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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
CBG	Code block group
CP	Cyclic prefix
CQI	Channel quality indicator
CPU	CSI processing unit
CRC	Cyclic redundancy check
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
SR	Scheduling Request
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 *powerControlOffsetSS* 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 described in Subclause 5.1.6.2. The DM-RS scaling factor β_{PDSCH}^{DMRS} specified in Subclause 7.4.1.1.2 of [4, TS 38.211] is given by $\beta_{PDSCH}^{DMRS} = 10^{-\frac{\beta_{DMRS}}{20}}$.

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 PT-RS ports associated with the PDSCH and when the PT-RS port is associated to n_{DMRS}^{PTRS} DM-RS ports,

- if the UE is configured with the higher layer parameter *epre-Ratio*, the ratio of PT-RS EPRE to PDSCH EPRE per layer per RE for PT-RS port (ρ_{PTRS}) is given by Table 4.1-2 according to the *epre-Ratio*, the PT-RS scaling factor β_{PTRS} specified in subclause 7.4.1.2.2 of [4, TS 38.211] is given by $\beta_{PTRS} = 10^{-\frac{\rho_{PTRS}}{20}}$.
- otherwise, the UE shall assume *epre-Ratio* is set to state '0' in Table 4.1-2 if not configured.

Table 4.1-2: PT-RS EPRE to PDSCH EPRE per layer per RE (α_{PTRS})

epre-Ratio	**The number of PDSCH layers**					
	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*. For any two HARQ process IDs in a given cell, if the UE is scheduled to start receiving a PDSCH in symbol *j* by a PDCCH starting in symbol *i*, the UE is not expected to be scheduled to receive a PDSCH starting earlier than symbol *j* with a PDCCH starting later than symbol *i*.

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 PRBs containing SS/PBCH block are not available for PDSCH 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 the PRBs containing SS/PBCH block are not available for PDSCH 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 scheduled with SI-RNTI in PDCCH Type0 common search space, the 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 scheduled with SI-RNTI in PDCCH Type0a common search space, RA-RNTI, P-RNTI or TC-RNTI, the UE assumes SS/PBCH block transmission according to *ssb-PositionsInBurst*, and if the PDSCH resource allocation overlaps with PRBs containing SS/PBCH block transmission resources the UE shall assume that the PRBs containing SS/PBCH block are not available for PDSCH in the OFDM symbols where SS/PBCH block is transmitted.

When receiving PDSCH scheduled with SI-RNTI or P-RNTI, 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 scheduled with RA-RNTI 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 used for RACH association and transmission with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable. When receiving a PDSCH scheduled with RA-RNTI in response to a random access procedure triggered by a PDCCH order which triggers non-contention based random access procedure, the UE may assume that the DM-RS port of the received PDCCH order and the DM-RS ports of PDSCH of the corresponding PDSCH scheduled with RA-RNTI are quasi co-located with the same SS/PBCH block or CSI-RS with respect to Doppler shift, Doppler spread, average delay, delay spread, spatial RX parameters when applicable.

When receiving PDSCH scheduled with TC-RNTI 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.

The UE in RRC Idle mode shall be able to decode two PDSCHs each scheduled with SI-RNTI, P-RNTI, RA-RNTI or TC-RNTI, with the two PDSCHs partially or fully overlapping in time in non-overlapping PRBs.

On a frequency range 1 cell, the UE shall be able to decode a PDSCH scheduled with C-RNTI or CS-RNTI and, during a process of P-RNTI triggered SI acquisition, another PDSCH scheduled with SI-RNTI that partially or fully overlap in time in non-overlapping PRBs.

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 in non-overlapping PRBs.

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

If the UE is configured by higher layers to decode a PDCCH with its CRC scrambled by a CS-RNTI, the UE shall receive PDSCH transmissions without corresponding PDCCH transmissions using the higher-layer-provided PDSCH configuration for those PDSCHs.

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], subject to the DM-RS reception procedures in Subclause 5.1.6.2.

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 value *m* of the DCI provides a row index *m* + 1 to an allocation table. The determination of the used resource allocation table is defined in sub-clause 5.1.2.1.1. The indexed row defines the slot offset K_0, the start and length indicator *SLIV*, or directly the start symbol *S* and the allocation length *L*, 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 μ_{PDSCH} and μ_{PDCCH} are the subcarrier spacing configurations for PDSCH and PDCCH, respectively, 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} (Note 1)	{3,…,14}	{3,…,14}	{0,1,2,3} (Note 1)	{3,…,12}	{3,…,12}
Type B	{0,…,12}	{2,4,7}	{2,…,14}	{0,…,10}	{2,4,6}	{2,…,12}
Note 1: S = 3 is applicable only if *dmrs-TypeA-Posiition* = 3						

When the UE is configured with *aggregation*FactorDL > 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. The redundancy version to be applied on the n^{th} transmission occasion of the TB is determined according to table 5.1.2.1-2.

Table 5.1.2.1-2: Applied redundancy version when *aggregationFactorDL* > 1

rv_{id} indicated by the DCI scheduling the PDSCH	rv_{id} to be applied to n^{th} transmission occasion			
	***n* mod 4 = 0**	***n* mod 4 = 1**	***n* mod 4 = 2**	***n* mod 4 = 3**
0	0	2	3	1
2	2	3	1	0
3	3	1	0	2
1	1	0	2	3

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.

The UE is not expected to receive a PDSCH with mapping type A in a slot, if the PDCCH scheduling the PDSCH was received in the same slot and was not contained within the first three symbols of the slot.

The UE is not expected to receive a PDSCH with mapping type B in a slot, if the first symbol of the PDCCH scheduling the PDSCH was received in a later symbol than the first symbol indicated in the PDSCH time domain resource allocation.

5.1.2.1.1 Determination of the resource allocation table to be used for PDSCH

Table 5.1.2.1.1-1 defines which PDSCH time domain resource allocation configuration to apply. Either a default PDSCH time domain allocation A, B or C according to tables 5.1.2.1.1-2, 5.1.2.1.1-3, 5.1.2.1.1.-4 and 5.1.2.1.1-5 is applied, or the higher layer configured *pdsch-AllocationList* in either *pdsch-ConfigCommon* or *pdsch-Config* is applied.

Table 5.1.2.1.1-1: Applicable PDSCH time domain resource allocation

RNTI	PDCCH search space	SS/PBCH block and CORESET multiplexing pattern	*pdsch-ConfigCommon* includes *pdsch-AllocationList*	*pdsch-Config* includes *pdsch-AllocationList*	PDSCH time domain resource allocation to apply
SI-RNTI	Type0 common	1	-	-	Default A for normal CP
		2	-	-	Default B
		3	-	-	Default C
	Type0A common				
RA-RNTI, TC-RNTI,	Type1 common	1, 2, 3	No	-	Default A
		1, 2, 3	Yes	-	*pdsch-AllocationList* provided in *pdschConfigCommon*
P-RNTI	Type2 common				
C-RNTI, CS-RNTI	Any common search space associated with CORESET#0	1, 2, 3	No	-	Default A
		1, 2, 3	Yes	-	*pdsch-AllocationList* provided in *pdschConfigCommon*
C-RNTI, CS-RNTI	Any common search space not associated with CORESET#0 UE specific search space	1,2,3	No	No	Default A
		1,2,3	Yes	No	*pdsch-AllocationList* provided in *pdsch-ConfigCommon*
		1,2,3	No/Yes	Yes	*pdsch-AllocationList* provided in *pdsch-Config*

Table 5.1.2.1.1-2: Default PDSCH time domain resource allocation A for normal CP

Row index	*dmrs-TypeA-Position*	PDSCH mapping type	K_0	*S*	*L*
1	2	Type A	0	2	12
	3	Type A	0	3	11
2	2	Type A	0	2	10
	3	Type A	0	3	9
3	2	Type A	0	2	9
	3	Type A	0	3	8
4	2	Type A	0	2	7
	3	Type A	0	3	6
5	2	Type A	0	2	5
	3	Type A	0	3	4
6	2	Type B	0	9	4
	3	Type B	0	10	4
7	2	Type B	0	4	4
	3	Type B	0	6	4
8	2,3	Type B	0	5	7
9	2,3	Type B	0	5	2
10	2,3	Type B	0	9	2
11	2,3	Type B	0	12	2
12	2,3	Type A	0	1	13
13	2,3	Type A	0	1	6
14	2,3	Type A	0	2	4
15	2,3	Type B	0	4	7
16	2,3	Type B	0	8	4

Table 5.1.2.1.1-3: Default PDSCH time domain resource allocation A for extended CP

Row index	*dmrs-TypeA-Position*	PDSCH mapping type	K_0	*S*	*L*
1	2	Type A	0	2	6
	3	Type A	0	3	5
2	2	Type A	0	2	10
	3	Type A	0	3	9
3	2	Type A	0	2	9
	3	Type A	0	3	8
4	2	Type A	0	2	7
	3	Type A	0	3	6
5	2	Type A	0	2	5
	3	Type A	0	3	4
6	2	Type B	0	6	4
	3	Type B	0	8	2
7	2	Type B	0	4	4
	3	Type B	0	6	4
8	2,3	Type B	0	5	6
9	2,3	Type B	0	5	2
10	2,3	Type B	0	9	2
11	2,3	Type B	0	10	2
12	2,3	Type A	0	1	11
13	2,3	Type A	0	1	6
14	2,3	Type A	0	2	4
15	2,3	Type B	0	4	6
16	2,3	Type B	0	8	4

Table 5.1.2.1.1-4: Default PDSCH time domain resource allocation B

Row index	*dmrs-TypeA-Position*	PDSCH mapping type	K_0	*S*	*L*
1	2,3	Type B	0	2	2
2	2,3	Type B	0	4	2
3	2,3	Type B	0	6	2
4	2,3	Type B	0	8	2
5	2,3	Type B	0	10	2
6	2,3	Type B	1	2	2
7	2,3	Type B	1	4	2
8	2,3	Type B	0	2	4
9	2,3	Type B	0	4	4
10	2,3	Type B	0	6	4
11	2,3	Type B	0	8	4
12 (Note 1)	2,3	Type B	0	10	4
13 (Note 1)	2,3	Type B	0	2	7
14 (Note 1)	2	Type A	0	2	12
	3	Type A	0	3	11
15	2,3	Type B	1	2	4
16	Reserved				
Note 1: If the PDSCH was scheduled with SI-RNTI in PDCCH Type0 common search space, the UE may assume that this PDSCH resource allocation is not applied					

Table 5.1.2.1.1-5: Default PDSCH time domain resource allocation C

Row index	*dmrs-TypeA-Position*	PDSCH mapping type	K_0	*S*	*L*
1 (Note 1)	2,3	Type B	0	2	2
2	2,3	Type B	0	4	2
3	2,3	Type B	0	6	2
4	2,3	Type B	0	8	2
5	2,3	Type B	0	10	2
6	Reserved				
7	Reserved				
8	2,3	Type B	0	2	4
9	2,3	Type B	0	4	4
10	2,3	Type B	0	6	4
11	2,3	Type B	0	8	4
12	2,3	Type B	0	10	4
13 (Note 1)	2,3	Type B	0	2	7
14 (Note 1)	2	Type A	0	2	12
	3	Type A	0	3	11
15 (Note 1)	2,3	Type A	0	0	6
16 (Note 1)	2,3	Type A	0	2	6
Note 1: The UE may assume that this PDSCH resource allocation is not used, if the PDSCH was scheduled with SI-RNTI in PDCCH Type0 common search space					

5.1.2.2 Resource allocation in frequency domain

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 domain resource assignment* field by setting a higher layer parameter *resourceAllocation* in *pdsch-Config* to 'dynamicswitch', the UE shall use downlink resource allocation type 0 or type 1 as defined by this DCI field. Otherwise the UE shall use the downlink frequency resource allocation type as defined by the higher layer parameter *resourceAllocation*.

For a PDSCH scheduled with a DCI format 1_0 in any type of PDCCH common search space, regardless of which bandwidth part is the active bandwidth part, RB numbering starts from the lowest RB of the CORESET in which the DCI was received.

For a PDSCH scheduled otherwise, 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 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 bandwidth part indicated by bandwidth part indicator field value in the DCI. 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 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 by *PDSCH-Config* 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 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 non-interleaved or interleaved virtual resource blocks within the active bandwidth part of size N_{BWP}^{size} PRBs except for the case when DCI format 1_0 is decoded in any common search space in CORESET 0 in which case the initial bandwidth part of size $N_{\mathrm{BWP,0}}^{size}$ 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 $(L_{RBs}-1)\le\lfloor N_{BWP}^{size}/2\rfloor$ 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 $L_{RBs}\ge 1$ and shall not exceed $N_{BWP}^{size}-RB_{start}$.

When the DCI size for DCI format 1_0 in USS is derived from the initial BWP with size $N_{\mathrm{BWP}}^{initial}$ but applied to another active BWP with size of $N_{\mathrm{BWP}}^{active}$, a downlink type 1 resource block assignment field consists of a resource indication value (*RIV*) corresponding to a starting resource block $RB_{start}=0,K,2\cdot K,\ldots,(N_{\mathrm{BWP}}^{initial}-1)\cdot K$ and a length in terms of virtually contiguously allocated resource blocks $L_{RBs}=K,2\cdot K,\ldots,N_{\mathrm{BWP}}^{initial}\cdot K$.

The resource indication value is defined by:

if $(L'_{RBs}-1)\le\lfloor N_{BWP}^{initial}/2\rfloor$ then

$$RIV=N_{BWP}^{initial}(L'_{RBs}-1)+RB'_{start}$$

else

$$RIV=N_{BWP}^{initial}(N_{BWP}^{initial}-L'_{RBs}+1)+(N_{BWP}^{initial}-1-RB'_{start})$$

where $L'_{RBs}=L_{RBs}/K$, $RB'_{start}=RB_{start}/K$ and where L'_{RBs} shall not exceed $N_{BWP}^{initial}-RB'_{start}$.

If $N_{BWP}^{active}>N_{BWP}^{initial}$, *K* is the maximum value from set {1, 2, 4, 8} which satisfies $K\le\lfloor N_{BWP}^{active}/N_{BWP}^{initial}\rfloor$; otherwise *K* = 1.

5.1.2.3 Physical resource block (PRB) bundling

A UE may assume that precoding granularity is $P'_{BWP,i}$ consecutive resource blocks in the frequency domain. $P'_{BWP,i}$ can be equal to one of the values among {2, 4, wideband}.

If $P'_{BWP,i}$ 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.

If $P'_{BWP,i}$ is determined as one of the values among {2, 4}, Precoding Resource Block Group (PRGs) partitions the bandwidth part *i* with $P'_{BWP,i}$ consecutive PRBs. Actual number of consecutive PRBs in each PRG could be one or more.

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.

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 a UE is scheduled a PDSCH with DCI format 1_0, the UE shall assume that $P'_{BWP.i}$ is equal to 2 PRBs.

When receiving PDSCH scheduled by PDCCH with DCI format 1_1 with CRC scrambled by C-RNTI or CS-RNTI, $P'_{BWP.i}$ for bandwidth part is equal to 2 PRBs unless configured by the higher layer parameter *prb-BundlingType* given by *PDSCH-Config*.

When receiving PDSCH scheduled by PDCCH with DCI format 1_1 with CRC scrambled by C-RNTI or CS-RNTI, if the higher layer parameter *prb-BundlingType* is set to 'dynamicBundling', the higher layer parameters *bundleSizeSet1* and *bundleSizeSet2* configure two sets of $P'_{BWP.i}$ values, the first set can take one or two $P'_{BWP.i}$ values among {2, 4, wideband}, and the second set can take one $P'_{BWP.i}$ value among {2, 4, wideband}.

