UE shall not transmit simultaneously SRS resource(s) and PRACH. If a UE is configured with an SRS resource and PRACH in the same OFDM symbols in a slot, SRS is not transmitted in the overlapping symbols.

6.2.1.1 UE SRS frequency hopping procedure

A UE may be configured to transmit an SRS resource on $N_s \in \{1,2,4\}$ adjacent symbols within the last six symbols of a slot, where all antenna ports of the SRS resource are mapped to each symbol of the resource. For a given SRS resource, the UE is configured with repetition factor R∈{1,2,4} by higher layer parameter *SRS-ResourceMapping* where $R \le N_s$. When frequency hopping within an SRS resource in each slot is not configured ($R=N_s$), all antenna ports of the SRS resource in each slot are mapped in each of the N_s symbols to the same set of subcarriers in the same set of PRBs. When frequency hopping within as SRS resource in each slot is configured without repetition (*R=1*), according to the SRS hopping parameters B_{SRS}, C_{SRS} and b_{hop} defined in Subclause 6.4.1.4 of [4, TS 38.211], all antenna ports of the SRS resource in each slot are mapped to different sets of subcarriers in each OFDM symbol, where the same transmission comb value is assumed for different sets of subcarriers. When both frequency hopping and repetition within an SRS resource in each slot are configured ($N_s=4$, $R=2$), all antenna ports of the SRS resource in each slot are mapped to the same set of subcarriers within each pair of R adjacent OFDM symbols, and frequency hopping across the two pairs is according to the SRS hopping parameters B_{SRS}, C_{SRS} and b_{hop}.

A UE may be configured $N_s = 2 \; or \; 4$ adjacent symbol aperiodic SRS resource with intra-slot frequency hopping within a bandwidth part, where the full hopping bandwidth is sounded with an equal-size subband across N_s symbols when frequency hopping is configured with *R=1*. A UE may be configured $N_s = 4$ adjacent symbols aperiodic SRS resource with intra-slot frequency hopping within a bandwidth part, where the full hopping bandwidth is sounded with an equal-size subband across two pairs of *R* adjacent OFDM symbols, when frequency hopping is configured with *R*=2. All antenna ports of the SRS resource are mapped to the same set of subcarriers within each pair of R adjacent OFDM symbols of the resource.

A UE may be configured $N_s = 1$ symbol periodic or semi-persistent SRS resource with inter-slot hopping within a bandwidth part, where the SRS resource occupies the same symbol location in each slot. A UE may be configured $N_s = 2 \; or \; 4$ symbol periodic or semi-persistent SRS resource with intra-slot and inter-slot hopping within a bandwidth part, where the N-symbol SRS resource occupies the same symbol location(s) in each slot. For N_s=4, when frequency hopping is configured with *R*=2, intra-slot and inter-slot hopping is supported with all antenna ports of the SRS resource mapped to different sets of subcarriers across two pairs of *R* adjacent OFDM symbol(s) of the resource in each slot. All antenna ports of the SRS resource are mapped to the same set of subcarriers within each pair of *R* adjacent OFDM symbols of the resource in each slot. For N_s= *R*, when frequency hopping is configured, inter-slot frequency hopping is supported with all antenna ports of the SRS resource mapped to the same set of subcarriers in *R* adjacent OFDM symbol(s) of the resource in each slot.

6.2.1.2 UE antenna switching

When UE antenna switching is enabled by the higher layer parameter *SRS-SetUse* set as 'antenna switching' for a UE that supports transmit antenna switching, a UE may be configured with one of the following configurations depending on the UE capability:

- SRS resource set with two SRS resources transmitted in different symbols, each SRS resource consisting of a single SRS port being associated with different UE antenna ports, or
- SRS resource set with two SRS resources transmitted in different symbols, each SRS resource consisting of two SRS ports where the port pair of the second resource is associated with a different UE antenna pair than the port pair of the first resource, or
- SRS resource set with four SRS resources transmitted in different symbols, each SRS resource consisting of a single SRS port being associated with different UE antenna ports,

and a guard period where UE does not transmit any other signal of Y symbols in-between the SRS resources is used in case the SRS resources are transmitted in the same slot.

