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Multiplexing and channel coding  
(3GPP TS 38.212 version 15.5.0 Release 15)**



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# Contents

Intellectual Property Rights .....	2
Foreword.....	2
Modal verbs terminology.....	2
Foreword.....	6
1 Scope .....	7
2 References .....	7
3 Definitions, symbols and abbreviations .....	7
3.1 Definitions .....	7
3.2 Symbols.....	7
3.3 Abbreviations .....	7
4 Mapping to physical channels .....	8
4.1 Uplink.....	8
4.2 Downlink.....	9
5 General procedures.....	9
5.1 CRC calculation .....	9
5.2 Code block segmentation and code block CRC attachment.....	10
5.2.1 Polar coding .....	10
5.2.2 Low density parity check coding .....	10
5.3 Channel coding.....	12
5.3.1 Polar coding.....	13
5.3.1.1 Interleaving .....	13
5.3.1.2 Polar encoding.....	14
5.3.2 Low density parity check coding .....	18
5.3.3 Channel coding of small block lengths .....	25
5.3.3.1 Encoding of 1-bit information.....	25
5.3.3.2 Encoding of 2-bit information.....	25
5.3.3.3 Encoding of other small block lengths .....	25
5.4 Rate matching.....	26
5.4.1 Rate matching for Polar code.....	26
5.4.1.1 Sub-block interleaving .....	26
5.4.1.2 Bit selection.....	27
5.4.1.3 Interleaving of coded bits.....	28
5.4.2 Rate matching for LDPC code.....	29
5.4.2.1 Bit selection.....	29
5.4.2.2 Bit interleaving.....	31
5.4.3 Rate matching for channel coding of small block lengths .....	32
5.5 Code block concatenation .....	32
6 Uplink transport channels and control information.....	32
6.1 Random access channel.....	32
6.2 Uplink shared channel .....	32
6.2.1 Transport block CRC attachment.....	32
6.2.2 LDPC base graph selection.....	33
6.2.3 Code block segmentation and code block CRC attachment .....	33
6.2.4 Channel coding of UL-SCH.....	33
6.2.5 Rate matching .....	33
6.2.6 Code block concatenation.....	33
6.2.7 Data and control multiplexing .....	34
6.3 Uplink control information.....	44
6.3.1 Uplink control information on PUCCH.....	44
6.3.1.1 UCI bit sequence generation .....	44
6.3.1.1.1 HARQ-ACK/SR only .....	44
6.3.1.1.2 CSI only.....	44
6.3.1.1.3 HARQ-ACK/SR and CSI .....	51