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 $P'_{BWP.i}$ 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.

When receiving PDSCH scheduled by PDCCH with DCI format 1_1 with CRC scrambled by C-RNTI or CS-RNTI, if the higher layer parameter *prb-BundlingType* is set to 'staticBundling', 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 for bandwidth part *i* according to Subclause 5.1.2.2.1, or when a UE is configured with interleaving unit of 2 for VRB to PRB mapping provided by the higher layer parameter *vrb-ToPRB-Interleaver* given by *PDSCH-Config* for bandwidth part *i*, the UE is not expected to be configured with $P'_{BWP,i} = 4$.

5.1.3 Modulation order, target code rate, redundancy version 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

- read *redundancy version* field (rv) in the DCI to determine the redundancy version..

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 scheduled by a PDCCH with DCI format 1_0 or format 1_1 with CRC scrambled by C-RNTI, new-RNTI, TC-RNTI, CS-RNTI, SI-RNTI, RA-RNTI, or P-RNTI,

if the higher layer parameter *mcs-Table* given by *PDSCH-Config* is set to 'qam256', and the PDSCH is scheduled by a PDCCH with a DCI format 1_1 and the CRC is scrambled by C-RNTI or CS-RNTI

- 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 the UE is not configured with new-RNTI, the higher layer parameter *mcs-Table* given by *PDSCH-Config* is set to 'qam64LowSE', and the PDSCH is scheduled with C-RNTI, and the PDSCH is assigned by a PDCCH in a UE-specific search space

- the UE shall use I_{MCS} and Table 5.1.3.1-3 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel.

elseif the UE is configured with new-RNTI, and the PDSCH is scheduled with new-RNTI

- the UE shall use I_{MCS} and Table 5.1.3.1-3 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel.

elseif the UE is not configured with the higher layer parameter *mcs-Table* given by *SPS-config*, the higher layer parameter *mcs-Table* given by *PDSCH-Config* is set to 'qam256', the PDSCH is scheduled with CS-RNTI, and the PDSCH is assigned by a PDCCH with DCI format 1_1

- 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 the UE is configured with the higher layer parameter *mcs-Table* given by *SPS-config* set to 'qam64LowSE', and the PDSCH is scheduled with CS-RNTI

- the UE shall use I_{MCS} and Table 5.1.3.1-3 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 5.1.3.1-1 to determine the modulation order (Q_m) and Target code rate (R) used in the physical downlink shared channel.

end

The UE is not expected to decode a PDSCH scheduled with P-RNTI, RA-RNTI, 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	

Table 5.1.3.1-3: MCS index table 3 for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x [1024]	Spectral efficiency
0	2	30	0.0586
1	2	40	0.0781
2	2	50	0.0977
3	2	64	0.1250
4	2	78	0.1523
5	2	99	0.1934
6	2	120	0.2344
7	2	157	0.3066
8	2	193	0.3770
9	2	251	0.4902
10	2	308	0.6016
11	2	379	0.7402
12	2	449	0.8770
13	2	526	1.0273
14	2	602	1.1758
15	4	340	1.3281
16	4	378	1.4766
17	4	434	1.6953
18	4	490	1.9141
19	4	553	2.1602
20	4	616	2.4063
21	6	438	2.5664
22	6	466	2.7305
23	6	517	3.0293
24	6	567	3.3223
25	6	616	3.6094
26	6	666	3.9023
27	6	719	4.2129
28	6	772	4.5234
29	2	reserved	
30	4	reserved	
31	6	reserved	

5.1.3.2 Transport block size determination

In case the higher layer parameter *maxNrofCodeWordsScheduledByDCI* indicates that two codeword transmission is enabled, then a transport block is disabled by DCI format 1_1 if I_{MCS} = 26 and if rv_{id} = 1 for the corresponding transport block, otherwise the transport block is enabled. If both transport blocks are enabled, transport block 1 and 2 are mapped to codeword 0 and 1 respectively. If only one transport block is enabled, then the enabled transport block is always mapped to the first codeword.

For the PDSCH assigned by a PDCCH with DCI format 1_0 or format 1_1 with CRC scrambled by C-RNTI, new-RNTI, TC-RNTI, CS-RNTI, or SI-RNTI, if Table 5.1.3.1-2 is used and $0 \le I_{MCS} \le 27$, or a table other than Table 5.1.3.1-2 is used and $0 \le I_{MCS} \le 28$, the UE shall, except if the transport block is disabled in DCI format 1_1, 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 without data, as indicated by DCI format 1_1 or as described for format 1_0 in Subclause 5.1.6.2, and N_{oh}^{PRB} is the overhead configured by higher layer parameter *xOverhead* in *PDSCH-ServingCellConfig*. If the *xOverhead* in *PDSCH-ServingCellconfig* is not configured (a value from 0, 6, 12, or 18), the N_{oh}^{PRB} is set to 0. If the PDSCH is scheduled by PDCCH with a CRC scrambled by SI-RNTI, RA-RNTI or P-RNTI, N_{oh}^{PRB} is assumed to be 0.

- A UE determines the total number of REs allocated for PDSCH (N_{RE}) by $N_{RE} = \min\left(156, N'_{RE}\right) \cdot n_{PRB}$, where n_{PRB} is the total number of allocated PRBs for the UE.

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

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 $N'_{info} = \max\left(24, 2^n \cdot \left\lfloor \frac{N_{info}}{2^n} \right\rfloor\right)$, where $n = \max\left(3, \left\lfloor \log_2\left(N_{info}\right) \right\rfloor - 6\right)$.

- 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 $N_{info} \leq 3824$

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 $N'_{info} = \max\left(3840, 2^n \times round\left(\frac{N_{info}-24}{2^n}\right)\right)$, where $n = \lfloor \log_2(N_{info}-24) \rfloor - 5$ and ties in the round function are broken towards the next largest integer.

- if $R \leq 1/4$

$$TBS = 8 \cdot C \cdot \left\lceil \frac{N'_{info} + 24}{8 \cdot C} \right\rceil - 24 \text{, where } C = \left\lceil \frac{N'_{info} + 24}{3816} \right\rceil$$

else

if $N'_{info} > 8424$

$$TBS = 8 \cdot C \cdot \left\lceil \frac{N'_{info} + 24}{8 \cdot C} \right\rceil - 24 \text{, where } C = \left\lceil \frac{N'_{info} + 24}{8424} \right\rceil$$

else

$$TBS = 8 \cdot \left\lceil \frac{N'_{info} + 24}{8} \right\rceil - 24$$

end if

end if

else if Table 5.1.3.1-2 is used 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.

For the PDSCH assigned by a PDCCH with DCI format 1_0 with CRC scrambled by P-RNTI, or RA-RNTI, TBS determination follows the steps 1-4 with the following modification in step 2: a scaling $N_{info} = S \cdot N_{RE} \cdot R \cdot Q_m \cdot \upsilon$ is applied in the calculation of N_{info}, where the scaling factor is determined based on the *TB scaling* field in the DCI as in Table 5.1.3.2-3.

Table 5.1.3.2-3: Scaling factor of N_{info} for P-RNTI and RA-RNTI

TB scaling field	Scaling factor S
00	1
01	0.5
10	0.25
11	

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

When receiving PDSCH not conveying [RAR, OSI, Paging, Msg4, SIB1], 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:

- *rateMatchPatternToAddModList* given by *PDSCH-Config* configuring up to 4 *RateMatchPattern(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 *resourceBlocks* given by *RateMatchPattern*) with 1RB granularity and a symbol level bitmap spanning one or two slots (higher layer parameters *symbolsInResourceBlock* given by *RateMatchPattern*) for which the reserved RBs apply. The bit equal to 1 in the RB and symbol level bitmaps indicates that corresponding resource is not available for PDSCH. For each pair of RB and symbol level bitmaps, a UE may be configured with a time-domain pattern (higher layer parameter *periodicityAndPattern* given by *RateMatchPattern*) corresponding to a unit equal to a duration of the symbol level bitmap, and bit equal to 1 indicating the pair is present in the unit. The *periodicityAndPattern* can be {1, 2, 4, 5, 8, 10, 20 or 40} units long, but maximum 40ms. When *periodicityAndPattern* is not configured for a pair, for the pair spanning two slots, first slot corresponds to even slots, second slot corresponds to odd slots, and for the pair spanning one slot, the slot corresponds to every slot. The pair configured as dynamic by higher layer can be included in one or two groups of resource sets (higher layer parameters *rateMatchPatternGroup1*and *rateMatchPatternGroup2*). The *rateMatchPatternToAddModList* given by *ServingCellConfigCommon* configuration in numerology μ applies only to PDSCH of the same numerology μ.
    - within a BWP, a frequency domain resource of a CORESET with *controlResourceSetId*and time domain resource determined by the higher layer parameters *monitoringSlotPeriodicityAndOffset* and *monitoringSymbolsWithinSlot* of search-space-sets associated with the CORESET with a *controlResourceSetId*. This resource not available for PDSCH can be included in one or two groups of resource sets (higher layer parameters *rateMatchPatternGroup1* and *rateMatchPatternGroup2*).

- *rateMatchPatternToAddModList* given by *ServingCellConfigCommon* configuring up to 4 *RateMatchPattern(s)* which may contain:
  - within a serving cell, a pair of reserved resources in numerology μ configured by higher layer parameter *subcarrierSpacing* given by *RateMatchPattern* is indicated by an RB level bitmap (higher layer parameter *resourceBlocks*) with RB granularity and a symbol level bitmap spanning one or two slots (higher layer parameters *symbolsInResourceBlock*) 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 *periodicityAndPattern*) 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 *periodicityAndPattern* 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 *rateMatchPatternGroup1* and *rateMatchPatternGroup2*).

A configured group *rateMatchPatternGroup1* or *rateMatchPatternGroup2* contains a list of RB symbol level resource set indices forming a union of resource-sets not available for PDSCH dynamically if corresponding bit is equal to 1 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 either of the two groups are not available for PDSCH.

For a bitmap pair included in one or two groups of resource sets, the dynamic indication of availability for PDSCH applies to a set of slot(s) where the *rateMatchPatternToAddModList* given by *PDSCH-Config* and *rateMatchPatternToAddModList* given by *ServingCellConfigCommon* is present among the slots of scheduled PDSCH.

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 union of detected PDCCH that scheduled the PDSCH and associated PDCCH DM-RS 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-CRS-ToMatchAround* in *ServingCellConfigCommon* 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 *v-Shift* consisting of LTE-CRS-vshift(s), *nrofCRS-Ports* consisting of LTE-CRS antenna ports 1, 2 or 4 ports, *carrierFreqDL* representing the LTE carrier centre subcarrier location determined by offset from (reference) point A, *carrierBandwidthDL* representing the LTE carrier bandwidth, and may also configure *mbsfn-SubframeConfigList* 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-ResourceToAddModList* in *ZP-CSI-RS-ResourceSet*), with each ZP-CSI-RS resource set consisting of at most 16 ZP CSI-RS resources (higher layer parameter *ZP-CSI-RS-Resource*) in numerology of the BWP. The following parameters are configured via higher layer signaling for each ZP CSI-RS resource configuration:
  - *zp-CSI-RS-ResourceId* in *ZP-CSI-RS-Resource* determines ZP CSI-RS resource configuration identity.
  - *NrofPorts* defines the number of CSI-RS ports, 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].
  - *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]. If the configured bandwidth is larger than the corresponding BWP, UE shall assume that the actual CSI-RS bandwidth is equal to the BWP size.
  - *resourceMapping* given by *ZP-CSI-RS-Resource* 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].
  - *periodicityAndOffset* in *ZP-CSI-RS-Resource* defines the ZP-CSI-RS periodicity and slot offset for periodic/semi-persistent ZP-CSI-RS.
  - *resourceType* in *ZP-CSI-RS-ResourceSet* 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 *ZP-CSI-RS-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-ResourceSet(s)*, provided by higher layer parameter *aperiodic-ZP-CSI-RS-ResourceSetsToAddModList* in *PDSCH-Config* , is configured for aperiodic triggering. The maximum number of aperiodic *ZP-CSI-RS-ResourceSet(s)* configured per BWP is 3. The bit-length of DCI field *ZP CSI-RS trigger* depends on the number of aperiodic *ZP-CSI-RS-ResourceSet(s)*configured (up to 2 bits). Each non-zero codepoint of *ZP CSI-RS trigger* in DCI triggers one aperiodic *ZP-CSI-RS*-ResourceSet in the list *aperiodic-ZP-CSI-RS-ResourceSetsToAddModList* by indicating the aperiodic ZP CSI-RS resource set ID. The DCI codepoint '01' triggers the resource set with ZP-CSI-RS-ResourceSetIds = 1, the DCI codepoint '10' triggers the resource set with ZP-CSI-RS-ResourceSetIds = 2, and the DCI codepoint '11' triggers the resource set with ZP-CSI-RS-ResourceSetIds = 3. Codepoint '00' is reserved for not triggering aperiodic ZP CSI-RS.

For a UE configured with the higher layer parameter *resourceType* set to 'semiPersistent ', a list of *ZP-CSI-RS-ResourceSet(s)*, provided by higher layer parameter *sp-ZP-CSI-RS-ResourceSetsToAddModList*, is configured

- when the HARQ-ACK corresponding to the PDSCH carrying the activation command [10, TS 38.321] for ZP CSI-RS resource(s) transmitted 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 starting from slot n $+ 3N_{slot}^{subframe,\mu} + 1$.
- when the HARQ-ACK corresponding to the PDSCH carrying the 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 starting from slot n $+ 3N_{slot}^{subframe,\mu} + 1$.

5.1.5 Antenna ports quasi co-location

The UE can be configured with a list of up to *M TCI-State* configurations within the higher layer parameter *PDSCH-Config* 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 *TCI-State* contains parameters for configuring a quasi co-location relationship between one or two downlink reference signals and the DM-RS ports of the PDSCH. The quasi co-location relationship is configured by the higher layer parameter *qcl-Type1* for the first DL RS, and *qcl-Type2* for the second DL RS (if configured). 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 corresponding to each DL RS is given by the higher layer parameter *qcl-Type* in *QCL-Info* and may take one of the following values:

- 'QCL-TypeA': {Doppler shift, Doppler spread, average delay, delay spread}
- 'QCL-TypeB': {Doppler shift, Doppler spread}
- 'QCL-TypeC': {Doppler shift, average delay}
- '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'*. When the HARQ-ACK corresponding to the PDSCH carrying the activation command is transmitted in slot n, the indicated mapping between TCI states and codepoints of the DCI field *'Transmission Configuration Indication'* should be applied starting from slot $n + 3N_{slot}^{subframe,\mu}$+1. After a UE receives higher layer configuration of TCI states and before reception of the activation command, the UE may assume that the DM-RS ports of PDSCH of a serving cell are quasi co-located with the SS/PBCH block determined in the initial access procedure with respect to 'QCL-TypeA', and when applicable, also with respect to'QCL-TypeD'.

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 DCI format 1_1 of the PDCCH transmitted on the CORESET. If *tci-PresentInDCI* is not configured 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', when the PDSCH is scheduled by DCI format 1_1, the UE shall use the *TCI-State* 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 DM-RS ports of PDSCH of a serving cell are quasi co-located with the RS(s) in the TCI state 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 reported UE capability [12, TS 38.331].