The value of *Y* is defined by Table 6.2.1.2-1.

Table 6.2.1.2-1: The minimum guard period between two SRS resources of an SRS resource set for antenna switching

μ	$\Delta f = 2^{\mu} \cdot 15 [\text{kHz}]$	*Y* [symbol]
0	15	1
1	30	1
2	60	1
3	120	2

6.2.1.3 UE sounding procedure between component carriers

For a carrier of a serving cell with slot formats comprised of DL and UL symbols, not configured for PUSCH/PUCCH transmission, the UE shall not transmit SRS whenever SRS transmission (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL)* on the carrier of the serving cell and PUSCH/PUCCH transmission carrying HARQ-ACK/positive SR/RI/CRI and/or PRACH happen to overlap in the same symbol and that can result in uplink transmissions beyond the UE's indicated uplink carrier aggregation capability included in the [*SRS_capability* [13, TS 38.306].

For a carrier of a serving cell with slot formats comprised of DL and UL symbols, not configured for PUSCH/PUCCH transmission, the UE shall not transmit a periodic/semi-persistent type 0 SRS whenever periodic/semi-persistent SRS transmission (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL)* on the carrier of the serving cell and PUSCH transmission carrying aperiodic CSI happen to overlap in the same symbol and that can result in uplink transmissions beyond the UE's indicated uplink carrier aggregation capability included in the [*SRS_capability* [13, TS 38.306].

For a carrier of a serving cell with slot formats comprised of DL and UL symbols, not configured for PUSCH/PUCCH transmission, the UE shall drop PUCCH/PUSCH transmission carrying periodic CSI comprising only CQI/PMI, and/or SRS transmission on another serving cell configured for PUSCH/PUCCH transmission whenever the transmission and SRS transmission (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL)* on the serving cell happen to overlap in the same symbol and that can result in uplink transmissions beyond the UE's indicated uplink carrier aggregation capability included in the [*SRS_capability* [13, TS 38.306].

For a carrier of a serving cell with slot formats comprised of DL and UL symbols, not configured for PUSCH/PUCCH transmission, the UE shall drop PUSCH transmission carrying aperiodic CSI comprising only CQI/PMI whenever the transmission and aperiodic SRS transmission (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133]) as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL)* on the carrier of the serving cell happen to overlap in the same symbol and that can result in uplink transmissions beyond the UE's indicated uplink carrier aggregation capability included in the [*SRS_capability* [13, TS 38.306].

[A UE can be configured with SRS resource(s) on a carrier c_1 with slot formats comprised of DL and UL symbols and not configured for PUSCH/PUCCH transmission. For carrier c_1, the UE is configured with higher layer parameter *srs-SwitchFromServCellIndex* the switching from carrier c_2 which is configured for PUSCH/PUCCH transmission. During SRS transmission on carrier c_1 (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL*), uplink transmission is interrupted on carrier c_2]

[If the UE is not configured for PUSCH/PUCCH transmission on carrier c_1 with slot formats comprised of DL and UL symbols, and if the UE is not capable of simultaneous reception and transmission on carrier c_1 and serving cell c_2, the UE is not expected to be configured or indicated with SRS resource(s) such that SRS transmission on carrier c_1 (including any interruption due to uplink or downlink RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL*) would collide with the REs corresponding to the SS/PBCH blocks configured for the UE or the slots belonging to a control resource set indicated by [SystemInformationBlockType0] or [SystemInformationBlockType1] on serving cell c_2.]

6.2.2 UE DM-RS transmission procedure

When transmitted PUSCH is not scheduled by PDCCH with CRC scrambled by C-RNTI or CS-RNTI, the UE shall use single symbol front-loaded DM-RS of configuration type 1 on DM-RS port 0 and the remaining REs not used for DM-RS in the symbols are not used for any PUSCH transmission, additional DM-RS can be transmitted according to the scheduling type and the PUSCH duration as specified in Table 6.4.1.1.3-3 of [4, TS38.211], and

- For PUSCH with allocation duration of more than 7 symbols, the UE shall assume *dmrs-AdditionalPosition*=2 and up to two additional DM-RS can be transmitted according to PUSCH duration, or
- For PUSCH with allocation duration of 7 symbols with mapping type B, the UE shall assume *dmrs-AdditionalPosition*=1 and one additional DM-RS can be transmitted
- For PUSCH with allocation duration of less than 7 symbols with mapping type B, the UE shall assume *dmrs-AdditionalPosition*=0 and not transmit additional DM-RS.