6.3.1.2	Code block segmentation and CRC attachment .....	52
6.3.1.2.1	UCI encoded by Polar code .....	52
6.3.1.2.2	UCI encoded by channel coding of small block lengths.....	52
6.3.1.3	Channel coding of UCI .....	53
6.3.1.3.1	UCI encoded by Polar code .....	53
6.3.1.3.2	UCI encoded by channel coding of small block lengths.....	53
6.3.1.4	Rate matching .....	53
6.3.1.4.1	UCI encoded by Polar code .....	53
6.3.1.4.2	UCI encoded by channel coding of small block lengths.....	54
6.3.1.5	Code block concatenation .....	55
6.3.1.6	Multiplexing of coded UCI bits to PUCCH .....	55
6.3.2	Uplink control information on PUSCH .....	57
6.3.2.1	UCI bit sequence generation .....	57
6.3.2.1.1	HARQ-ACK .....	57
6.3.2.1.2	CSI.....	58
6.3.2.2	Code block segmentation and CRC attachment .....	61
6.3.2.2.1	UCI encoded by Polar code .....	61
6.3.2.2.2	UCI encoded by channel coding of small block lengths.....	61
6.3.2.3	Channel coding of UCI .....	61
6.3.2.3.1	UCI encoded by Polar code .....	61
6.3.2.3.2	UCI encoded by channel coding of small block lengths.....	61
6.3.2.4	Rate matching .....	62
6.3.2.4.1	UCI encoded by Polar code .....	62
6.3.2.4.1.1	HARQ-ACK .....	62
6.3.2.4.1.2	CSI part 1 .....	63
6.3.2.4.1.3	CSI part 2.....	66
6.3.2.4.2	UCI encoded by channel coding of small block lengths.....	67
6.3.2.4.2.1	HARQ-ACK .....	67
6.3.2.4.2.2	CSI part 1 .....	68
6.3.2.4.2.3	CSI part 2.....	68
6.3.2.5	Code block concatenation .....	68
6.3.2.6	Multiplexing of coded UCI bits to PUSCH.....	68
7	Downlink transport channels and control information .....	68
7.1	Broadcast channel.....	68
7.1.1	PBCH payload generation .....	69
7.1.2	Scrambling .....	70
7.1.3	Transport block CRC attachment.....	71
7.1.4	Channel coding .....	71
7.1.5	Rate matching .....	71
7.2	Downlink shared channel and paging channel .....	71
7.2.1	Transport block CRC attachment.....	71
7.2.2	LDPC base graph selection.....	71
7.2.3	Code block segmentation and code block CRC attachment .....	72
7.2.4	Channel coding .....	72
7.2.5	Rate matching .....	72
7.2.6	Code block concatenation.....	72
7.3	Downlink control information.....	72
7.3.1	DCI formats .....	72
7.3.1.0	DCI size alignment.....	73
7.3.1.1	DCI formats for scheduling of PUSCH.....	75
7.3.1.1.1	Format 0_0 .....	75
7.3.1.1.2	Format 0_1 .....	77
7.3.1.2	DCI formats for scheduling of PDSCH.....	89
7.3.1.2.1	Format 1_0 .....	89
7.3.1.2.2	Format 1_1 .....	92
7.3.1.3	DCI formats for other purposes.....	99
7.3.1.3.1	Format 2_0 .....	99
7.3.1.3.2	Format 2_1 .....	99
7.3.1.3.3	Format 2_2 .....	99
7.3.1.3.4	Format 2_3 .....	99
7.3.2	CRC attachment.....	100

7.3.3 Channel coding .....100  
7.3.4 Rate matching .....101  
**Annex <A> (informative): Change history .....102**  
History .....103

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# Foreword

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# 1 Scope

The present document specifies the coding, multiplexing and mapping to physical channels for 5G NR.

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## 2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
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- [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 38.213: "NR; Physical layer procedures for control"
  - [6] 3GPP TS 38.214: "NR; Physical layer procedures for data"
  - [7] 3GPP TS 38.215: "NR; Physical layer measurements"
  - [8] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"
  - [9] 3GPP TS 38.331: "NR; Radio Resource Control (RRC) protocol specification"
- 

## 3 Definitions, symbols and abbreviations

### 3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP 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 3GPP 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 3GPP 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 3GPP TR 21.905 [1].

BCH	Broadcast channel
CBG	Code block group
CBGTI	Code block group transmission information
CORESET	Control resource set
CQI	Channel quality indicator



CRC	Cyclic redundancy check
CRI	CSI-RS resource indicator
CSI	Channel state information
CSI-RS	CSI reference signal
DAI	Downlink assignment index
DCI	Downlink control information
DL	Downlink
DL-SCH	Downlink shared channel
DMRS	Dedicated demodulation reference signal
HARQ	Hybrid automatic repeat request
HARQ-ACK	Hybrid automatic repeat request acknowledgement
LDPC	Low density parity check
LI	Layer indicator
MCS	Modulation and coding scheme
OFDM	Orthogonal frequency division multiplex
PBCH	Physical broadcast channel
PCH	Paging channel
PDCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PMI	Precoding matrix indicator
PRB	Physical resource block
PRACH	Physical random access channel
PTRS	Phase-tracking reference signal
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
RACH	Random access channel
RI	Rank indicator
RSRP	Reference signal received power
SFN	System frame number
SR	Scheduling request
SRS	Sounding reference signal
SS	Synchronisation signal
SUL	Supplementary uplink
TPC	Transmit power control
TrCH	Transport channel
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel
VRB	Virtual resource block
ZP CSI-RS	Zero power CSI-RS

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## 4 Mapping to physical channels

### 4.1 Uplink

Table 4.1-1 specifies the mapping of the uplink transport channels to their corresponding physical channels. Table 4.1-2 specifies the mapping of the uplink control channel information to its corresponding physical channel.