For both the cases when *tci-PresentInDCI* is set to 'enabled' and *tci-PresentInDCI* is not configured, 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 DM-RS ports of PDSCH of a serving cell are quasi co-located with the RS(s) in the TCI state with respect to the QCL parameter(s) used for PDCCH quasi co-location indication of the lowest *CORESET-ID* in the latest slot in which one or more CORESETs within the active BWP of the serving cell are configured for the UE. If none of configured TCI states contains '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.

For a periodic CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info*, the UE shall expect that a TCI-State indicates one of the following quasi-colocation type(s):

- 'QCL-TypeC' with an SS/PBCH block and, when applicable, 'QCL-TypeD' with the same SS/PBCH block, or
- 'QCL-TypeC' with an SS/PBCH block and, when applicable,'QCL-TypeD' with a CSI-RS resource in an *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition*, or

For an aperiodic CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info,* the UE shall expect that a *TCI-State* indicates 'QCL-TypeA' with a periodic CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable,'QCL-TypeD' with the same periodic CSI-RS resource.

For a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured without higher layer parameter *trs-Info* and without the higher layer parameter *repetition*, the UE shall expect that a *TCI-State* indicates one of the following quasi co-location type(s):

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with an SS/PBCH block , or
- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition*, or
- 'QCL-TypeB' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* when 'QCL-TypeD' is not applicable.

For a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition,* the UE shall expect that a *TCI-State* indicates one of the following quasi co-location type(s):

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with the same CSI-RS resource, or
- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition*, or
- 'QCL-TypeC' with an SS/PBCH block and, when applicable, 'QCL-TypeD' with the same SS/PBCH block.

For the DM-RS of PDCCH, the UE shall expect that a *TCI-State* indicates one of the following quasi co-location type(s):

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with the same CSI-RS resource, or
- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with a CSI-RS resource in an *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition*, or

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured without higher layer parameter trs-Info and without higher layer parameter *repetition,* when 'QCL-TypeD' is not applicable.

For the DM-RS of PDSCH, the UE shall expect that a *TCI-State* indicates one of the following quasi co-location type(s):

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with the same CSI-RS resource, or

- 'QCL-TypeA' with a CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info* and, when applicable, 'QCL-TypeD' with a CSI-RS resource in an *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *repetition*,or

- QCL-TypeA' with CSI-RS resource in a *NZP-CSI-RS-ResourceSet* configured without higher layer parameter *trs-Info* and without *repetition* and, when applicable, 'QCL-TypeD' with the same CSI-RS resource.

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 configured with a CSI-RS resource and a search space set associated with a CORESET in the same OFDM symbol(s), the UE may assume that the CSI-RS and a PDCCH DM-RS transmitted in all the search space sets associated with 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 in the OFDM symbols occupied by the search space set(s).

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

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 *NZP-CSI-RS-ResourceSet* configured with higher layer parameter *trs-Info*.

For a *NZP-CSI-RS-ResourceSet* 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 *NZP-CSI-RS-ResourceSet* is the same. For frequency range 1, the UE may be configured with a *NZP-CSI-RS-ResourceSet* of four periodic NZP CSI-RS resources in two consecutive slots with two periodic NZP CSI-RS resources in each slot. For frequency range 2 the UE may be configured with a *NZP-CSI-RS-ResourceSet* of two periodic CSI-RS resources in one slot or with a *NZP-CSI-RS-ResourceSet* of four periodic NZP CSI-RS resources in two consecutive slots with two periodic NZP CSI-RS resources in each slot.

A UE configured with *NZP-CSI-RS-ResourceSet(s)* configured with higher layer parameter *trs-Info* may have the CSI-RS resources configured as:

- Periodic, with the CSI-RS resources in the *NZP-CSI-RS-ResourceSet* configured with same periodicity, bandwidth and subcarrier location
- Periodic CSI-RS resource in one set and aperiodic CSI-RS resources in a second set, with the aperiodic CSI-RS and periodic CSI-RS resource having the same bandwidth (with same RB location)and the aperiodic CSI-RS being 'QCL-Type-A' and 'QCL-TypeD', where applicable, with the periodic CSI-RS resources. The UE does not expect that the scheduling offset between the triggering DCI and the first symbol of the aperiodic CSI-RS resources is smaller than the UE reported *ThresholdSched-Offset*. The UE shall expect that the periodic CSI-RS resource set and aperiodic CSI-RS resource set are configured with the same number of CSI-RS resources. For the aperiodic CSI-RS resource set if triggered, and if the associated periodic CSI-RS resource set is configured with four periodic CSI-RS resources with two consecutive slots with two periodic CSI-RS resources in each slot, the higher layer parameter *aperiodicTriggeringOffset* indicates the triggering offset for the first slot for the first two CSI-RS resources in the set.

A UE does not expect to be configured with a *CSI-ReportConfig* that is linked to a *CSI-ResourceConfig* containing an *NZP-CSI-RS-ResourceSet* configured with *trs-Info* and with the *CSI-ReportConfig* configured with the higher layer parameter *timeRestrictionForChannelMeasurements* set to 'configured'.

A UE does not expect to be configured with a *CSI-ReportConfig* with the higher layer parameter *reportQuantity* set to other than 'none' for aperiodic NZP CSI-RS resource set configured with *trs-Info.*

A UE does not expect to be configured with a *CSI-ReportConfig* for periodic NZP CSI-RS resource set configured with *trs-Info*.

A UE does not expect to be configured with a *NZP-CSI-RS-ResourceSet* configured both with *trs-Info* and *repetition*.

Each CSI-RS resource, defined in Subclause 7.4.1.5.3 of [4, TS 38.211], is configured by the higher layer parameter *NZP-CSI-RS-Resource* 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 (which are the same across 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 from [4, TS 38.211] and higher layer parameter *density* configured by *CSI-RS-ResourceMapping*.
- the bandwidth of the CSI-RS resource, as given by the higher layer parameter *freqBand* configured by *CSI-RS-ResourceMapping*, 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 *periodicityAndOffset* configured by *NZP-CSI-RS-Resource*, 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 *powerControlOffset* and *powerControlOffsetSS* given by *NZP-CSI-RS-Resource* value across all resources.

5.1.6.1.2 CSI-RS for L1-RSRP computation

If a UE is configured with a *NZP-CSI-RS-ResourceSet* configured with the higher layer parameter *repetition* set to 'on', the UE may assume that the CSI-RS resources, described in Subclause 5.2.2.3.1, within the *NZP-CSI-RS-ResourceSet* are transmitted with the same downlink spatial domain transmission filter, where the CSI-RS resources in the *NZP-CSI-RS-ResourceSet* are transmitted in different OFDM symbols. The UE is not expected to receive different periodicity in *periodicityAndOffset* in every CSI-RS resource within the set. If *repetition* is set to 'off', the UE shall not assume that the CSI-RS resources within the *NZP-CSI-RS-ResourceSet* are transmitted with the same downlink spatial domain transmission filter.

If the UE is configured with a *CSI-ReportConfig* with *reportQuantity* set to "cri-RSRP", or "none" and if the *CSI-ResourceConfig* for channel measurement (higher layer parameter *resourcesForChannelMeasurement*) contains a *NZP-CSI-RS-ResourceSet* that is configured with the higher layer parameter *repetition* and without the higher layer parameter *trs-Info*, the UE can only be configured with the same number (1 or 2) of ports with the higher layer parameter *nrofPorts* for all CSI-RS resources within the set. If the UE is configured with the CSI-RS resource in the same OFDM symbol(s) as an SS/PBCH block, 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 REs that overlap with 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.

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 *cellId* 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 respect to ['QCL-TypeD'].

A UE configured with the higher layer parameters *CSI-RS-Resource-Mobility* may expect to be configured

- with no more than 96 CSI-RS resources when all CSI-RS resources per frequency layer have been configured with *associatedSSB*, or,
- with no more than 64 CSI-RS resources per frequency layer when all CSI-RS resources have been configured without *associatedSSB* or when only some of the CSI-RS resources have been configured with associatedSSB
  - For frequency range 1 the *associatedSSB* is optionally present for each CSI-RS resource

For frequency range 2 the *associatedSSB* is either present for all configured CSI-RS resources or not present for any configured CSI-RS resource~~s~~ per frequency layer.

5.1.6.2 DM-RS reception procedure

When receiving PDSCH scheduled by DCI format 1_0 or receiving PDSCH before dedicated higher layer configuration of any of the parameters *dmrs-AdditionalPosition*, *maxLength* 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*='pos2' 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 for normal CP or 6 symbols for extended CP 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 DCI format 1_1 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 *maxLength* given by *DMRS-DownlinkConfig*..
  - if *maxLength* is set to 'len1', 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 set to 'pos0', 'pos1', 'pos 2' or 'pos 3'.
  - if *maxLength* is set to '*len2*', 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 set to 'pos0' or 'pos1'.
  - 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].

For the UE-specific reference signals generation as defined in Subclause 7.4.1.1 of [4, TS 38.211], a UE can be configured by higher layers with one or two scrambling identity(s), $n_{ID}^{DMRS,i}$ i = 0,1 which are the same for both PDSCH mapping Type A and Type B.

For PDSCH carrying SIB1, 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 *PTRS-DownlinkConfig*, 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 *maxLength being set* equal to 'len2' 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].

When receiving PDSCH scheduled by DCI format 1_1, the UE shall assume that the CDM groups indicated in the configured index from Tables 7.3.1.2.2-1, 7.3.1.2.2-2, 7.3.1.2.2-3, 7.3.1.2.2-4 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 Tables 7.3.1.2.2-1, 7.3.1.2.2-2, 7.3.1.2.2-3, 7.3.1.2.2-4 of [5, TS. 38.212] correspond to CDM group 0, {0,1}, {0,1,2}, respectively.

When receiving PDSCH scheduled by DCI format 1_0, the UE shall assume the number of DM-RS CDM groups without data is 1 which corresponds to CDM group 0 for the case of PDSCH with allocation duration of 2 symbols, and the UE shall assume that the number of DM-RS CDM groups without data is 2 which corresponds to CDM group {0,1} for all other cases.

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 with 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 *phaseTrackingRS* in *DMRS-DownlinkConfig*,

- the higher layer parameters *timeDensity* and *frequencyDensity* in *PTRS-DownlinkConfig* indicate the threshold values $ptrs\text{-}MCS_i$, i=1,2,3 and $N_{RB,i}$, i=0,1, as shown in Table 5.1.6.3-1 and Table 5.1.6.3-2, respectively.
- 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* given by *PTRS-DownlinkConfig* is not configured, the UE shall assume $L_{PT\text{-}RS}$ = 1.
  - if the higher layer parameter *frequencyDensity* given by *PTRS-DownlinkConfig* is not configured, the UE shall assume $K_{PT\text{-}RS}$ = 2.
- otherwise, if neither 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 is present with $L_{PT\text{-}RS}$ = 1, $K_{PT\text{-}RS}$ = 2, and
- The UE shall assume 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

- otherwise, if the RNTI equals RA-RNTI, SI-RNTI, or P-RNTI, the UE shall assume PT-RS is not present

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 not configured with the higher layer parameter *phaseTrackingRS* in *DMRS-DownlinkConfig*, 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 *frequencyDensity* in *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-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 $N_{RBi} = N_{RBi+1}$, 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-RS}) and PT-RS frequency density (K_{PT-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 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.

The DL DM-RS port(s) 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* for PDSCH, the UE shall determine the number of CBGs for atransport block reception 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 transport block 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*, $m = 0,1,\ldots,M_1 - 1$, 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 $M_1 \cdot K_1 + (m - M_1) \cdot K_2 + k, k = 0,1,\ldots,K_2 - 1$.

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* for PDSCH,

- The CBG transmission information (CBGTI) field of DCI format 1_1 is of length $N_{TB} \cdot N_{HARQ-ACK}^{CBG/TB,max}$ bits, where N_{TB} is the value of the higher layer parameter *maxNrofCodeWordsScheduledByDCI*. If $N_{TB} = 2$ the CBGTI field bits are mapped such that the first set of $N_{HARQ-ACK}^{CBG/TB,max}$ bits starting from the MSB corresponds to the first TB while the second set of $N_{HARQ-ACK}^{CBG/TB,max}$ bits corresponds to a second TB, if scheduled. The first *M* bits of each set of $N_{HARQ-ACK}^{CBG/TB,max}$ bits in the CBGTI field have an in-order one-to-one mapping with the *M* CBGs of the TB, with the MSB mapped to CBG #0.
- 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.
  - If the CBG flushing out information *(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.
  - A CBG contains the same CBs as in the initial transmission of the TB.

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), SS/PBCH Block Resource indicator (SSBRI), layer indicator (LI), rank indicator (RI) and/or L1-RSRP.

For CQI, PMI, CRI, SSBRI, 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 one or two list(s) of trigger states (given by the higher layer parameters *aperiodicTriggerStateList* and *semiPersistentOnPUSCH-TriggerStateList*). Each trigger state in *aperiodicTriggerStateList* contains a list of associated *CSI-ReportConfigs* indicating the Resource Set IDs for channel and optionally for interference. Each trigger state in *semiPersistentOnPUSCH-TriggerStateList* contains one associated *CSI-ReportConfig*.

5.2.1.1 Reporting settings

Each Reporting Setting *CSI-ReportConfig* is associated with a single downlink BWP (indicated by higher layer parameter *bwp-Id*) given in the associated *CSI-ResourceConfig* for channel measurement and contains the parameter(s) for one CSI reporting band:codebook configuration including codebook subset restriction, time-domain behavior, frequency granularity for CQI and PMI, measurement restriction configurations, and the CSI-related quantities to be reported by the UE such as the layer indicator (LI), L1-RSRP, CRI, and SSBRI (SSB Resource Indicator).

The time domain behavior of the *CSI-ReportConfig* is indicated by the higher layer parameter *reportConfigType* and can be set to 'aperiodic', 'semiPersistentOnPUCCH', 'semiPersistentOnPUSCH', or 'periodic'. For periodic and semiPersistentOnPUCCH/semiPersistentOnPUSCH 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 *timeRestrictionForChannelMeasurements* parameter in *CSI-ReportConfig* can be configured to enable time domain restriction for channel measurements and *timeRestrictionForInterferenceMeasurements* can be configured to enable 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 (given by higher layer parameter *csi-RS-ResourceSetList*), 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 *resourceType* 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.* When a UE is configured with multiple *CSI-ResourceConfigs* consisting the same NZP CSI-RS resource ID, the same time domain behavior shall be configured for the *CSI-ResourceConfigs*. When a UE is configured with multiple *CSI-ResourceConfigs* consisting the same CSI-IM resource ID, the same time-domain behavior shall be configured for the *CSI-ResourceConfigs*.

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 higher layer parameter *NZP-CSI-RS-ResourceSet* and when the higher layer parameter *repetition* 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 *repetition* 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 *reportSlotOffsetList*. 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 bandwidth part according to Table 5.2.1.4-2.

Table 5.2.1.4-2: Configurable subband sizes

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

- *reportQuantity* is set to 'cri-RI-PMI-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' or 'cri-RI-i1-CQI' and *cqi-FormatIndicator* indicates single CQI reporting, or
- *reportQuantity* is set to 'cri-RSRP' or 'ssb-Index-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-BundleSizeForCSI*

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 *CSI-AperiodicTriggerState* is associated with 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 (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement for L1-RSRP computation.