When transmitting PUSCH scheduled by PDCCH with CRC scrambled by C-RNTI or CS-RNTI,

- the UE may be configured with higher layer parameter *dmrs-Type*, and the configured DM-RS configuration type is used for transmitting PUSCH in as defined in Subclause 6.4.1.1 of [4, TS 38.211].

- the UE may be configured with the maximum number of front-loaded DM-RS symbols for PUSCH by higher layer parameter *UL-DMRS-max-len.*
  - if *UL-DMRS-max-len* is equal to 1, single-symbol DM-RS can be scheduled for the UE by DCI, and the UE can be configured with a number of additional DM-RS for PUSCH by higher layer parameter *dmrs-AdditionalPosition,* which can be 0, 1, 2 or 3.
  - if *UL-DMRS-max-len* equal to 2, both single-symbol DM-RS and double symbol DM-RS can be scheduled for the UE by DCI, and the UE can be configured with a number of additional DM-RS for PUSCH by higher layer parameter *dmrs-AdditionalPosition,* which can be 0 or 1.
  - and, the UE shall transmit a number of additional DM-RS as specified in Table 6.4.1.1.3-3 and Table 6.4.1.1.3-4 in -Subclause 6.4.1.1.3 of [4, TS 38.211].

If a UE transmitting PUSCH is configured with the higher layer parameter *UL-PTRS-present*, the UE may assume that the following configurations are not occurring simultaneously for the transmitted PUSCH

- any DM-RS ports among 4-7 or 6-11 for DM-RS configurations type 1 and type 2, respectively are scheduled for the UE and PT-RS is transmitted from the UE.

If transform precoding is not enabled, the reference point for k is subcarrier 0 in common resource block 0, otherwise the subcarrier 0 of the lowest-numbered resource block of the scheduled PUSCH allocation.

A UE shall assume the DM-RS CDM groups indicated in Tables 7.3.1.1.2-6 to 7.3.1.1.2-23 of Subclause 7.3.1.1 of [5, TS38.212] are not used for data transmission, where "1", "2" and "3" for the number of DM-RS CDM group(s) correspond to CDM group 0, {0,1}, {0,1,2}, respectively.

For uplink DM-RS with PUSCH, the UE may assume the ratio of PUSCH EPRE to DM-RS EPRE ($1/\beta_{\mathrm{DMRS}}$ [dB]) is given by Table 6.2.2-1 according to the number of DM-RS CDM groups without data as signalled by DCI [5, TS 38.212].

Table 6.2.2-1: The ratio of PUSCH EPRE to DM-RS EPRE

Number of DM-RS CDM groups without data	DM-RS configuration type 1	DM-RS configuration type 2
1	0 dB	0 dB
2	-3 dB	-3 dB
3	-	-4.77 dB

6.2.3 UE PT-RS transmission procedure

If a UE is configured with the higher layer parameter *Uplink-PTRS-Config,* set to 'OFF', the UE shall not transmit PT-RS.

6.2.3.1 UE PT-RS transmission procedure when transform precoding is not enabled

When transform precoding is not enabled and if a UE is configured with the higher layer parameter *UL-PTRS-present* set to 'ON',

- if the additional higher layer parameters *UL-PTRS-time-density* and *UL-PTRS-frequency-density* are configured, and the RNTI equals C-RNTI, CS-RNTI, SPS-CSI-RNTI, the UE shall assume the PT-RS antenna ports' presence and pattern are a function of the corresponding scheduled MCS and scheduled bandwidth in a corresponding bandwidth part as shown in Table 6.2.3.1-1 and Table 6.2.3.1-2,
  - if the higher layer parameter *timeDensity* is not configured, the UE may assume $L_{PT\text{-}RS} = 1$.
  - if the higher layer parameter *frequencyDensity* is not configured, the UE may assume $K_{PT\text{-}RS} = 2$.
- otherwise the UE may assume that PT-RS is not present when the RNTI equals TC-RNTI.