**Table 4.1-1**

TrCH	Physical Channel
UL-SCH	PUSCH
RACH	PRACH

Table 4.1-2

Control information	Physical Channel
UCI	PUCCH, PUSCH

## 4.2 Downlink

Table 4.2-1 specifies the mapping of the downlink transport channels to their corresponding physical channels. Table 4.2-2 specifies the mapping of the downlink control channel information to its corresponding physical channel.

Table 4.2-1

TrCH	Physical Channel
DL-SCH	PDSCH
BCH	PBCH
PCH	PDSCH

Table 4.2-2

Control information	Physical Channel
DCI	PDCCH

# 5 General procedures

Data and control streams from/to MAC layer are encoded /decoded to offer transport and control services over the radio transmission link. Channel coding scheme is a combination of error detection, error correcting, rate matching, interleaving and transport channel or control information mapping onto/splitting from physical channels.

## 5.1 CRC calculation

Denote the input bits to the CRC computation by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , and the parity bits by  $p_0, p_1, p_2, p_3, \dots, p_{L-1}$ , where  $A$  is the size of the input sequence and  $L$  is the number of parity bits. The parity bits are generated by one of the following cyclic generator polynomials:

- $g_{\text{CRC24A}}(D) = [D^{24} + D^{23} + D^{18} + D^{17} + D^{14} + D^{11} + D^{10} + D^7 + D^6 + D^5 + D^4 + D^3 + D + 1]$  for a CRC length  $L = 24$ ;
- $g_{\text{CRC24B}}(D) = [D^{24} + D^{23} + D^6 + D^5 + D + 1]$  for a CRC length  $L = 24$ ;
- $g_{\text{CRC24C}}(D) = [D^{24} + D^{23} + D^{21} + D^{20} + D^{17} + D^{15} + D^{13} + D^{12} + D^8 + D^4 + D^2 + D + 1]$  for a CRC length  $L = 24$ ;
- $g_{\text{CRC16}}(D) = [D^{16} + D^{12} + D^5 + 1]$  for a CRC length  $L = 16$ ;
- $g_{\text{CRC11}}(D) = [D^{11} + D^{10} + D^9 + D^5 + 1]$  for a CRC length  $L = 11$ ;
- $g_{\text{CRC6}}(D) = [D^6 + D^5 + 1]$  for a CRC length  $L = 6$ .

The encoding is performed in a systematic form, which means that in GF(2), the polynomial:

$$a_0 D^{A+L-1} + a_1 D^{A+L-2} + \dots + a_{A-1} D^L + p_0 D^{L-1} + p_1 D^{L-2} + \dots + p_{L-2} D^1 + p_{L-1}$$

yields a remainder equal to 0 when divided by the corresponding CRC generator polynomial.

The bits after CRC attachment are denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$ , where  $B = A + L$ . The relation between  $a_k$  and  $b_k$  is:

$$b_k = a_k \quad \text{for } k = 0, 1, 2, \dots, A-1$$

$$b_k = p_{k-A} \quad \text{for } k = A, A+1, A+2, \dots, A+L-1.$$

## 5.2 Code block segmentation and code block CRC attachment

### 5.2.1 Polar coding

The input bit sequence to the code block segmentation is denoted by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , where  $A > 0$ .

if  $I_{seg} = 1$

Number of code blocks:  $C = 2$ ;

else

Number of code blocks:  $C = 1$

end if

$$A' = \lceil A/C \rceil \cdot C;$$

for  $i = 0$  to  $A'-A-1$

$$a'_i = 0;$$

end for

for  $i = A'-A$  to  $A'-1$

$$a'_i = a_{i-(A'-A)};$$

end for

$s = 0$ ;

for  $r = 0$  to  $C-1$

for  $k = 0$  to  $A'/C-1$

$$c_{rk} = a'_s;$$

$$s = s + 1;$$

end for

The sequence  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(A'/C-1)}$  is used to calculate the CRC parity bits  $p_{r0}, p_{r1}, p_{r2}, \dots, p_{r(L-1)}$  according to Subclause 5.1 with a generator polynomial of length  $L$ .

for  $k = A'/C$  to  $A'/C+L-1$

$$c_{rk} = p_{r(k-A'/C)};$$

end for

end for

The value of  $A$  is no larger than 1706.

### 5.2.2 Low density parity check coding

The input bit sequence to the code block segmentation is denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$ , where  $B > 0$ . If  $B$  is larger than the maximum code block size  $K_{cb}$ , segmentation of the input bit sequence is performed and an additional CRC sequence of  $L=24$  bits is attached to each code block.