- When two Resource Settings are configured, the first one Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement and the second one (given by either higher layer parameter *csi-IM-ResourcesForInterference* or higher layer parameter *nzp-CSI-RS-ResourcesForInterference*) is for interference measurement performed on CSI-IM or on NZP CSI-RS.
- When three Resource Settings are configured, the first Resource Setting (higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement, the second one (given by higher layer parameter *csi-IM-ResourcesForInterference*) is for CSI-IM based interference measurement and the third one (given by higher layer parameter *nzp-CSI-RS-ResourcesForInterference*) 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 (given by higher layer parameter *resourcesForChannelMeasurement*) is configured, the Resource Setting is for channel measurement for L1-RSRP computation.
- When two Resource Settings are configured, the first Resource Setting (given by higher layer parameter *resourcesForChannelMeasurement*) is for channel measurement and the second Resource Setting (given by higher layer parameter *csi-IM-ResourcesForInterference*) 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. The UE configured with the higher layer parameter *nzp-CSI-RS-ResourcesForInterference* may expect no more than 18 NZP CSI-RS ports configured in a NZP CSI-RS resource set.

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-RSRP', 'cri-RI-PMI-CQI ', 'cri-RI-i1', 'cri-RI-i1-CQI', 'cri-RI-CQI' or 'cri-RI-LI-PMI-CQI', and $K_s > 1$ 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, where CRI *k* (*k* ≥ 0) corresponds to the configured (*k*+1)-th entry of associated *nzp-CSI-RSResource* in the corresponding *nzp-CSI-RS-ResourceSet* for channel measurement, and (*k*+1)-th entry of associated *csi-IM-Resource* in the corresponding *csi-IM-ResourceSet* (if configured) If $K_s = 2$ CSI-RS resources are configured, each resource shall contain at most 16 CSI-RS ports. If $2 < K_s \leq 8$ CSI-RS resources are configured, each resource shall contain at most 8 CSI-RS ports.

If the UE is configured with a *CSI-ReportConfig* with the higher layer parameter *reportQuantity* set to 'cri-RSRP' or 'ssb-Index-RSRP'

- if the UE is configured with the higher layer parameter *groupBasedBeamReporting* set to 'disabled', 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 *groupBasedBeamReporting* set to 'enabled', 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 'none' and the *CSI-ReportConfig* is linked to a resource setting configured with the higher layer parameter *resourceType* 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-PMI-CQI', or 'cri-RI-LI-PMI-CQI', the UE shall report a preferred precoder matrix for the entire reporting band, or a preferred precoder matrix per subband, according to Subclause 5.2.2.2.

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-ResourceId* in the linked CSI resource setting for channel measurement given by higher layer parameter *resourcesForChannelMeasurement*. The higher layer parameter *non-PMI-PortIndication* contains a sequence $p_0^{(1)}, p_0^{(2)}, p_1^{(2)}, p_0^{(3)}, p_1^{(3)}, p_2^{(3)}, \ldots, p_0^{(R)}, p_1^{(R)}, \ldots, p_{R-1}^{(R)}$ of port indices, where $p_0^{(\nu)}, \ldots, p_{\nu-1}^{(\nu)}$ are the CSI-RS port indices associated with rank ν and $R \in \{1,2,\ldots,\min(8,P)\}$ 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 'none', 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.*

The LI indicates which column of the precoder matrix of the reported PMI corresponds to the strongest layer of the codeword corresponding to the largest reported wideband CQI. If two wideband CQIs are reported and have equal value, the LI corresponds to strongest layer of the first codeword.

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 resources, when resource-wise quasi co-located with 'QCL-Type A' and 'QCL-TypeD'.

- 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* in *CSI-ReportConfig* 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 *groupBasedBeamReporting* is configured as 'enabled', the UE shall use differential L1-RSRP based reporting, where the largest measured value of L1-RSRP is quantized to a 7-bit value in the range [-140, -44] dBm with 1dB step size, and the differential L1-RSRP is quantized to a 4-bit value. The differential L1-RSRP value is computed with 2 dB step size with a reference to the largest measured 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 *resourceType* set to 'aperiodic', periodic', or semi-persistent', trigger states for Reporting Setting(s) (configured with the higher layer parameter *reportConfigType* set to 'aperiodic') and/or Resource Setting for channel and/or interference measurement on one or more component carriers are configured using the higher layer parameter *CSI-AperiodicTriggerStateList*. 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 *CSI-AperiodicTriggerStateList* 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 HARQ/ACK corresponding to the PDSCH carrying the selection command is transmitted in the slot *n*, the corresponding action in [10, TS 38.321] and UE assumption on the mapping of the selected CSI trigger state(s) to the codepoint(s) of DCI CSI request field shall be applied starting from slot $n+3N_{slot}^{subframe,\mu}+1$.

- When the number of CSI triggering states in *CSI-AperiodicTriggerStateList* is less than or equal to $2^{N_{\mathrm{TS}}}-1$, 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 in a CSI-RS resource set 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* which contains a list of references to *TCI-State's* for the aperiodic CSI-RS resources associated with the CSI triggering state. If a *State* referred to 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.

- A non-zero codepoint of the CSI request field in the DCI is mapped to a CSI triggering state according to the order of the CSI triggering state ID in the up to $2^{N_{TS}} - 1$ trigger states with codepoint '1' mapped to the triggering state having the smallest triggering state ID

For a UE configured with the higher layer parameter *CSI-AperiodicTriggerStateList*, if a Resource Setting linked to a *CSI-ReportConfig* has multiple aperiodic resource sets, only one of the aperiodic CSI-RS resource sets from the Resource Setting is associated with the trigger state, and the UE is higher layer configured per trigger state per Resource Setting to select the one CSI-IM/NZP CSI-RS resource set 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 *aperiodicTriggeringOffset*. The CSI-RS triggering offset has the range of 0 to 4 slots. If all the associated trigger states do not have the higher layer parameter *qcl-Type* set to 'QCL-TypeD' in the corresponding TCI states, the CSI-RS triggering offset is fixed to zero. The aperiodic triggering offset of the CSI-IM follows offset of the associated NZP CSI-RS for channel measurement.

The UE does not expect that aperiodic CSI-RS is transmitted before the OFDM symbol(s) carrying its triggering DCI.

If interference measurement is performed on aperiodic NZP CSI-RS, a UE is not expected to be configured with a different aperiodic triggering offset of the NZP CSI-RS for interference measurement from the associated NZP CSI-RS for channel measurement.

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 *CSI-SemiPersistentOnPUSCH-TriggerStateList,* the CSI request field in DCI scrambled with SP-CSI-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. When the HARQ-ACK corresponding to the PDSCH carrying the activation command is transmitted in slot n, the indicated semi-persistent Reporting Setting should be applied starting from slot $n + 3N_{slot}^{subframe,\mu}$+1. 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 *reportConfigType* set to 'semiPersistentOnPUCCH' .

- 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), and when the HARQ-ACK corresponding to the PDSCH carrying the selection command is transmitted in slot n, the corresponding actions in [10, TS 38.321] and the UE assumptions (including QCL assumptions provided by a list of reference to *TCI-State'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 starting from slot $n + 3N_{slot}^{subframe,\mu} + 1$. If a *TCI-State* referred to 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), and when the HARQ-ACK corresponding to the PDSCH carrying the selection command is transmitted 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 starting from slot $n + 3N_{slot}^{subframe,\mu} + 1$. If a *TCI-State* referred to 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.

A UE validates, for semi-persistent CSI activation or release, a DL semi-persistent assignment PDCCH on a DCI only if the following conditions are met:

- the CRC parity bits of the DCI format are scrambled with a SP-CSI-RNTI provided by higher layer parameter *sp-csi-RNTI*

All fields for the DCI format are set according to Table 5.2.1.5.2-1 or Table 5.2.1.5.2-2.

If validation is achieved, the UE considers the information in the DCI format as a valid activation or valid release of semi-persistent CSI transmission. If validation is not achieved, the UE considers the DCI format as having been detected with a non-matching CRC.

Table 5.2.1.5.2-1: Special fields for semi-persistent CSI activation PDCCH validation

	DCI format 0_1
HARQ process number	set to all '0's
Redundancy version	set to '00'

Table 5.2.1.5.2-2: Special fields for semi-persistent CSI deactivation PDCCH validation

	DCI format 0_1
HARQ process number	set to all '0's
Modulation and coding scheme	set to all '1's
Resource block assignment	If higher layer configures RA type 0 only, set to all '0's; If higher layer configures RA type 1 only, set to all '1's; If higher layer configures dynamic switch between RA type 0 and 1, then if MSB is'0', set to all '0's; else, set to all '1's
Redundancy version	set to '00'

If the UE has an active semi-persistent CSI-RS/CSI-IM resource configuration, or an active semi-persistent ZP CSI-RS resource set configuration, and has not received a deactivation command, the semi-persistent CSI-RS/CSI-IM resource configuration or the semi-persistent ZP CSI-RS resource set configurations are considered to be active in the DL BWP which is active when the resource sets are activated, otherwise they are considered suspended.

If the UE is configured with carrier deactivation, the following resources configured in the carrier in activated state would also be deactivated and need re-activation configuration(s): semi-persistent CSI-RS/CSI-RS resource, semi-persistent CSI reporting on PUCCH, semi-persistent SRS, semi-persistent ZP CSI-RS resource set.

5.2.1.6 CSI processing criteria

The UE indicates the number of supported simultaneous CSI calculations N_{CPU}. If a UE supports N_{CPU} simultaneous CSI calculations it is said to have N_{CPU} CSI processing units for processing CSI reports across all configured cells. If L CPUs are occupied for calculation of CSI reports in a given OFDM symbol, the UE has $N_{CPU}-L$ unoccupied CPUs. If a UE receives an aperiodic CSI request for N CSI reports, where each CSI report $n=0,\dots,N-1$ has $K_s^{(n)}$CSI-RS resources in the CSI-RS resource set for channel measurement, the UE is not required to update the $N-M$ requested CSI reports with lowest priority (according to Subclause 5.2.5), where $0\le M\le N$ is the largest value such that $\sum_{n=0}^{M}K_s^{(n)}\le N_{CPU}-L$ holds.

The UE is not required to update a periodic or semi-persistent CSI report if $N_{CPU}-L\le K_s$ on the earliest one of the first symbol of the latest CSI-RS/CSI-RS resource earlier than the corresponding CSI reference resource of the CSI report.

Processing of a CSI report occupies a number of CPUs for a number of symbols as follows:

- A CSI report with *CSI-ReportConfig* with higher layer parameter *reportQuantity* set to 'cri-RSRP' or 'none' occupies one CPU.
- A CSI report with *CSI-ReportConfig* with higher layer parameter *reportQuantity* set to 'cri-RSRP' or 'none' occupies K_s CPUs, where K_s is the number of CSI-RS resources in the CSI-.RS resource set for channel measurement.
- A CSI report aperiodically triggered without transmitting a PUSCH with either transport block or HARQ-ACK or both when L = 0 CPUs are occupied, where the CSI corresponds to wideband frequency-granularity and to at most 4 CSI-RS ports in a single resource without CRI report and where *codebookType* is set to 'TypeI-SinglePanel' or where *reportQuantity* is set to 'cri-RI-CQI', occupies N_{CPU} CPUs.

The CPU(s) are occupied for a number of OFDM symbols as follows:

- A periodic or semi-persistent CSI report occupies CPU(s) from the first symbol of the earliest one of the for each CSI-RS/CSI-IM resource for channel or interference measurement, respective latest CSI-RS/CSI-IM occasion no later than the corresponding CSI reference resource until the last symbol of the PUSCH/PUCCH carrying the report.
- An aperiodic CSI report used with periodic or semi-persistent CSI-RS occupies CPU(s) from the first symbol of the earliest one of each CSI-RS/CSI-IM resource for channel or interference measurement respective latest CSI-RS/CSI-IM occasions no later than the corresponding CSI reference resource until the last symbol of the PUSCH carrying the report.
- An aperiodic CSI report used with aperiodic CSI-RS occupies a CPU from the first symbol after the PDCCH triggering the CSI report until the last symbol of the PUSCH carrying the report.

In any slot, the UE is not expected to have more active CSI-RS ports or active CSI-RS resources than reported as capability. NZP CSI-RS resource is active in a duration of time defined as follows. For aperiodic CSI-RS, starting from the end of the PDCCH containing the request and ending at the end of the PUSCH containing the report associated with this aperiodic CSI-RS. For semi-persistent CSI-RS, starting from the end of when the activation command is applied, and ending at the end of when the deactivation command is applied. For periodic CSI-RS, starting when the periodic CSI-RS is configured by higher layer signalling, and ending when the periodic CSI-RS configuration is released.

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 or Table 5.2.2.1-4 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* in *CSI-ReportConfig* configures 'table1' (corresponding to Table 5.2.2.1-2), or 'table2' (corresponding to Table 5.2.2.1-3), or
  - 0.00001, if the higher layer parameter *cqi-Table* in *CSI-ReportConfig* configures 'table3' (corresponding to Table 5.2.2.1-4).

If a UE is not configured with higher layer parameter *timeRestrictionForChannelMeasurements*, the UE shall derive the channel measurements for computing CSI 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 *timeRestrictionForChannelMeasurements* in *CSI-ReportConfig*, 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 *timeRestrictionForInterferenceMeasurements*, the UE shall derive the interference measurements for computing CSI 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 *timeRestrictionForInterferenceMeasurements* in *CSI-ReportConfig*, the UE shall derive the interference measurements for computing the CSI 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*) = sub-band CQI index (*s*) - wideband CQI index.

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 5.2.2.1-4: 4-bit CQI Table 3

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	30	0.0586
2	QPSK	50	0.0977
3	QPSK	78	0.1523
4	QPSK	120	0.2344
5	QPSK	193	0.3770
6	QPSK	308	0.6016
7	QPSK	449	0.8770
8	QPSK	602	1.1758
9	16QAM	378	1.4766
10	16QAM	490	1.9141
11	16QAM	616	2.4063
12	64QAM	466	2.7305
13	64QAM	567	3.3223
14	64QAM	666	3.9023
15	64QAM	772	4.5234

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
    - if a single CSI-RS resource is configured for channel measurement n_{CQI_ref} is the smallest value greater than or equal to $4 \cdot 2^{\min(\mu_{DL},\mu_{UL})}$, such that it corresponds to a valid downlink slot, or
    - if multiple CSI-RS resources are configured for channel measurement n_{CQI_ref} is the smallest value greater than or equal to $5 \cdot 2^{\min(\mu_{DL},\mu_{UL})}$, 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 comprises at least one higher layer configured downlink or flexible symbol, 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 in DRS Active Time 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 *maxLength* in *DMRS-DownlinkConfig.*
- Assume the same number of additional DM-RS symbols as the additional symbols configured by the higher layer parameter *dmrs-AdditionalPosition*.
- 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,…, 1000+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. If the higher layer parameter *reportQuantity* in *CSI-ReportConfig* for which the CQI is reported is set to either 'cri-RI-PMI-CQI' or 'cri-RI-LI-PMI-CQI', *W(i)* is the precoding matrix corresponding to the reported PMI applicable to *x(i)*. If the higher layer parameter *reportQuantity* in *CSI-ReportConfig* for which the CQI is reported is set to 'cri-RI-CQI', *W(i)* is the precoding matrix corresponding to the procedure described in Subclause 5.2.1.4.2. If the higher layer parameter *reportQuantity* in *CSI-ReportConfig* for which the CQI is reported is set to 'cri-RI-i1-CQI', *W(i)* is the precoding matrix corresponding to the reported i1 according to the procedure described in Subclause 5.2.1.4.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 *twoTX-CodebookSubsetRestriction*. The bitmap parameter *twoTX-CodebookSubsetRestriction* forms the bit sequence $a_5,\ldots,a_1,a_0$ 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 parameter *n1-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 N_2 is 1.