Table 6.2.3.1-1: Time density of PT-RS as a function of scheduled MCS

Scheduled MCS	Time density(L_{PT-RS})
I_{MCS} < ptrs-MCS_1	PT-RS is not present
ptrs-MCS1 ≤ I_{MCS} < ptrs-MCS2	4
ptrs-MCS2 ≤ I_{MCS} < ptrs-MCS3	2
ptrs-MCS3 ≤ I_{MCS} < ptrs-MCS4	1

Table 6.2.3.1-2: Frequency density of PT-RS as a function of scheduled bandwidth

Scheduled bandwidth	Frequency density (K_{PT-RS})
$N_{RB} < N_{RB0}$	PT-RS is not present
$N_{RB0} \leq N_{RB} < N_{RB1}$	2
$N_{RB1} \leq N_{RB}$	4

The higher layer parameter *PTRS-UplinkConfig* provides the parameters *ptrs-MCS$_i$*, *i*=1,2,3 and with values in 0-29 when MCS Table 5.1.3.1-1 is configured and 0-28 when MCS Table

5.1.3.1-2 is configured, respectively. *ptrs-MCS4* is not explicitly configured by higher layers but assumed 29 when MCS Table 5.1.3.1-1 is configured and 28 when MCS Table 5.1.3.1-2 is configured. The higher layer parameter *PTRS-UplinkConfig* provides the parameters N_{RBi} i=0,1 with values in range 0-276.

If the higher layer parameter *PTRS-UplinkConfig* indicates that the time density thresholds $ptrs\text{-}MCS_i = ptrs\text{-}MCS_{i+1}$, then the time density L_{PTRS} of the associated row where both these thresholds appear in Table 6.2.3.1-1 is disabled. If the higher layer parameter *PTRS-UplinkConfig* indicates that the frequency density thresholds $N_{RB,i} = N_{RB,i+1}$, then the frequency density K_{PTRS} of the associated row where both these thresholds appear in Table 6.2.3.1-2 is disabled.

If either or both of the parameters PT-RS time density ($L_{PT\text{-}RS}$) and PT-RS frequency density ($K_{PT\text{-}RS}$), shown in Table 6.2.3.1-1 and Table 6.2.3.1-2, indicates that are configured as 'PT-RS not present', the UE shall assume that PT-RS is not present.

If a UE is configured with the higher layer parameters *UL-PTRS-present* and the number of configured PT-RS ports is 1, the UE is indicated a DM-RS port to be associated with the PT-RS by UL DCI.

When a UE is scheduled to transmit PUSCH with allocation duration of 2 symbols with mapping type A, and if $L_{PT\text{-}RS}$ is set to 2 or 4, the UE shall not transmit PT-RS. When a UE is scheduled to transmit PUSCH with allocation duration of 4 symbols with mapping type A, and if $L_{PT\text{-}RS}$ is set to 4, the UE shall not transmit PT-RS.

When a UE is scheduled to transmit PUSCH for retransmission, if the UE is scheduled with $I_{MCS} > V$, where $V = 28$ for MCS table 1 and $V = 27$ for MCS table 2, respectively, the MCS for PT-RS time-density determination is obtained from the DCI for the same transport block in the initial transmission, which is smaller than or equal to V.

The maximum number of configured PT-RS ports is given by the higher layer parameter *UL-PTRS-ports.* The UE is not expected to be configured with a larger number of UL PT-RS ports than it has reported need for.

If a UE has reported the capability of supporting [full-coherent UL transmission], the UE may expect the number of UL PT-RS ports to be configured as one.

For non-codebook based UL transmission, the UL PT-RS port index is signalled by a DCI associated to each SRS resource as described in Subclause 7.3.1.1.2 of [5, TS 38.212].

For non-codebook based UL transmission, the actual number of UL PT-RS port(s) to transmit is determined based on SRI(s). A UE may be configured with the PT-RS port index for each configured SRS resource by the higher layer parameter *UL-PTRS-SRS-mapping-non-CB*. If the PT-RS port index associated with different SRIs are the same, the corresponding UL DM-RS ports are associated to the one UL PT-RS port.