For LDPC base graph 1, the maximum code block size is:

$$- K_{cb} = 8448.$$

For LDPC base graph 2, the maximum code block size is:

$$- K_{cb} = 3840.$$

Total number of code blocks  $C$  is determined by:

if  $B \leq K_{cb}$

$$L = 0$$

Number of code blocks:  $C = 1$

$$B' = B$$

else

$$L = 24$$

Number of code blocks:  $C = \lceil B / (K_{cb} - L) \rceil$ .

$$B' = B + C \cdot L$$

end if

The bits output from code block segmentation are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $0 \leq r < C$  is the code block number, and  $K_r = K$  is the number of bits for the code block number  $r$ .

The number of bits  $K$  in each code block is calculated as:

$$K' = B' / C ;$$

For LDPC base graph 1,

$$K_b = 22.$$

For LDPC base graph 2,

if  $B > 640$

$$K_b = 10 ;$$

elseif  $B > 560$

$$K_b = 9 ;$$

elseif  $B > 192$

$$K_b = 8 ;$$

else

$$K_b = 6 ;$$

end if

find the minimum value of  $Z$  in all sets of lifting sizes in Table 5.3.2-1, denoted as  $Z_c$ , such that  $K_b \cdot Z_c \geq K'$ , and set  $K = 22Z_c$  for LDPC base graph 1 and  $K = 10Z_c$  for LDPC base graph 2;

The bit sequence  $c_{rk}$  is calculated as:

$s = 0$ ;

for  $r = 0$  to  $C - 1$

for  $k = 0$  to  $K' - L - 1$

$c_{rk} = b_s$ ;

$s = s + 1$ ;

end for

if  $C > 1$

The sequence  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K'-L-1)}$  is used to calculate the CRC parity bits  $p_{r0}, p_{r1}, p_{r2}, \dots, p_{r(L-1)}$  according to Subclause 5.1 with the generator polynomial  $g_{\text{CRC24B}}(D)$ .

for  $k = K' - L$  to  $K' - 1$

$c_{rk} = p_{r(k+L-K')}$ ;

end for

end if

for  $k = K'$  to  $K - 1$  -- Insertion of filler bits

$c_{rk} = \langle \text{NULL} \rangle$ ;

end for

end for

## 5.3 Channel coding

Usage of coding scheme for the different types of TrCH is shown in table 5.3-1. Usage of coding scheme for the different control information types is shown in table 5.3-2.

**Table 5.3-1: Usage of channel coding scheme for TrCHs**

TrCH	Coding scheme
UL-SCH	LDPC
DL-SCH	
PCH	
BCH	Polar code

**Table 5.3-2: Usage of channel coding scheme for control information**

Control Information	Coding scheme
DCI	Polar code
UCI	Block code
	Polar code

### 5.3.1 Polar coding

The bit sequence input for a given code block to channel coding is denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits to encode. After encoding the bits are denoted by  $d_0, d_1, d_2, \dots, d_{N-1}$ , where  $N = 2^n$  and the value of  $n$  is determined by the following:

Denote by  $E$  the rate matching output sequence length as given in Subclause 5.4.1;

If  $E \leq (9/8) \cdot 2^{\lceil \log_2 E \rceil - 1}$  and  $K/E < 9/16$

$$n_1 = \lceil \log_2 E \rceil - 1;$$

else

$$n_1 = \lceil \log_2 E \rceil;$$

end if

$$R_{\min} = 1/8;$$

$$n_2 = \lceil \log_2 (K / R_{\min}) \rceil;$$

$$n = \max\{\min\{n_1, n_2, n_{\max}\}, n_{\min}\}$$

where  $n_{\min} = 5$ .

UE is not expected to be configured with  $K + n_{PC} > E$ , where  $n_{PC}$  is the number of parity check bits defined in Subclause 5.3.1.2.