The bitmap parameter *n1-n2* 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 $A_c = N_1O_1N_2O_2$. 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 $r_7,...,r_1,r_0$ 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**
$0,1,...,\frac{N_1O_1}{2}-1$	$0,1,...,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1},2i_{1,2},0}$	$W^{(1)}_{2i_{1,1},2i_{1,2},1}$	$W^{(1)}_{2i_{1,1},2i_{1,2},2}$	$W^{(1)}_{2i_{1,1},2i_{1,2},3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	**5**	**6**	**7**
$0,1,...,\frac{N_1O_1}{2}-1$	$0,1,...,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},0}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},1}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},2}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2},3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	**9**	**10**	**11**
$0,1,...,\frac{N_1O_1}{2}-1$	$0,1,...,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,0}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,1}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,2}$	$W^{(1)}_{2i_{1,1},2i_{1,2}+1,3}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	**13**	**14**	**15**
$0,1,...,\frac{N_1O_1}{2}-1$	$0,1,...,\frac{N_2O_2}{2}-1$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,0}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,1}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,2}$	$W^{(1)}_{2i_{1,1}+1,2i_{1,2}+1,3}$
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**
$0,1,...,\frac{N_1O_1}{2}-1$	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**
$0,1,...,\frac{N_1O_1}{2}-1$	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**
$0,1,...,\frac{N_1O_1}{2}-1$	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**
$0,1,...,\frac{N_1O_1}{2}-1$	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	
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,2},i_{1,3},i_2}$
where $W^{(3)}_{l,m,p,n} = \frac{1}{\sqrt{3P_{\text{CSI-RS}}}}\begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} & \theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} & -\varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}$.				

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	
$0,\ldots,N_1O_1-1$	$0,1,\ldots,N_2O_2-1$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_2}$
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	
$0,\ldots,\frac{N_1O_1}{2}-1$	$0,\ldots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,2},i_{1,3},i_2}$
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	
$N_2 > 1$	$0,\ldots,N_1O_1-1$	$0,\ldots,N_2O_2-1$	$0,1$	$W^{(5)}_{i_{1,1},i_{1,1}+O_1,i_{1,1}+O_1,i_{1,2},i_{1,2},i_{1,2}+O_2,i_2}$
$N_1 > 2, N_2 = 1$	$0,\ldots,N_1O_1-1$	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 *ng-n1-n2*. 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 $2N_gN_1N_2$.
- When $N_g=2$, *codebookMode* shall be set to either '1' or '2'. When $N_g=4$, *codebookMode* shall be set to '1'.

The bitmap parameter *ng-n1-n2* 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 $A_c=N_1O_1N_2O_2$. Bit $a_{N_2O_2l+m}$ is associated with all precoders based on the quantity $v_{l,m}$, $l=0,\ldots,N_1O_1-1$, $m=0,\ldots,N_2O_2-1$, as defined below. The bitmap parameter *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 N_2 is 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 $W^{1,N_g,1}_{l,m,p,n}$ and $W^{2,N_g,1}_{l,m,p,n}$ ($N_g \in \{2,4\}$) are given by

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

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

where

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

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

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

where

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

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

***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_{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_{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_{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 parameter *n1-n2-codebookSubsetRestriction*. 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 'true' or 'false'.
- The UE shall not report RI > 2.

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

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

$$i_2 = \begin{cases} \begin{bmatrix} i_{2,1,1} \end{bmatrix} & \mathit{subbandAmplitude} = \text{'false'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,1,2} \end{bmatrix} & \mathit{subbandAmplitude} = \text{'false'},\ \upsilon = 2 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} \end{bmatrix} & \mathit{subbandAmplitude} = \text{'true'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} & i_{2,1,2} & i_{2,2,2} \end{bmatrix} & \mathit{subbandAmplitude} = \text{'true'},\ \upsilon = 2 \end{cases}..$$

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

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

$$i_{1,2} \in \left\{0,1,\ldots,\binom{N_1N_2}{L}-1\right\}.$$

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

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

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
$i_{1,2} - s_{i-1} \geq C\left(x^*, L-i\right)$
$e_i = C\left(x^*, L-i\right)$
$s_i = s_{i-1} + e_i$
$n^{(i)} = N_1N_2 - 1 - x^*$
$n_1^{(i)} = n^{(i)} \bmod N_1$
$n_2^{(i)} = \dfrac{\left(n^{(i)} - n_1^{(i)}\right)}{N_1}$

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

$n^{(i)} = N_1 n_2^{(i)} + n_1^{(i)}$ 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 'false',
    - $k_{l,i}^{(2)} = 1$ 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 'true',
  - 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 'true'

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

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

$$u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}.$$

$$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \cdots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$$

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

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 $W^{l}_{q_1,q_2,n_1,n_2,p_l^{(1)},p_l^{(2)},c_l} = \frac{1}{\sqrt{N_1 N_2 \sum_{i=0}^{2L-1}\left(p_{l,i}^{(1)} p_{l,i}^{(2)}\right)^2}} \begin{bmatrix} \sum_{i=0}^{L-1} v_{m_1^{(i)},m_2^{(i)}} p_{l,i}^{(1)} p_{l,i}^{(2)} \varphi_{l,i} \\ \sum_{i=0}^{L-1} v_{m_1^{(i)},m_2^{(i)}} p_{l,i+L}^{(1)} p_{l,i+L}^{(2)} \varphi_{l,i+L} \end{bmatrix}$, $l = 1,2$, 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', thebitmap 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 *n1-n2-codebookSubsetRestriction* forms the bit sequence $B = B_1 B_2$ where bit sequences B_1, and B_2 are concatenated to form B. To define B_1 and B_2, first define the $O_1 O_2$ vector groups $G(r_1, r_2)$ as

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

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 $\beta_1 - s_{k-1} \geq C\left(x^*, 4-k\right)$
$e_k = C\left(x^*, 4-k\right)$
$s_k = s_{k-1} + e_k$
$g^{(k)} = O_1 O_2 - 1 - x^*$
$r_1^{(k)} = g^{(k)} \bmod O_1$
$r_2^{(k)} = \frac{\left(g^{(k)} - r_1^{(k)}\right)}{O_1}$

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 'true' or 'false'.
- The UE shall not report RI > 2.

The UE is also configured with the higher layer parameter *typeII-PortSelectionRI-Restriction*. The bitmap parameter *typeII-PortSelectionRI-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

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

$$i_2 = \begin{cases} \begin{bmatrix} i_{2,1,1} \end{bmatrix} & subbandAmplitude = \text{'false'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,1,2} \end{bmatrix} & subbandAmplitude = \text{'false'},\ \upsilon = 2 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} \end{bmatrix} & subbandAmplitude = \text{'true'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} & i_{2,1,2} & i_{2,2,2} \end{bmatrix} & subbandAmplitude = \text{'true'},\ \upsilon = 2 \end{cases}.$$

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 'false',
  - $k_{l,i}^{(2)}=1$ 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 'true',
  - 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

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

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$_{CSI-RS}$

<table>
<tr><th>Layers</th><th></th></tr>
<tr><td>$\upsilon = 1$</td><td>$W^{(1)}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}} = W^{1}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}}$</td></tr>
<tr><td>$\upsilon = 2$</td><td>$W^{(2)}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}} = \frac{1}{\sqrt{2}}\begin{bmatrix} W^{1}_{i_{1,1},p_1^{(1)},p_1^{(2)},i_{2,1,1}} & W^{2}_{i_{1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}} \end{bmatrix}$</td></tr>
<tr><td colspan="2">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.</td></tr>
</table>

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 parameters *CSI-ResourceConfig,* and *NZP-CSI-RS-ResourceSet.* 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 the higher layer parameter *NZP-CSI-RS-Resource* for each CSI-RS resource configuration:

- *nzp-CSI-RS-ResourceId* determines CSI-RS resource configuration identity.

- *periodicityAndOffset* defines the CSI-RS periodicity and slot offset for periodic/semi-persistent CSI-RS. All the CSI-RS resources within one set are configured with the same periodicity, while the slot offset can be same or different for different CSI-RS resources.

- *CSI-RS-resourceMapping* defines the number of ports, CDM-type, and 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].

- *nrofPorts* in *CSI-RS-ResourceMapping* defines the number of CSI-RS ports, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211].

- *density* in *CSI-RS-ResourceMapping* defines CSI-RS frequency density of each CSI-RS port per PRB, and CSI-RS PRB offset in case of the density value of 1/2, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211]. For density 1/2, the odd/even PRB allocation indicated in *density* is with respect to the common resource block grid.

- *cdm-Type* in *CSI-RS-ResourceMapping* defines CDM values and pattern, where the allowable values are given in Subclause 7.4.1.5 of [4, TS 38.211].
- *powerControlOffset*: 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.
- *powerControlOffsetSS*: 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.
- *bwp-Id* in *CSI-ResourceConfig* defines which bandwidth part the configured CSI-RS is located in.
- *repetition* in *NZP-CSI-RS-ResourceSet* is associated with a CSI-RS resource set and 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 'none'.
- *qcl-InfoPeriodicCSI-RS* contains a reference to a *TCI-State* indicating QCL source RS(s). If the *TCI-State* 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.
- *trs-Info* in *NZP-CSI-RS-ResourceSet* is associated with a CSI-RS resource set and for which the UE can assume that the antenna port with the same port index of the configured NZP CSI-RS resources in the *NZP-CSI-RS-ResourceSet* is the same as described in Subclause 5.1.6.1.1 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 unconfigured or set to 'none'.

All CSI-RS resources within one set are configured with same *bwp-Id*, same *density* and same *nrofPorts*, except for the NZP CSI-RS resources used for interference measurement.

The bandwidth and initial CRB index of a CSI-RS resource within a BWP, as defined in Subclause 7.4.1.5 of [4, TS 38.211], are determined based on the higher layer parameters *nrofRBs* and *startingRB*, respectively, within the CSI-FrequencyOccupation IE configured by the higher layer parameter *freqBand* within the *CSI-RS-ResourceMapping* IE. Both *nrofRBs* and *startingRB* are configured as integer multiples of 4 RBs, and the reference point for *startingRB* is CRB 0 on the common resource block grid. If $startingRB < N_{BWP}^{start}$, the UE shall assume that the initial CRB index of the CSI-RS resource is $N_{initial\ RB} = N_{BWP}^{start}$, otherwise $N_{initial\ RB} = startingRB$. If $nrofRBs > N_{BWP}^{size} + N_{BWP}^{start} - N_{initial\ RB}$, the UE shall assume that the bandwidth of the CSI-RS resource is $N_{CSI-RS}^{BW} =$

$N_{BWP}^{size} + N_{BWP}^{start} - N_{initial\ RB}$, otherwise $N_{CSI-RS}^{BW} = nrofRBs$. In all cases, the UE shall expect that $N_{CSI-RS}^{BW} \geq \min(24, N_{BWP}^{size})$.

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-ResourceSet*. Each CSI-IM resource set consists of K≥1 CSI-IM resource(s).

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

- *csi-IM-ResourceId* determines CSI-IM resource configuration identity
- *subcarrierLocation-p0* or *subcarrierLocation-p1* defines subcarrier occupancy of the CSI-IM resource within a slot for *csi-IM-ResourceElementPattern* set to 'pattern0' or 'pattern1', respectively.
- *symbolLocation-p0* or *subcarrierLocation-p1* defines OFDM symbol location of the CSI-IM resource within a slot for *csi-IM-ResourceElementPattern* set to 'pattern0' or 'pattern1', respectively.
- *periodicityAndOffset* defines the CSI-IM periodicity and slot offset for periodic/semi-persistent CSI-IM.
- f*reqBand* includes parameters to enable configuration of frequency-occupancy of CSI-IM

In each of the PRBs configured by f*reqBand,* 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-ResourceElementPattern* 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-ResourceElementPattern* is set to 'pattern1',

where k_{CSI-IM} and l_{CSI-IM} are the configured frequency-domain location and time-domain location, respectively, given by the higher layer parameters in the above list.

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 'ssb-Index-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 $2N_{\mathrm{Rep}}$ is the lowest priority and the CSI report numbers correspond to the order of the associated $\mathrm{Pri}_{i,\mathrm{CSI}}(y,k,c,s)$ value as defined in Subclause 5.2.5. 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

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

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

If the UE is in an active semi-persistent CSI reporting configuration on PUSCH, the CSI reporting is suspended when either the downlink BWP or the uplink BWP is changed. A re-activation command is required to enables the semi-persistent CSI reporting.

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 applied starting from slot $n + 3N_{slot}^{subframe,\mu} + 1$ after the HARQ-ACK corresponding to the PDSCH carrying the selection command [10, TS 38.321] is transmitted in slot *n*. 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.

If the UE is in an active semi-persistent CSI reporting configuration on PUCCH, and has not received a deactivation command, the CSI reporting takes place when the BWP in which the reporting is configured to take place is the active BWP, otherwise the CSI reporting is suspended.

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 $\mathrm{Pri}_{iCSI}(y,k,c,s) = 2 \cdot N_{cells} \cdot M_s \cdot y + N_{cells} \cdot M_s \cdot k + M_s \cdot c + s$ 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 PUCCH;
- $k = 0$ for CSI reports carrying L1-RSRP and $k = 1$ for CSI reports not carrying L1-RSRP;
- c is the serving cell index and N_{cells} is the value of the higher layer parameter *maxNrofServingCells*;
- s is the *reportConfigID* and M_s is the value of the higher layer parameter *maxNrofCSI-ReportConfigurations.*

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, when the starting symbols between the two channels are aligned, the CSI report shall not be transmitted by the UE.

5.3 UE PDSCH processing procedure time

If the first uplink symbol of the physical channel which carries the HARQ-ACK information, as defined by the assigned HARQ-ACK timing K_1 and the PUSCH or 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 $T_{proc,1} = \left((N_1 + d_{1,1} + d_{1,2})(2048+144)\cdot \kappa 2^{-\mu}\right)\cdot T_C$ 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 and table 5.3-2 for UE processing capability 1 and 2 respectively, where μ corresponds to the one of (μ_{PDCCH}, μ_{PDSCH}, μ_{UL}) resulting with the largest $T_{proc,1}$, where the μ_{PDCCH} corresponds to the subcarrier spacing of the PDCCH scheduling the PDSCH, the μ_{PDSCH} corresponds to the subcarrier spacing of the scheduled PDSCH, and μ_{UL} corresponds to the subcarrier spacing of the uplink channel with which the HARQ-ACK is to be transmitted, and κ is defined in subclause 4.41 of [4, TS 38.211].

- 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 first uplink symbol which carries the HARQ-ACK information further includes the effect of timing difference between the component carriers as given in [11, TS 38.133].
- 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 $d_{1,2} = 7 - i$,
- For UE processing capability 1: If the PDSCH is mapping type B as given in subclause 7.4.1.1 of [4, TS 38.211], and
  - if the number of PDSCH symbols allocated is 4, then $d_{1,2} = 3$
  - if the number of PDSCH symbols allocated is 2, then$d_{1,2} = 3+d$, where d is the number of overlapping symbols of the scheduling PDCCH and the scheduled PDSCH.
- For UE processing capability 2: If the PDSCH is mapping type B as given in subclause 7.4.1.1 of [4, TS 38.211], if the number of PDSCH symbols allocated is 2 or 4, then $d_{1,2}$ is the number of overlapping symbols of the scheduling PDCCH and the scheduled PDSCH..
- For UE processing capability 2 with scheduling limitation when μ = 1, if the scheduled RB allocation exceeds 136 RBs, the UE defaults to capability 1 processing time.