For partial-coherent and non-coherent codebook based UL transmission, the actual number of UL PT-RS port(s) is determined based on TPMI and/or TRI in DCI format 0_1:

- if the UE is configured with the higher layer parameter *PTRS-UplinkConfig* which is further configured with *maxNrofPorts* set to n2', the actual UL PT-RS port(s) and the associated transmission layer(s) are derived from indicated TPMI as:
- SRS port 0 and 2 in indicated TPMI share PT-RS port 0, and SRS port 1 and 3 in indicated TPMI share PT-RS port 1.
  - UL PT-RS port 0 is associated with the UL layer [x] of layers which are transmitted with SRS port 0 and SRS port 2 in indicated TPMI, and UL PT-RS port 1 is associated with the UL layer [y] of layers which are transmitted with SRS port 1 and SRS port 3 in indicated TPMI, where [x] and/or [y] are given by DCI parameter *PTRS-DMRS association* as shown in DCI format 0_1 described in Subclause 6.2.3 of [5, TS38.212].

For PT-RS, the transmit power of PT-RS is derived from ρ_{PTRS}^{PUSCH}, which is the power ratio between power of PUSCH and power of PT-RS per port.

For codebook based coherent uplink transmission, when the UE is scheduled with Q_p={1,2}one PT-RS port(s) in uplink and the number of scheduled layers is n_{layer}^{PUSCH},

- If the UE is configured with higher layer parameter *UL-PTRS-power*, the PUSCH to PT-RS power ratio per layer per RE ρ_{PTRS}^{PUSCH} is given by $\rho_{PTRS}^{PUSCH} = -\alpha_{PTRS}^{PUSCH}[dB]$, where α_{PTRS}^{PUSCH} is shown in the Table 6.2.3.1-3 according to the higher layer parameter *UL-PTRS-power*, the PT-RS scaling factor $\beta_{PTRS,i}$ specified in subclause 7.4.1.2.2 of [4, TS 38.211] is given by $\beta_{PTRS,i} = 10^{-\frac{\rho_{PTRS,i}}{20}}$ and also on the *ULCodebookSubset* according to [7, TS 38.212].
- The UE shall assume *UL-PTRS-power* is set to state "00" in Table 6.2.3.1-3 if not configured.

Table 6.2.3.1-3: Factor related to PUSCH to PT-RS power ratio per layer per RE α_{PTRS}^{PUSCH}

***UL-PTRS-power* / α_{PTRS}^{PUSCH}**		**The number of PUSCH layers (n_{layer}^{PUSCH})**						
	1	**2**		**3**		**4**		
	All cases	Full coherent	Partial and non-coherent	Full coherent	Partial and non-coherent	Full coherent	Partial coherent	Non-coherent
00	0	3	$3Q_p$-3	4.77	$3Q_p$-3	6	$3Q_p$	$3Q_p$-3
01	0	3	3	4.77	4.77	6	6	6
10	Reserved							
11	Reserved							

6.2.3.2 UE PT-RS transmission procedure when transform precoding is enabled

When transform precoding is enabled and if a UE is configured with the higher layer parameter *UL-PTRS-present-transform-precoding,*

- the UE shall be configured with the higher layer parameters *sampleDensity* and the UE shall assume the PT-RS antenna ports' presence and PT-RS group pattern are a function of the corresponding scheduled bandwidth in a corresponding bandwidth part, as shown in Table 6.2.3.2-1. The UE shall assume no PT-RS is present when the number of scheduled RBs is less than or equal to N_{RB0} if $N_{RB0} > 0$ or if the RNTI equals TC-RNTI.
- and the UE may be configured PT-RS time density $L_{PTRS} = 2$ with the higher layer parameter *timeDensity.* Otherwise, the UE shall assume $L_{PTRS} = 1$.
- if the higher layer parameter *PTRS-UplinkConfig* indicates that the sample density thresholds $N_{RB,i} = N_{RB,i+1}$, then the associated row where both these thresholds appear in Table 6.2.3.2-1 is disabled.