#### 5.3.1.1 Interleaving

The bit sequence  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$  is interleaved into bit sequence  $c'_0, c'_1, c'_2, c'_3, \dots, c'_{K-1}$  as follows:

$$c'_k = c_{\Pi(k)}, \quad k = 0, 1, \dots, K-1$$

where the interleaving pattern  $\Pi(k)$  is given by the following:

if  $I_{LL} = 0$

$$\Pi(k) = k, \quad k = 0, 1, \dots, K-1$$

else

$$k = 0;$$

for  $m = 0$  to  $K_{LL}^{\max} - 1$

if  $\Pi_{LL}^{\max}(m) \geq K_{LL}^{\max} - K$

$$\Pi(k) = \Pi_{LL}^{\max}(m) - (K_{LL}^{\max} - K);$$

$$k = k + 1;$$

end if

end for

end if

where  $\Pi_{LL}^{\max}(m)$  is given by Table 5.3.1.1-1 and  $K_{LL}^{\max} = 164$ .

Table 5.3.1.1-1: Interleaving pattern  $\Pi_{LL}^{\max}(m)$ 

$m$	$\Pi_{LL}^{\max}(m)$	$m$	$\Pi_{LL}^{\max}(m)$	$m$	$\Pi_{LL}^{\max}(m)$	$m$	$\Pi_{LL}^{\max}(m)$	$m$	$\Pi_{LL}^{\max}(m)$	$m$	$\Pi_{LL}^{\max}(m)$
0	0	28	67	56	122	84	68	112	33	140	38
1	2	29	69	57	123	85	73	113	36	141	144
2	4	30	70	58	126	86	78	114	44	142	39
3	7	31	71	59	127	87	84	115	47	143	145
4	9	32	72	60	129	88	90	116	64	144	40
5	14	33	76	61	132	89	92	117	74	145	146
6	19	34	77	62	134	90	94	118	79	146	41
7	20	35	81	63	138	91	96	119	85	147	147
8	24	36	82	64	139	92	99	120	97	148	148
9	25	37	83	65	140	93	102	121	100	149	149
10	26	38	87	66	1	94	105	122	103	150	150
11	28	39	88	67	3	95	107	123	117	151	151
12	31	40	89	68	5	96	109	124	125	152	152
13	34	41	91	69	8	97	112	125	131	153	153
14	42	42	93	70	10	98	114	126	136	154	154
15	45	43	95	71	15	99	116	127	142	155	155
16	49	44	98	72	21	100	121	128	12	156	156
17	50	45	101	73	27	101	124	129	17	157	157
18	51	46	104	74	29	102	128	130	23	158	158
19	53	47	106	75	32	103	130	131	37	159	159
20	54	48	108	76	35	104	133	132	48	160	160
21	56	49	110	77	43	105	135	133	75	161	161
22	58	50	111	78	46	106	141	134	80	162	162
23	59	51	113	79	52	107	6	135	86	163	163
24	61	52	115	80	55	108	11	136	137		
25	62	53	118	81	57	109	16	137	143		
26	65	54	119	82	60	110	22	138	13		
27	66	55	120	83	63	111	30	139	18		

### 5.3.1.2 Polar encoding

The Polar sequence  $\mathbf{Q}_0^{N_{\max}-1} = \{Q_0^{N_{\max}}, Q_1^{N_{\max}}, \dots, Q_{N_{\max}-1}^{N_{\max}}\}$  is given by Table 5.3.1.2-1, where  $0 \leq Q_i^{N_{\max}} \leq N_{\max} - 1$  denotes a bit index before Polar encoding for  $i = 0, 1, \dots, N_{\max} - 1$  and  $N_{\max} = 1024$ . The Polar sequence  $\mathbf{Q}_0^{N_{\max}-1}$  is in ascending order of reliability  $W(Q_0^{N_{\max}}) < W(Q_1^{N_{\max}}) < \dots < W(Q_{N_{\max}-1}^{N_{\max}})$ , where  $W(Q_i^{N_{\max}})$  denotes the reliability of bit index  $Q_i^{N_{\max}}$ .

For any code block encoded to  $N$  bits, a same Polar sequence  $\mathbf{Q}_0^{N-1} = \{Q_0^N, Q_1^N, Q_2^N, \dots, Q_{N-1}^N\}$  is used. The Polar sequence  $\mathbf{Q}_0^{N-1}$  is a subset of Polar sequence  $\mathbf{Q}_0^{N_{\max}-1}$  with all elements  $Q_i^{N_{\max}}$  of values less than  $N$ , ordered in ascending order of reliability  $W(Q_0^N) < W(Q_1^N) < W(Q_2^N) < \dots < W(Q_{N-1}^N)$ .