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]	
	dmrs-AdditionalPosition = pos0 in *DMRS-DownlinkConfig* in either of *dmrs-DownlinkForPDSCH-MappingTypeA*, *dmrs-DownlinkForPDSCH-MappingTypeB*	*dmrs-AdditionalPosition* ≠ pos0 in *DMRS-DownlinkConfig* in either of *dmrs-DownlinkForPDSCH-MappingTypeA*, *dmrs-DownlinkForPDSCH-MappingTypeB*
0	8	13
1	10	13
2	17	20
3	20	24

Table 5.3-2: PDSCH processing time for PDSCH processing capability 2

μ	PDSCH decoding time N_1 [symbols]	
	dmrs-AdditionalPosition = pos0 in *DMRS-DownlinkConfig* in either of *dmrs-DownlinkForPDSCH-MappingTypeA*, *dmrs-DownlinkForPDSCH-MappingTypeB*	*dmrs-AdditionalPosition* ≠ pos0 in *DMRS-DownlinkConfig* in either of *dmrs-DownlinkForPDSCH-MappingTypeA*, *dmrs-DownlinkForPDSCH-MappingTypeB*
0	3	[13]
1	4.5	[13]
2	9 for frequency range 1	[20]

5.4 UE CSI computation time

When the *CSI request* field on a DCI triggers a CSI report(s) on PUSCH, the UE shall provide valid CSI report(s),

- if the first uplink symbol to carry the corresponding CSI report(s) including the effect of the timing advance, starts no earlier than at symbol Z_{ref} , 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 $\left((Z+d)(2048+144)\cdot\kappa 2^{-\mu}\right)\cdot T_C$ after the end of the last symbol of the PDCCH triggering the CSI report, and where Z'_{ref}, is defined as the next uplink symbol with its CP starting after $\left((Z'+d)\cdot(2048+144)\cdot\kappa 2^{-\mu}\right)\cdot T_C$ 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 for triggered CSI report *n*,

When the *CSI request* field on a DCI triggers a CSI report(s) on PUSCH, if the first uplink symbol to carry the corresponding CSI report(s) including the effect of the timing advance, starts no earlier than at symbol Z_{ref},

- the UE may ignore the scheduling DCI if no HARQ-ACK or transport block is multiplexed on the PUSCH, or
- the UE drops the CSI for the triggered CSI reports if either HARQ-ACK or transport block is multiplexed on the PUSCH,

When the *CSI request* field on a DCI triggers a CSI report(s) on PUSCH, 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},

- the UE may ignore the scheduling DCI if the number of triggered reports is one and no HARQ-ACK or transport block is multiplexed on the PUSCH
- Otherwise, the UE is not required to update the CSI for the triggered CSI report *n*.

Z and *Z'* are defined as:

$Z = \max_{m=0,\ldots,M-1}(Z_m)$ and $Z' = \max_{m=0,\ldots,M-1}(Z'_m)$, where *M* is the number of updated CSI report(s) according to Subclause 5.2.1.6, (Z_m, Z'_m) corresponds to the *m*-th requested CSI report and is defined as

- (Z_1, Z'_1) of the table 5.4-1 if the CSI is triggered without a PUSCH with either transport block or HARQ-ACK or both when *L* = 0 CPUs are occupied (according to Subclause 5.2.1.6) and the CSI to be transmitted corresponds to wideband frequency-granularity where the CSI corresponds to at most 4 CSI-RS ports in a single resource without CRI report and where *CodebookType* is set to 'TypeI-SinglePanel' or where *reportQuantity* is set to 'cri-RI-CQI', or
- (Z_1, Z'_1) of the table 5.4-2 if the CSI is triggered without a PUSCH with either a transport block or HARQ-ACK or both and the CSI to be transmitted corresponds to wideband frequency-granularity where the CSI corresponds to at most 4 CSI-RS ports in a single resource without CRI report and where *CodebookType* is set to 'TypeI-SinglePanel' or where *reportQuantity* is set to 'cri-RI-CQI', or
- If *reportQuantity* is set to 'cri-RSRP' or 'ssb-Index-RSRP', $Z'_m$is according to UE reported capability and $Z_m$is FFS, or
- (Z_2, Z'_2) of table 5.4-2 otherwise.
- μ of table 5.4-1 and table 5.4-2 corresponds to the min (μ_{PDCCH}, μ_{CSI-RS}, μ_{UL}) where the μ_{PDCCH} 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 and $\mu_{CSI\text{-}RS}$ corresponds to the minimum subcarrier spacing of the aperiodic CSI-RS triggered by the DCI

- *d* = 0 if the CSI is not multiplexed with a PUSCH with either a transport block or HARQ-ACK of both. If CSI is multiplexed with a PUSCH with either a transport block or HARQ-ACK of both, *d* = 2 for μ = 0,1, *d* = 3 for μ = 2 and *d* = 3 for μ = 4

Table 5.4-1: CSI computation delay requirement 1

μ	Z_1 [symbols]	
	Z_1	Z'_1
0	[9 or 10]	[7 or 8]
1	13	11
2	25	21
3	43	36

Table 5.4-2: CSI computation delay requirement 2

μ	Z_1 [symbols]		Z_2 [symbols]	
	Z_1	Z'_1	Z_2	Z'_2
0	22	16	40	37
1	33	30	72	69
2	44	42	141	140
3	97	85	152	140

6 Physical uplink shared channel related procedure

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 *configuredGrantConfig* including *rrc-ConfiguredUplinkGrant* without the detection of an UL grant in a DCI, or *configurdGrantConfig* not including *rrc-ConfiguredUplinkGrant* semi-persistently scheduled by an UL grant in a DCI after the reception of higher layer parameter *configurdGrantConfig* not including *rrc-ConfiguredUplinkGrant*.

A UE shall upon detection of a PDCCH with a configured DCI format 0_0 or 0_1 transmit the corresponding PUSCH as indicated by that DCI. For any two HARQ process IDs in a given cell, if the UE is scheduled to start a PUSCH transmission in symbol *j* by a PDCCH in symbol *i*, the UE is not expected to be scheduled to transmit a PUSCH starting earlier than symbol *j* by a PDCCH starting later than symbol *i*.

For PUSCH scheduled by DCI format 0_0 on a cell, the UE shall transmit PUSCH according to the spatial relation, if applicable, corresponding to the PUCCH resource with the lowest ID within the active UL BWP of the cell, as described in sub-clause 9.2.1 of [6, TS 38.213].

For uplink, 16 HARQ processes per cell is supported by the UE.

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 *txConfig* in *PUSCH-Config* is set to 'codebook', the UE is configured non-codebook based transmission when the higher layer parameter *txConfig* is set to 'nonCodebook'. If the higher layer parameter *txConfig* 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, if PUSCH is scheduled by DCI format 0_1, the UE determines its PUSCH transmission precoder based on SRI, TPMI and the transmission rank from the DCI, given by DCI fields of SRS resource indicator and Precoding information and number of layers in subclause 7.3.1.1.2 of [TS 38.212], where the TPMI is used to indicate the precoder to be applied over the antenna ports $\{0\ldots \nu\text{-}1\}$ and that corresponds to the SRS resource selected by the SRI when multiple SRS resources are configured, or if a single SRS resource is configured TPMI is used to indicate the precoder to be applied over the antenna ports $\{0\ldots \nu\text{-}1\}$ and that corresponds to the SRS resource. The transmission precoder is selected from the uplink codebook that has a number of antenna ports equal to higher layer parameter *nrofSRS-Ports* in SRS-Config, as defined in Subclause 6.3.1.5 of [4, TS 38.211]. When the UE is configured with the higher layer parameter *txConfig* 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 *codebookSubset* in *PUSCH-Config* which may be configured with 'fullAndPartialAndNonCoherent', or 'partialAndNonCoherent' , or 'nonCoherent' depending on the UE capability. The maximum transmission rank may be configured by the higher parameter *maxRank* in *PUSCH-Config* .

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

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

A UE shall not expect to be configured with the higher layer parameter *codebookSubset* set to 'partialAndNonCoherent' when higher layer parameter *nrofSRS-Ports* in an *SRS-ResourceSet* with *usage* set to 'codeBook' indicates that two SRS antenna ports are configured.

For codebook based transmission, the UE may be configured with a single *SRS-ResourceSet* set to 'codeBook' 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. If aperiodic SRS is configured for a UE, the SRS request field in DCI triggers the transmission of aperiodidc SRS resources.

When multiple SRS resources are configured by *SRS-ResourceSet* with *usage* set to 'codeBook', the UE shall expect that higher layer parameters *nrofSRS-Ports* in *SRS-ResourceSet* in *SRS-ResourceSet* shall be configured with the same value for all these 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 when multiple SRS resources are configured, where the SRI is given by the SRS resource indicator in DCI according to subclause 7.3.1.1.2 of [5, 38.212], or the SRI is given by *srs-ResourceIndicator* according to subclause 6.1.2.3. 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 a UE capability. Only one SRS port for each SRS resource is configured. Only one SRS resource set can be configured with higher layer parameter *usage* in *SRS-ResourceSet* 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 calculate the precoder used for the transmission of precoded SRS based on measurement of an associated NZP CSI-RS resource. A UE can be configured with only one NZP CSI-RS resource for the SRS resource set with higher layer parameter usage in *SRS-ResourceSet* set to 'nonCodebook'.

- If aperiodic SRS resource set is configured, the associated NZP-CSI-RS for UL channel measurement is indicated via SRS request field in DCI format 0_1 and 1_1, where *AperiodicSRS-ResourceTrigger* (indicating the association among aperiodic SRS triggering state), triggered SRS resource(s) *srs-ResourceSetId*, *csi-RS* (indicating the associated *NZP-CSI-RS-ResourceId* for UL channel measurement) are higher layer configured in *SRS-ResourceSet*. A UE is not expected to update the SRS precoding information if the gap from the last symbol of the reception of the aperiodic NZP-CSI-RS resource and the first symbol of the aperiodic SRS transmission is less than 42 OFDM symbols.

- If the UE configured with aperiodic SRS associated with aperiodic NZP CSI-RS resource, the presence of the associated CSI-RS is indicated by the SRS request field if the value of the SRS request field is not '00' as in Table 7.3.1.1.2-24 of [5, TS 38.212]. The CSI-RS is located in the same slot as the SRS request field, while any of the *tci-States* for aperiodic CSI-RS shall not be configured with 'QCL-Type-D'.

- If periodic or semi-persistent SRS resource set is configured, the *NZP-CSI-RS-ResourceConfigID* for measurement is indicated via higher layer parameter *associatedCSI-RS* in *SRS-ResourceSet*.

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 in increasing order.

For non-codebook based transmission, the UE does not expect to be configured with both *spatialRelationInfo* for SRS resource and *associatedCSI-RS* in *SRS-Config* for SRS resource set.

For non-codebook based transmission, the UE can be scheduled with DCI format 0_1 when at least one SRS resource is configured in *SRS-ResourceSet* with *usage* set to 'nonCodebook'.

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 value *m* of the DCI provides a row index *m* + 1 to an allocated table. The determination of the used resource allocation table is defined in sub-clause 6.1.2.1.1. The indexed row defines the slot offset K_2, the start and length indicator *SLIV*, or directly the start symbol *S* and the allocation length *L*, 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 resource assignment* field value *m* of the DCI provides a row index *m* + 1 to an allocated table. The determination of the applied resource allocation table is defined in sub-clause 6.1.2.1.1. The indexed row defines the start and length indicator SLIV, or directly the start symbol *S* and the allocation length *L*, and the PUSCH mapping type to be applied in the PUSCH transmission and K_2 is determined based on the corresponding list entries $Y_j, j = 0,\ldots,N_{\text{Rep}}-1$ of the higher layer parameter *reportSlotConfig* in *CSI-ReportConfig* 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 μ_{PUSCH} and μ_{PDCCH} are the subcarrier spacing configurations for PUSCH and PDCCH, respectively, 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 $(L-1)\le 7$ then

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

  else

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

  where $0 < L \le 14-S$, 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	$\{4,\ldots,14\}$	$\{4,\ldots,14\}$	0	$\{4,\ldots,12\}$	$\{4,\ldots,12\}$
Type B	$\{0,\ldots,13\}$	$\{1,\ldots,14\}$	$\{1,\ldots,14\}$	$\{0,\ldots,12\}$	$\{1,\ldots,12\}$	$\{1,\ldots,12\}$

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. The redundancy version to be applied on the n^{th} transmission occasion of the TB is determined according to table 6.1.2.1-2.

Table 6.1.2.1-2: Redundancy version when *aggregationFactorUL* > 1

rv_{id} indicated by the DCI scheduling the PUSCH	rv_{id} to be applied to n^{th} transmission occasion			
	n mod 4 = 0	*n* mod 4 = 1	*n* mod 4 = 2	*n* mod 4 = 3
0	0	2	3	1
2	2	3	1	0
3	3	1	0	2
1	1	0	2	3

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.

6.1.2.1.1 Determination of the resource allocation table to be used for PUSCH

Table 6.1.2.1.1-1 defines which PUSCH time domain resource allocation configuration to apply. Either a default PUSCH time domain allocation A according to table 6.1.2.1.1-2, is applied, or the higher layer configured *pusch-AllocationList* in either *pusch-ConfigCommon* or *pusch-Config* is applied.

Table 6.1.2.1.1-4 defines the subcarrier spacing specific values *j*. *j* is used in determination of K_2 in conjunction to table 6.1.2.1.1-2, for normal CP or table 6.1.2.1.1.-3 for extended CP, where μ_{PUSCH} is the subcarrier spacing configurations for PUSCH.

Table 6.1.2.1.1-5 defines the additional subcarrier spacing specific slot delay value for the first transmission of for MSG3 scheduled by the RAR. When the UE transmits a MSG3 scheduled by RAR, the Δ value specific to MSG3 subcarrier spacing μ_{PUSCH} is applied in addition to the K_2 value.

Table 6.1.2.1.1-1: Applicable PUSCH time domain resource allocation

RNTI	PDCCH search space	*pusch-ConfigCommon* includes *pusch-AllocationList*	*pusch-Config* includes *pusch-AllocationList*	PUSCH time domain resource allocation to apply
PUSCH scheduled by MAC RAR as described in subclause 8.2 of [6, TS 38.213]		No	-	Default A
		Yes		*pusch-AllocationList* provided in *pusch-ConfigCommon*
C-RNTI, TC-RNTI	Any common search space associated with CORESET 0	No	-	Default A
		Yes		*pusch-AllocationList* provided in *pusch-ConfigCommon*
C-RNTI, CS-RNTI	Any common search space not associated with CORESET 0, UE specific search space	No	No	Default A
		Yes	No	*pusch-AllocationList* provided in *pusch-ConfigCommon*
		No/Yes	Yes	*pusch-AllocationList* provided in *pusch-Config*

Table 6.1.2.1.1-2: Default PUSCH time domain resource allocation A for normal CP

Row index	PUSCH mapping type	K_2	S	L
1	Type A	j	0	14
2	Type A	j	0	12
3	Type A	j	0	10
4	Type B	j	2	10
5	Type B	j	4	10
6	Type B	j	4	8
7	Type B	j	4	6
8	Type A	j+1	0	14
9	Type A	j+1	0	12
10	Type A	j+1	0	10
11	Type A	j+2	0	14
12	Type A	j+2	0	12
13	Type A	j+2	0	10
14	Type B	j	8	6
15	Type A	j+3	0	14
16	Type A	j+3	0	10

Table 6.1.2.1.1-3: Default PUSCH time domain resource allocation A for extended CP

Row index	PUSCH mapping type	K_2	S	L
1	Type A	j	0	8
2	Type A	j	0	12
3	Type A	j	0	10
4	Type B	j	2	10
5	Type B	j	4	4
6	Type B	j	4	8
7	Type B	j	4	6
8	Type A	j+1	0	8
9	Type A	j+1	0	12
10	Type A	j+1	0	10
11	Type A	j+2	0	6
12	Type A	j+2	0	12
13	Type A	j+2	0	10
14	Type B	j	8	4
15	Type A	j+3	0	8
16	Type A	j+3	0	10

Table 6.1.2.1.1-4: Definition of value *j*

μ_{PUSCH}	j
0	1
1	1
2	2
3	3

Table 6.1.2.1.1-5: Definition of value *Δ*

μ_{PUSCH}	Δ
0	2
1	3
2	4
3	6

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 PUSCH only when transform precoding is disabled. 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 uplink resource allocation type as part of the *Frequency domain resource* assignment field by setting a higher layer parameter *resourceAllocation* in *pusch-Config* to 'dynamicswitch', the UE shall use uplink resource allocation type 0 or type 1 as defined by this DCI field. Otherwise the UE shall use the uplink frequency resource allocation type as defined by the higher layer parameter *resourceAllocation*.