Table 6.2.3.2-1: PT-RS group pattern as a function of scheduled bandwidth

Scheduled bandwidth	Number of PT-RS groups	Number of samples per PT-RS group
$N_{RB0} \le N_{RB} < N_{RB1}$	2	2
$N_{RB1} \le N_{RB} < N_{RB2}$	2	4
$N_{RB2} \le N_{RB} < N_{RB3}$	4	2
$N_{RB3} \le N_{RB} < N_{RB4}$	4	4
$N_{RB4} \le N_{RB}$	8	4

When transform precoding is enabled and if a UE is configured with the higher layer parameter *UL-PTRS-present-transform-precoding,* the PT-RS scaling factor β specified in Subclause 6.4.1.2.2.2 of [4, TS 38.211] is determined by the scheduled modulation order as shown in table 6.2.3.2-1.

Table 6.2.3.2-1: PT-RS scaling factor (β) when transform coding enabled.

Scheduled modulation	PT-RS scaling factor (β)
π/2-BPSK	1
QPSK	1
16QAM	$3/\sqrt{5}$
64QAM	$7/\sqrt{21}$
256QAM	$15/\sqrt{85}$

6.3 UE PUSCH frequency hopping procedure

When transform precoding is enabled for PUSCH transmission, the UE shall perform, at least for the 14-symbol slot, PUSCH frequency hopping [if the frequency hopping field in the corresponding detected PDCCH DCI format is set to 1]; otherwise no PUSCH frequency hopping is performed.

In case of resource allocation type 1, whether or not transform precoding is enabled for PUSCH transmission, the UE may perform PUSCH frequency hopping, otherwise no PUSCH frequency hopping is performed. When transform precoding and frequency hopping are enabled for PUSCH, the RE mapping is performed in the following order: the modulated symbols are first mapped across sub-carriers, then across transform precoded symbols within a frequency-hop, then across frequency hops occupying different sets of PRBs.

If a UE is configured by higher layer parameter *Frequency-hopping-PUSCH*, one of two frequency hopping modes can be configured:

- Intra-slot frequency hopping, applicable to single slot and multi-slot PUSCH transmission.
- Inter-slot frequency hopping, applicable to multi-slot PUSCH transmission.

When frequency hopping on PUSCH is enabled and for resource allocation type 1, frequency offsets are configured by higher layer parameter *Frequency-hopping-offsets-set*:

- when the size of the active BWP is less than 50 PRBs, one of two higher layer configured offsets is indicated in the UL grant
- when the size of the active BWP is equal to or greater than 50 PRBs, one of four higher layer configured offsets is indicated in the UL grant.

The starting RB during in each hop is given by:

$$\mathrm{RB}_{\mathrm{start}} = \begin{cases} \mathrm{RB}_{\mathrm{start}} & \text{First hop} \\ \left(\mathrm{RB}_{\mathrm{start}} + \mathrm{RB}_{\mathrm{offset}}\right) \bmod N_{BWP}^{size} & \text{Second hop} \end{cases},$$

where $\mathrm{RB}_{\mathrm{start}}$ be the starting resource within the UL BWP, as calculated from the resource block assignment information of resource allocation type 1 (described in sub-clause 6.1.2.2.2) and $\mathrm{RB}_{\mathrm{offset}}$ is the frequency offset in RBs between the two frequency hops.

In case of intra-slot frequency hopping is configured for PUSCH without repetitions, the number of symbols in the first hop is given by $\left\lfloor N_{symb}^{PUSCH,s}/2 \right\rfloor$, the number of symbols in the second hop is given by $N_{symb}^{PUSCH,s} - \left\lfloor N_{symb}^{PUSCH,s}/2 \right\rfloor$, where $N_{symb}^{PUSCH,s}/2$ is the length of the PUSCH transmission in OFDM symbols in one slot.

In case of inter-slot frequency hopping, the starting RB during slot n_s^{μ} is given by:

$$\mathrm{RB}_{\mathrm{start}}\left(n_s^{\mu}\right)=\begin{cases}\mathrm{RB}_{\mathrm{start}} & n_s^{\mu} \bmod 2 = 0\\ \left(\mathrm{RB}_{\mathrm{start}}+\mathrm{RB}_{\mathrm{offset}}\right) \bmod N_{BWP}^{size} & n_s^{\mu} \bmod 2 = 1\end{cases},$$

where n_s^{μ} is the current slot number within a radio frame, where a multi-slot PUSCH transmission can take place, $\mathrm{RB}_{\mathrm{start}}$ is the starting resource within the UL BWP, as calculated from the resource block assignment information of resource allocation type 1 (described in sub-clause 6.1.2.2.2) and $\mathrm{RB}_{\mathrm{offset}}$ is the frequency offset in RBs between the two frequency hops.