Denote  $\overline{\mathbf{Q}}_I^N$  as a set of bit indices in Polar sequence  $\mathbf{Q}_0^{N-1}$ , and  $\overline{\mathbf{Q}}_F^N$  as the set of other bit indices in Polar sequence  $\mathbf{Q}_0^{N-1}$ , where  $\overline{\mathbf{Q}}_I^N$  and  $\overline{\mathbf{Q}}_F^N$  are given in Subclause 5.4.1.1,  $|\overline{\mathbf{Q}}_I^N| = K + n_{PC}$ ,  $|\overline{\mathbf{Q}}_F^N| = N - |\overline{\mathbf{Q}}_I^N|$ , and  $n_{PC}$  is the number of parity check bits.

Denote  $\mathbf{G}_N = (\mathbf{G}_2)^{\otimes n}$  as the  $n$ -th Kronecker power of matrix  $\mathbf{G}_2$ , where  $\mathbf{G}_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$ .

For a bit index  $j$  with  $j = 0, 1, \dots, N - 1$ , denote  $\mathbf{g}_j$  as the  $j$ -th row of  $\mathbf{G}_N$  and  $w(\mathbf{g}_j)$  as the row weight of  $\mathbf{g}_j$ , where  $w(\mathbf{g}_j)$  is the number of ones in  $\mathbf{g}_j$ . Denote the set of bit indices for parity check bits as  $\mathbf{Q}_{PC}^N$ , where  $|\mathbf{Q}_{PC}^N| = n_{PC}$ . A number of  $(n_{PC} - n_{PC}^{wm})$  parity check bits are placed in the  $(n_{PC} - n_{PC}^{wm})$  least reliable bit indices in  $\overline{\mathbf{Q}}_I^N$ . A number of  $n_{PC}^{wm}$  other parity check bits are placed in the bit indices of minimum row weight in  $\tilde{\mathbf{Q}}_I^N$ , where  $\tilde{\mathbf{Q}}_I^N$  denotes the  $(|\overline{\mathbf{Q}}_I^N| - n_{PC})$  most reliable bit indices in  $\overline{\mathbf{Q}}_I^N$ ; if there are more than  $n_{PC}^{wm}$  bit indices of the same minimum row weight in  $\tilde{\mathbf{Q}}_I^N$ , the  $n_{PC}^{wm}$  other parity check bits are placed in the  $n_{PC}^{wm}$  bit indices of the highest reliability and the minimum row weight in  $\tilde{\mathbf{Q}}_I^N$ .

Generate  $\mathbf{u} = [u_0 \ u_1 \ u_2 \ \dots \ u_{N-1}]$  according to the following:

$$k = 0;$$

if  $n_{PC} > 0$

$$y_0 = 0; y_1 = 0; y_2 = 0; y_3 = 0; y_4 = 0;$$

for  $n = 0$  to  $N - 1$

$$y_t = y_0; y_0 = y_1; y_1 = y_2; y_2 = y_3; y_3 = y_4; y_4 = y_t;$$

if  $n \in \overline{\mathbf{Q}}_t^N$

if  $n \in \mathbf{Q}_{PC}^N$

$$u_n = y_0;$$

else

$$u_n = c_k';$$

$$k = k + 1;$$

$$y_0 = y_0 \oplus u_n;$$

end if

else

$$u_n = 0;$$

end if

end for

else

for  $n = 0$  to  $N - 1$

if  $n \in \overline{\mathbf{Q}}_t^N$

$$u_n = c_k';$$

$$k = k + 1;$$

else

$$u_n = 0;$$

end if

end for

end if

The output after encoding  $\mathbf{d} = [d_0 \ d_1 \ d_2 \ \dots \ d_{N-1}]$  is obtained by  $\mathbf{d} = \mathbf{u}\mathbf{G}_N$ . The encoding is performed in GF(2).