The UE shall 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 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 bandwidth part indicated by bandwidth part indicator field value in the DCI, except for the case when DCI format 0_0 is decoded in any PDCCH 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 bandwidth part and then the resource allocation within the 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 in *pusch-Config* and the size of the 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 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 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 non-interleaved 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 Type0-PDCCH 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 $(L_{RBs}-1)\le \lfloor N_{BWP}^{size}/2 \rfloor$ 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 $L_{RBs} \ge 1$ and shall not exceed $N_{BWP}^{size}-RB_{start}$.

When the DCI size for DCI format 0_0 in USS is derived from the initial BWP with size $N_{\mathrm{BWP}}^{initial}$ but applied to another active BWP with size of $N_{\mathrm{BWP}}^{active}$, a downlink type 1 resource block assignment field consists of a resource indication value (*RIV*) corresponding to a starting resource block $RB_{start}=0, K, 2\cdot K, \ldots, (N_{\mathrm{BWP}}^{initial}-1)\cdot K$ and a length in terms of virtually contiguously allocated resource blocks $L_{RBs}=K, 2\cdot K, \ldots, N_{\mathrm{BWP}}^{initial}\cdot K$.

The resource indication value is defined by

if $(L'_{RBs}-1)\le \lfloor N_{BWP}^{initial}/2 \rfloor$ then

$$RIV = N_{BWP}^{initial}(L'_{RBs}-1)+RB'_{start}$$

else

$$RIV = N_{BWP}^{initial}(N_{BWP}^{initial}-L'_{RBs}+1)+(N_{BWP}^{initial}-1-RB'_{start})$$

where $L'_{RBs}=L_{RBs}/K$, $RB'_{start}=RB_{start}/K$ and where L'_{RBs} shall not exceed $N_{BWP}^{initial}-RB'_{start}$.

If $N_{BWP}^{active} > N_{BWP}^{initial}$, K is the maximum value from set {1, 2, 4, 8} which satisfies $K \le \lfloor N_{BWP}^{active}/N_{BWP}^{initial} \rfloor$; otherwise *K* = 1.

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* in *BWP* information element, and the PUSCH transmission corresponding to the configured grant triggered, the following higher layer parameters are applied in the transmission:

- For Type 1 PUSCH transmissions with a configured grant, the following parameters are given in *ConfiguredGrantConfig*:
  - The higher layer parameter *timeDomainAllocation* value *m* provides a row index m+1 pointing to an allocated table, indicating a combination of start symbol and length and PUSCH mapping type, where the table selection follows the rules for the UE specific search space, as defined in sub-clause 6.1.2.1.1;
  - 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 *antennaPort, dmrs-SeqInitialization, precodingAndNumberOfLayers*, and *srs-ResourceIndicator* respectively;
  - When frequency hopping is enabled, the frequency offset between two frequency hops can be configured by higher layer parameter *frequencyHoppingOffset.*
- For Type 2 PUSCH transmissions with a configured grant: the resource allocation follows the higher layer configuration according to [10, TS 38.321], and UL grant received on the DCI.

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 higher layer configured parameters *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. The UE is not expected to be configured with the time duration for the transmission of K repetitions larger than the time duration derived by the periodicity P.

For both Type 1 and Type 2 PUSCH transmissions with a configured grant, when the UE is configured with *repK* > 1, the UE shall repeat the TB across the *repK* 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.

6.1.3 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-transformPrecoding.*

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-transformPrecoding*.
- 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-transformPrecoding*.

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-transformPrecoding*.

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, new-RNTI, TC-RNTI, or SP-CSI-RNTI, the transform precoding is enabled if *transformPrecoder* in *PUSCH-Config* is set to 'enabled', or if *transformPrecoder* in *PUSCH-Config* is not configured and *msg3-transformPrecoding* in *rach-ConfigCommon* is set to 'enabled'; otherwise the transform precoding is disabled.

For the PUSCH assigned by a DCI format 0_0/0_1 with CRC scrambled by CS-RNTI, or the PUSCH with configured grant using CS-RNTI, the transform precoding is enabled if *transformPrecoder* in *ConfiguredGrantConfig* is set to 'enabled'; otherwise the transform precoding is disabled.

For a PUSCH scheduled by RAR UL grant or for a PUSCH scheduled by a DCI format 0_0/0_1 with CRC scrambled by C-RNTI, TC-RNTI, or CS-RNTI, or SP-CSI-RNTI, or for a PUSCH with configured grant using CS-RNTI,

if *transformPrecoder* is disabled for this PUSCH transmission

- if *mcs-Table* in *PUSCH-Config* is set to 'qam256', and PUSCH is scheduled with C-RNTI or SP-CSI-RNTI, and PUSCH is assigned by DCI format 0_1,
  - 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 uplink shared channel.
- elseif the UE is not configured with new-RNTI, *mcs-Table* in *PUSCH-Config* is set to 'qam64LowSE', the PUSCH is scheduled with C-RNTI, or SP-CSI-RNTI, and the PUSCH is assigned by a PDCCH in a UE-specific search space,
  - the UE shall use I_{MCS} and Table 5.1.3.1-3 to determine the modulation order (Q_m) and Target code rate (*R*) used in the physical uplink shared channel.
- elseif the UE is configured with new-RNTI, and the PUSCH is scheduled with new-RNTI,

  - the UE shall use I_{MCS} and Table 5.1.3.1-3 to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.
- elseif *mcs-Table* in *ConfiguredGrantConfig* is set to 'qam256', and PUSCH is scheduled with CS-RNTI,
  - 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 uplink shared channel.
- elseif *mcs-Table* in *ConfiguredGrantConfig* is set to 'qam64LowSE', and PUSCH is scheduled with CS-RNTI,
  - the UE shall use I_{MCS} and Table 5.1.3.1-3 to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.
- else
  - 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 uplink shared channel.

else

- if *mcs-TableTransformPrecoder* in *PUSCH-Config*is set to 'qam256', and the PUSCH is scheduled with C-RNTI or SP-CSI-RNTI, and PUSCH is assigned by DCI format 0_1,
  - 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 uplink shared channel.
- elseif the UE is not configured with new-RNTI, *mcs-TableTransformPrecoder* in *PUSCH-Config* is set to 'qam64LowSE', and the PUSCH is scheduled with C-RNTI, or SP-CSI-RNTI, and the PUSCH is assigned by a PDCCH in a UE-specific search space,
  - the UE shall use I_{MCS} and Table 6.1.4.1-2 to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.
- elseif the UE is configured with new-RNTI, and the PUSCH is scheduled with new-RNTI,
  - the UE shall use I_{MCS} and Table 6.1.4.1-2 to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.
- elseif *mcs-TableTransformPrecoder* in *ConfiguredGrantConfig* is set to 'qam256', and PUSCH is scheduled with CS-RNTI,
  - 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 uplink shared channel.
- elseif *mcs-TableTransformPrecoder* in *ConfiguredGrantConfig* is set to 'qam64LowSE', and PUSCH is scheduled with CS-RNTI,
  - the UE shall use I_{MCS} and Table 6.1.4.1-2 to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.

- else
  - the UE shall use I_{MCS} and Table 6.1.4.1-1to determine the modulation order (Q_m) and Target code rate (R) used in the physical uplink shared channel.

end

For Table 6.1.4.1-1 and Table 6.1.4.1-2, if higher layer parameter *PUSCH-tp-pi2BPSK* is configured, q = 1 otherwise q=2.

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	q	reserved	
29	2	reserved	
30	4	reserved	
31	6	reserved	

Table 6.1.4.1-2: MCS index table 2 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	$60/q$	0.0586
1	q	$80/q$	0.0781
2	q	$100/q$	0.0977
3	q	$128/q$	0.1250
4	q	$156/q$	0.1523
5	q	$198/q$	0.1934
6	2	120	0.2344
7	2	157	0.3066
8	2	193	0.3770
9	2	251	0.4902
10	2	308	0.6016
11	2	379	0.7402
12	2	449	0.8770
13	2	526	1.0273
14	2	602	1.1758
15	2	679	1.3262
16	4	378	1.4766
17	4	434	1.6953
18	4	490	1.9141
19	4	553	2.1602
20	4	616	2.4063
21	4	658	2.5703
22	4	699	2.7305
23	4	772	3.0156
24	6	567	3.3223
25	6	616	3.6094
26	6	666	3.9023
27	6	772	4.5234
28	q	reserved	
29	2	reserved	
30	4	reserved	
31	6	reserved	

6.1.4.2 Transport block size determination

For a PUSCH scheduled by RAR UL grant or for a PUSCH scheduled by a DCI format 0_0/0_1 with CRC scrambled by C-RNTI, new-RNTI, TC-RNTI, CS-RNTI, or SP-CSI-RNTI.

if

- $0 \le I_{MCS} \le 27$ and transform precoding is disabled and Table 5.1.3.1-2 is used, or
- $0 \le I_{MCS} \le 28$ and transform precoding is disabled and a table other than Table 5.1.3.1-2 is used, or
- $0 \le I_{MCS} \le 27$ and transform precoding is enabled, 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
  - $N'_{RE} = N_{sc}^{RB} \cdot N_{symb}^{sh} - N_{DMRS}^{PRB} - N_{oh}^{PRB}$, 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 without data, as indicated by DCI format 0_1 or as described for DCI format 0_0 in Subclause 6.2.2, and N_{oh}^{PRB} is the overhead configured by higher layer parameter *xOverhead* in *PUSCH-ServingCellConfig*. If the N_{oh}^{PRB} is not configured (a value from 0, 6, 12, or 18), the N_{oh}^{PRB} is assumed to be 0. For MSG3 transmission the N_{oh}^{PRB} is always set to 0..
  - A UE determines the total number of REs allocated for PUSCH $\left(N_{RE}\right)$ by $N_{RE} = \min\left(156, N'_{RE}\right) \cdot n_{PRB}$ where n_{PRB} is the total number of allocated PRBs for the UE.
  - Next, proceed with steps 2-4 as defined in Subclause 5.1.3.2

else if

- $28 \le I_{MCS} \le 31$ and transform precoding is disabled and Table 5.1.3.1-2 is used, or
- $28 \le I_{MCS} \le 31$ and transform precoding is enabled,
- 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 transmitted with configured grant, 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* in *PUSCH-ServingCellConfig*, 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* in *PUSCH-ServingCellConfig*, 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, $m = 0,1,...,M_1 - 1$, 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 $M_1 \cdot K_1 + (m - M_1) \cdot K_2 + k, k = 0,1,..., K_2 - 1$.

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* in *PUSCH-ServingCellConfig*,

- 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-ResourceSet*. For each SRS resource set, a UE may be configured with $K \ge 1$ SRS resources (higher later parameter

SRS-Resource), 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 SRS at 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-Resource*.

- *srs-ResourceId* determines SRS resource configuration identify.
- Number of SRS ports as defined by the higher layer parameter *nrofSRS-Ports* and described 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- resourceType*, 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 parameters *periodicityAndOffset-p* or *periodicityAndOffset-sp* for an SRS resource of type periodic or semi-persistent. The UE shall not expect to be configured with SRS resources in the same SRS resource set *SRS-ResourceSet* with different slot level periodicities. For an *SRS-ResourceSet* configured with higher layer parameter *resourceType* set to 'aperiodic', a slot level offset is defined by the higher layer parameter *slotOffset*.
- 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 *resourceMapping* and described 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 *freqHopping* and described in Subclause 6.4.1.4 of [4, TS 38.211].
- Frequency hopping bandwidth, b_{hop}, as defined by the higher layer parameter *freqHopping* and described 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 parameters *freqDomainPosition* and *freqDomainShift, respectively,* and described in Subclause 6.4.1.4 of [4, TS 38.211].
- Cyclic shift, as defined by the higher layer parameter *cyclicShift-n2* or *cyclicShift-n4* for transmission comb value 2 and 4, respectively, and described in Subclause 6.4.1.4 of [4, TS 38.211].

- Transmission comb value as defined by the higher layer parameter *transmissionComb* described in Subclause 6.4.1.4 of [4, TS 38.211].
- Transmission comb offset as defined by the higher layer parameter *combOffset-n2* or *combOffset-n4* for transmission comb value 2 or 4, respectively, and described in Subclause 6.4.1.4 of [4, TS 38.211].
- SRS sequence ID as defined by the higher layer parameter *sequenceId* in Subclause 6.4.1.4 of [4].
- The configuration of the spatial relation between a reference RS and the target SRS, where the higher layer parameter *spatialRelationInfo*, if configured, contains the ID of the reference RS. The reference RS can be an SS/PBCH block, CSI-RS or an SRS configured on the same or different component carrier and/or bandwidth part as the target SRS.

The UE may be configured by the higher layer parameter *resourceMapping* in *SRS-Resource* 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 *resourceType* in *SRS-Resource* is set to 'periodic':

- if the UE is configured with the higher layer parameter *spatialRelationInfo* containing the ID of a reference 'ssb-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference SS/PBCH block, if the higher layer parameter *spatialRelationInfo* contains the ID of a reference 'csi-RS-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference periodic CSI-RS or of the reference semi-persistent CSI-RS, if the higher layer parameter *spatialRelationInfo* containing the ID of a reference 'srs', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the transmission of the reference periodic SRS.

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

- when a UE receives an activation command [10, TS 38.321] for an SRS resource, and when the HARQ-ACK corresponding to the PDSCH carrying the selection command is transmitted 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 starting from slot $n + 3N_{slot}^{subframe,\mu} + 1$. The activation command also contains spatial relation assumptions provided by a list of references to reference signal IDs, one per element of the activated SRS resource set. Each ID in the list refers to a reference SS/PBCH block, NZP CSI-RS resource, or

SRS resource configured on the same or different component carrier and/or bandwidth part as the SRS resource(s) in the SRS resource set.

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

- when a UE receives a deactivation command [10, TS 38.321] for an activated SRS resource set, and when the HARQ-ACK corresponding to the PDSCH carrying the selection command is transmitted 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 starting from slot $n+3N_{slot}^{subframe,\mu}+1$.