6.4 UE PUSCH preparation procedure time

If the first uplink symbol in the PUSCH allocation, including the DM-RS, as defined by the slot offset K_2 and the start and length indicator *SLIV* of the scheduling DCI, is no earlier than at symbol L_2 then the UE shall transmit PUSCH where L_2 is defined as the next uplink symbol with its CP starting $T_{proc,2}=\left((N_2+d_{2,1}+d_{2,2})(2048+144)\cdot\kappa 2^{-\mu_{UL}}\right)\cdot T_C$ after the end of the last symbol of the PDCCH carrying the DCI scheduling the PUSCH, where N_2 is defined by table 6.4-1, where

- N_2 is based on μ of table 6.4-1, that corresponds to the min(μ_{DL}, μ_{UL}) where the μ_{DL} corresponds to the subcarrier spacing of the downlink with which the PDCCH carrying the DCI scheduling the PUSCH was transmitted and μ_{UL} corresponds to the subcarrier spacing of the uplink channel with which the PUSCH is to be transmitted.
- If the first symbol of the PUSCH allocation consists of DM-RS only, then $d_{2,1}=0$, otherwise $d_{2,1}=1$.
- If the UE is configured with multiple active component carriers, the value of $d_{2,2}$ is equal to maximum timing difference between component carriers as given in [11, TS 38.133], otherwise the value of $d_{2,2}=0$.

Otherwise the UE may ignore the scheduling DCI. The value of $T_{proc,2}$ is used both in the case of normal and extended cyclic prefix.

Table 6.4-1: PUSCH preparation time for PUSCH timing capability 1

μ	**PUSCH preparation time N_2 [symbols]**
0	10
1	12
2	23
3	36

Annex A (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2017-05	RAN1#89	R1-1708892	-	-	-	Draft skeleton	0.0.0
2017-07	AH_1706	R1-1712016				Inclusion of agreements up to and including RAN1#AH2	0.0.1
2017-08	AH_1706	R1-1714234				Inclusion of agreements up to and including RAN1#AH2	0.0.2
2017-08	RAN1#90	R1-1714596				Updated editor's version	0.0.3
2017-08	RAN1#90	R1-1714626				Updated editor's version	0.0.4
2017-08	RAN1#90	R1-1715077				Endorsed version by RAN1#90	0.1.0
2017-08	RAN1#90	R1-1715324				Inclusion of agreements up to and including RAN1#90	0.1.1
2017-08	RAN1#90	R1-1715331				Updated editor's version	0.1.2
2017-09	RAN#77	RP-172001				For information to plenary	1.0.0
2017-09	AH_1709	R1-1716930				Inclusion of agreements up to and including RAN1#AH3	1.0.1
2017-10	RAN1#90bis	R1-1718808				Updated editor's version	1.0.2
2017-10	RAN1#90bis	R1-1718819				Endorsed version by RAN1#90bis	1.1.0
2017-10	RAN1#90bis	R1-1719227				Inclusion of agreements up to and including RAN1#90bis	1.1.1
2017-11	RAN1#90bis	R1-1720113				Inclusion of agreements up to and including RAN1#90bis	1.1.2
2017-11	RAN1#90bis	R1-1720114				Inclusion of agreements up to and including RAN1#90bis	1.1.3
2017-11	RAN1#90bis	R1-1721051				Endorsed version	1.2.0
2017-12	RAN1#91	R1-1721344				Inclusion of agreements up to and including RAN1#91	1.3.0
2017-12	RAN#78	RP-172416				Endorsed version for approval by plenary	2.0.0
2017-12	RAN#78					Approved by plenary – Rel-15 spec under change control	15.0.0

2018-03	RAN#79	RP-180200	0001		F	CR capturing the Jan18 ad-hoc and RAN1#92 meeting agreements	15.1.0