- if the UE is configured with the higher layer parameter *spatialRelationInfo* containing the ID of a reference 'ssb-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference SS/PBCH block, if the higher layer parameter *spatialRelationInfo* contains the ID of a reference 'csi-RS-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference periodic CSI-RS or of the reference semi-persistent CSI-RS, if the higher layer parameter *spatialRelationInfo* contains the ID of a reference 'srs', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the transmission of the reference periodic SRS or of the reference semi-persistent SRS.

If the UE has an active semi-persistent SRS resource configuration and has not received a deactivation command, the semi-persistent SRS configuration is considered to be active in the UL BWP which is active when SRS resource configuration is activated, otherwise it is considered suspended.

For a UE configured with one or more SRS resource configuration(s), and when the higher layer parameter *resourceType* in *SRS-Resource* 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 command where a codepoint of the DCI may trigger one or more SRS resource set(s). The minimal time interval between the last symbol of the PDCCH triggering the aperiodic SRS transmission and the first symbol of SRS resource is N_2 + 42.

- if the UE is configured with the higher layer parameter *spatialRelationInfo* containing the ID of a reference 'ssb-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference SS/PBCH block, if the higher layer parameter *spatialRelationInfo* contains the ID of a reference 'csi-RS-Index', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the reception of the reference periodic CSI-RS or of the reference semi-persistent CSI-RS, or of the latest reference aperiodic CSI-RS. If the higher layer parameter *spatialRelationInfo* contains the ID of a reference 'srs', the UE shall transmit the target SRS resource with the same spatial domain transmission filter used for the transmission of the reference periodic SRS or of the reference semi-persistent SRS or of the reference 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 7.3.1.1.2-24 of [5, TS 38212]. 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].

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. A UE shall not transmit SRS when semi-persistent or periodic SRS is configured or aperiodic SRS is triggered to be transmitted in the same symbol(s) with PUCCH carrying HARQ-ACK and/or SR. 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 is triggered to be transmitted 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.

In case of intra-band carrier aggregation, 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.

In case of intra-band carrier aggregation, AaUE shall not transmit simultaneously SRS resource(s) and PRACH.

When the UE is configured with the higher layer parameter *usage* in *SRS-ResourceSet* set to 'antennaSwitching,' and a guard period of Y symbols is configured according to Subclause 6.2.1.2, the UE shall use the same priority rules as defined above during the guard period as if SRS was configured.

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 $R \in \{1,2,4\}$ by higher layer parameter *resourceMapping* in *SRS-Resource* 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 sounding procedure for DL CSI acquisition

When the UE is configured with the higher layer parameter *usage* in *SRS-ResourceSet* set as 'antennaSwitching', the UE may be configured with one of the following configurations depending on the indicated UE capability ('1T2R', '2T4R', '1T4R', '1T4R/2T4R', or 'T=R'):

- up to two SRS resource sets configured with a different value for the higher layer parameter *resourceType* in *SRS-ResourceSet* set, where each set has two SRS resources transmitted in different symbols, each SRS resource in a given set consisting of a single SRS port, and the SRS port of the second resource in the set is associated with a different UE antenna port than the SRS port of the first resource in the same set, or

- up to two SRS resource sets configured with a different value for the higher layer parameter *resourceType* in *SRS-ResourceSet* set, where each SRS resource set has two SRS resources transmitted in different symbols, each SRS resource in a given set consisting of two SRS ports, and the SRS port pair of the second resource is associated with a different UE antenna port pair than the SRS port pair of the first resource, or

- zero or one SRS resource set configured with higher layer parameter *resourceType* in *SRS-ResourceSet* set to 'periodic' or 'semi-persistent' with four SRS resources transmitted in different symbols, each SRS resource in a given set consisting of a single SRS port, and the SRS port of each resource is associated with a different UE antenna port, and

- zero or two SRS resource sets each configured with higher layer parameter *resourceType* in *SRS-ResourceSet* set to 'aperiodic' and with a total of four SRS resources transmitted in different symbols of two different slots, and where the SRS port of each SRS resource in given two sets is associated with a different UE antenna port. The two sets are each configured with two SRS resources, or one set is configured with one SRS resource and the other set is configured with three SRS resources. The UE shall expect that the two sets are both configured with the same values of the higher layer parameters *alpha*, *p0*, *pathlossReferenceRS*, and *srs-PowerControlAdjustmentStates* in *SRS-ResourceSet*. The UE shall expect that the value(s) of the higher layer parameter *aperiodicSRS-ResourceTrigger* in each *SRS-ResourceSet* are the same, and the value of the higher layer parameter *slottOffset* in each *SRS-ResourceSet* is different. Or,

- up to two SRS resource sets each with one SRS resource, where the number of SRS ports for each resource is equal to 1, 2, or 4.

The UE is configured with a guard period of Y symbols, in which the UE does not transmit any other signal, in the case the SRS resources of a set are transmitted in the same slot. The guard period is in-between the SRS resources of the set.

If the indicated UE capability is '1T4R/2T4R,' the UE shall expect to be configured with the same number of SRS ports, either one or two, for all SRS resources in the SRS resource set(s).

If the indicated UE capability is '1T2R', '2T4R', '1T4R', '1T4R/2T4R', the UE shall not expect to be configured or triggered with more than one SRS resource set in the same slot. If the indicated UE capability is 'T=R,' the UE shall not expect to be configured or triggered with more than one SRS resource set in the same symbol.

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].

For an aperiodic SRS triggered in DCI format 2_3 and if the UE is configured with higher layer parameter *srs-TPC-PDCCH-Group* set to 'typeA', and given by *SRS-CarrierSwitching,* without PUSCH/PUCCH transmission, the order of the triggered SRS transmission on the serving cells follow the order of the serving cells in the indicated set of serving cells configured by higher layers, where the UE in each serving cell transmits the configured one or two SRS resource set(s) with higher layer parameter *SRS-SetUse* set to 'antenna switching' and higher layer parameter *resourceType* in *SRS-ResourceSet* set to 'aperiodic'.

For an aperiodic SRS triggered in DCI format 2_3 and if the UE is configured with higher layer parameter *srs-TPC-PDCCH-Group* set to 'typeB' without PUSCH/PUCCH transmission, the order of the triggered SRS transmission on the serving cells follow the order of the serving cells with aperiodic SRS triggered in the DCI, and the UE in each serving cell transmits the configured one or two SRS resource set(s) with higher layer parameter *SRS-SetUse* set to 'antenna switching' and higher layer parameter *resourceType* in *SRS-ResourceSet* set to 'aperiodic'.

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* and *srs-SwitchFromCarrier* 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*), the UE temporarily suspends the uplink transmission 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.

For n-th ($n \geq 1$) aperiodic SRS transmission on a cell c, upon detection of a positive SRS request on a grant, the UE shall commence this SRS transmission on the configured symbol and slot provided

- it is no earlier than the summation of
  - the maximum time duration between the two durations spanned by N OFDM symbols of the numerology of cell c and the cell carrying the grant respectively, and

- the UL or DL RF retuning time [11, TS 38.133] as defined by higher layer parameters *rf-RetuningTimeUL* and *rf-RetuningTimeDL,*

- it does not collide with any previous SRS transmissions, or interruption due to UL or DL RF retuning time.

otherwise, *n*-th SRS transmission is dropped, where N is the reported capability as the minimum time interval in unit of symbols, between the DCI triggering and aperiodic SRS transmission.

In case of inter-band carrier aggregation, a UE can simultaneously transmit SRS and PUCCH/PUSCH across component carriers in different bands subject to the UE's capability.

In case of inter-band carrier aggregation, a UE can simultaneously transmit PRACH and SRS/PUCCH/PUSCH across component carriers in different bands subject to UE's capability.

6.2.2 UE DM-RS transmission procedure

When transmitted PUSCH is not scheduled by PDCCH format 0_1 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 except for PUSCH with allocation duration of 2 or less OFDM symbols with transform precoding disabled, 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] for frequency hopping disabled and as specified in Table 6.4.1.1.3-6 of [4, TS38.211] for frequency hopping enabled, and

If frequency hopping is disabled:

- Thehe UE shall assume *dmrs-AdditionalPosition*='pos2' and up to two additional DM-RS can be transmitted according to PUSCH duration, or

If frequency hopping is enabled:

- The UE shall assume *dmrs-AdditionalPosition*='pos1' and up to one additional DM-RS can be transmitted according to PUSCH duration.

A UE can be configured with one or two scrambling identity(s), $n_{ID}^{DMRS,i}$ *i* = 0,1 by higher layers for UE-specific reference signal generation as defined in Subclause 6.4.1.1 of [4, TS 38.211] to transmit PUSCH which are the same for both PUSCH mapping Type A and Type B.

For the UE-specific reference signals generation as defined in Subclause 6.4.1.1 of [4, TS 38.211], a UE can be configured by higher layers with one or two scrambling identity(s), $n_{ID}^{DMRS,i}$ *i* = 0,1 which are the same for both PUSCH mapping Type A and Type B.

When transmitting PUSCH scheduled by PDCCH format 0_1 with CRC scrambled by C-RNTI or CS-RNTI,

- the UE may be configured with higher layer parameter *dmrs-Type* in *DMRS-UplinkConfig*, 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 *maxLength* in *DMRS-UplinkConfig.*
  - if *maxLength* is not configured, 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 *maxLength* is configured, 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 'pos0' or 'pos1'.
  - 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 *phaseTrackingRS* in *DMRS-UplinkConfig*, 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.

For PUSCH scheduled by DCI format 0_1, the 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 PUSCH scheduled by DCI format 0_0, the UE shall assume the number of DM-RS CDM groups without data is 1 which corresponds to CDM group 0 for the case of PUSCH with allocation duration of 2 or less OFDM symbols with transform precoding disabled, and the UE shall assume that the number of DM-RS CDM groups without data is 2 which corresponds to CDM group {0,1} for all other cases.

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. The DM-RS scaling factor β_{PUSCH}^{DMRS} specified in subclause 6.4.1.1.3 of [4, TS 38.211] is given by $\beta_{PUSCH}^{DMRS} = 10^{-\frac{\beta_{DMRS}}{20}}$.

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 not configured with the higher layer parameter *phaseTrackingRS* in *DMRS-UplinkConfig*, the UE shall not transmit PT-RS. The PTRS may only be present if RNTI equals C-RNTI, CS-RNTI, SP-CSI-RNTI.

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 *phaseTrackingRS* in *DMRS-UplinkConfig* ,

- the higher layer parameters *timeDensity* and *frequencyDensity* in *PTRS-UplinkConfig* indicate the threshold values $ptrs\text{-}MCS_i$, i=1,2,3 and $N_{RB,i}$, i=0,1, as shown in Table 6.2.3.1-1 and Table 6.2.3.1-2, respectively.
- if an additional higher layer parameters *timeDensity* and/or *frequencyDensity* in *PTRS-UplinkConfig* are configured, 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, respectively,
  - 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.

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 $\leq$ I_{MCS} < ptrs-MCS2	4
ptrs-MCS2 $\leq$ I_{MCS} < ptrs-MCS3	2
ptrs-MCS3 $\leq$ 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-MCS*$_i$ = *ptrs-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 *frequencyDensity* in *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 *phaseTrackingRS* in *DMRS-UplinkConfig* 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 *maxNrofPorts* in *PTRS-UplinkConfig.* 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 shall expect the number of UL PT-RS ports to be configured as one if UL-PTRS is configured..

For codebook or non-codebook based UL transmission, the association between UL PT-RS port(s) and DM-RS port(s) is signalled by DCI 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 *ptrs-PortIndex* configured by *SRS-Config*. 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 *maxNrofPorts* in *PTRS-UplinkConfig* 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.

When the UE is scheduled with Q_p={1,2} 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 *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 *ptrs-Power*, the PT-RS scaling factor β_{PTRS} specified in subclause 6.4.1.2.2.1 of [4, TS 38.211] is given by $\beta_{PTRS} = 10^{-\frac{\rho_{PTRS}^{PUSCH}}{20}}$ and also on the TPMI field in DCI.
- The UE shall assume *ptrs-Power* in *PTRS-UplinkConfig* is set to state "00" in Table 6.2.3.1-3 if not configured or in case of non-codebook based PUSCH.

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

	The number of PUSCH layers (n_{layer}^{PUSCH})			
	1	**2**	**3**	**4**

UL-PTRS-power / α_{PTRS}^{PUSCH}	All cases	Full coherent	Partial and non-coherent and non-codebook based	Full coherent	Partial and non-coherent and non-codebook based	Full coherent	Partial coherent	Non-coherent and non-codebook based
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 *dft-S-OFDM* in *PTRS-UplinkConfig,*

- 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 N_{RB0} if $N_{RB0} > 1$ or if the RNTI equals TC-RNTI.
- and the UE may be configured PT-RS time density $L_{PT\text{-}RS} = 2$ with the higher layer parameter *timeDensity.* Otherwise, the UE shall assume $L_{PT\text{-}RS} = 1$.
- if the higher layer parameter *sampleDensity* 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
$N_{RB0} \leq N_{RB} < N_{RB1}$	2	2
$N_{RB1} \leq N_{RB} < N_{RB2}$	2	4
$N_{RB2} \leq N_{RB} < N_{RB3}$	4	2
$N_{RB3} \leq N_{RB} < N_{RB4}$	4	4
$N_{RB4} \leq N_{RB}$	8	4

When transform precoding is enabled and if a UE is configured with the higher layer parameter *dft-S-OFDM* in *PTRS-UplinkConfig,* 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 *frequencyHopping* in *PUSCH-Config*, 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 *frequencyHoppingOffsetLists* in *PUSCH-Config*:

- 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 $\lfloor N_{symb}^{PUSCH,s}/2 \rfloor$, the number of symbols in the second hop is given by $N_{symb}^{PUSCH,s} - \lfloor N_{symb}^{PUSCH,s}/2 \rfloor$, where $N_{symb}^{PUSCH,s}$ 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:

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

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 $T_{proc,2} = \max\left(\left((N_2 + d_{2,1} + d_{2,2})(2048+144)\cdot\kappa 2^{-\mu}\right)\cdot T_C, d_{2,3}\right)$after the end of the last symbol of the PDCCH carrying the DCI scheduling the PUSCH, where

- N_2 is based on μ of Table 6.4-1 and Table 6.4-2 for UE processing capability 1 and 2 respectively, where μ corresponds to the one of (μ_{DL}, μ_{UL}) resulting with the largest $T_{proc,2}$, 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, and κ is defined in subclause 4.1 of [4, TS 38.211].
- 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 HARQ-ACK is multiplexed on PUSCH, then $d_{2,2}$ = 1, otherwise $d_{2,2}$ = 1.
- If the UE is configured with multiple active component carriers, the first uplink symbol in the PUSCH allocation further includes the effect of timing difference between component carriers as given in [11, TS 38.133].
- If the scheduling DCI triggered a switch of BWP, $d_{2,3}$ equals to the switching time as defined in [11, TS 38.133], otherwise $d_{2,3}$=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

Table 6.4-2: PUSCH preparation time for PUSCH timing capability 2

μ	PUSCH preparation time N_2 [symbols]
0	5
1	5.5
2	11 for frequency range 1

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
2018-06	RAN#80	RP-181172	0002	1	F	CR to 38.214 capturing the RAN1#92bis and RAN1#93 meeting agreements	15.2.0
2018-06	RAN#80	RP-181257	0003	-	B	CR to 38.214 capturing the RAN1#92bis and RAN1#93 meeting agreements related to URLLC	15.2.0
2018-06	RAN#80	RP-181172	0004	-	F	CR to 38.214: maintenance according to agreed Rel 15 features	15.2.0