**Table 5.3.1.2-1: Polar sequence  $Q_0^{N_{\max}-1}$  and its corresponding reliability  $W(Q_i^{N_{\max}})$**



88	97	216	116	344	299	472	189	600	573	728	795	856	931	984	511
89	39	217	170	345	354	473	566	601	411	729	473	857	756	985	988
90	259	218	61	346	211	474	676	602	803	730	634	858	860	986	1001
91	84	219	531	347	401	475	361	603	789	731	744	859	499	987	951
92	138	220	525	348	185	476	706	604	709	732	852	860	731	988	1002
93	145	221	642	349	396	477	589	605	365	733	960	861	823	989	893
94	261	222	281	350	344	478	215	606	440	734	865	862	922	990	975
95	29	223	278	351	586	479	786	607	628	735	693	863	874	991	894
96	43	224	526	352	645	480	647	608	689	736	797	864	918	992	1009
97	98	225	177	353	593	481	348	609	374	737	906	865	502	993	955
98	515	226	293	354	535	482	419	610	423	738	715	866	933	994	1004
99	88	227	388	355	240	483	406	611	466	739	807	867	743	995	1010
100	140	228	91	356	206	484	464	612	793	740	474	868	760	996	957
101	30	229	584	357	95	485	680	613	250	741	636	869	881	997	983
102	146	230	769	358	327	486	801	614	371	742	694	870	494	998	958
103	71	231	198	359	564	487	362	615	481	743	254	871	702	999	987
104	262	232	172	360	800	488	590	616	574	744	717	872	921	1000	1012
105	265	233	120	361	402	489	409	617	413	745	575	873	501	1001	999
106	161	234	201	362	356	490	570	618	603	746	913	874	876	1002	1016
107	576	235	336	363	307	491	788	619	366	747	798	875	847	1003	767
108	45	236	62	364	301	492	597	620	468	748	811	876	992	1004	989
109	100	237	282	365	417	493	572	621	655	749	379	877	447	1005	1003
110	640	238	143	366	213	494	219	622	900	750	697	878	733	1006	990
111	51	239	103	367	568	495	311	623	805	751	431	879	827	1007	1005
112	148	240	178	368	832	496	708	624	615	752	607	880	934	1008	959
113	46	241	294	369	588	497	598	625	684	753	489	881	882	1009	1011
114	75	242	93	370	186	498	601	626	710	754	866	882	937	1010	1013
115	266	243	644	371	646	499	651	627	429	755	723	883	963	1011	895
116	273	244	202	372	404	500	421	628	794	756	486	884	747	1012	1006
117	517	245	592	373	227	501	792	629	252	757	908	885	505	1013	1014
118	104	246	323	374	896	502	802	630	373	758	718	886	855	1014	1017
119	162	247	392	375	594	503	611	631	605	759	813	887	924	1015	1018
120	53	248	297	376	418	504	602	632	848	760	476	888	734	1016	991
121	193	249	770	377	302	505	410	633	690	761	856	889	829	1017	1020
122	152	250	107	378	649	506	231	634	713	762	839	890	965	1018	1007
123	77	251	180	379	771	507	688	635	632	763	725	891	938	1019	1015
124	164	252	151	380	360	508	653	636	482	764	698	892	884	1020	1019
125	768	253	209	381	539	509	248	637	806	765	914	893	506	1021	1021
126	268	254	284	382	111	510	369	638	427	766	752	894	749	1022	1022
127	274	255	648	383	331	511	190	639	904	767	868	895	945	1023	1023

### 5.3.2 Low density parity check coding

The bit sequence input for a given code block to channel coding is denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits to encode as defined in Subclause 5.2.2. After encoding the bits are denoted by  $d_0, d_1, d_2, \dots, d_{N-1}$ , where  $N = 66Z_c$  for LDPC base graph 1 and  $N = 50Z_c$  for LDPC base graph 2, and the value of  $Z_c$  is given in Subclause 5.2.2.

For a code block encoded by LDPC, the following encoding procedure applies:

1) Find the set with index  $i_{LS}$  in Table 5.3.2-1 which contains  $Z_c$ .

2) for  $k = 2Z_c$  to  $K - 1$

if  $c_k \neq \text{NULL}$

$$d_{k-2Z_c} = c_k;$$

else

$$c_k = 0;$$

$$d_{k-2Z_c} = \text{NULL};$$

end if

end for

3) Generate  $N + 2Z_c - K$  parity bits  $\mathbf{w} = [w_0, w_1, w_2, \dots, w_{N+2Z_c-K}]^T$  such that  $\mathbf{H} \times \begin{bmatrix} \mathbf{c} \\ \mathbf{w} \end{bmatrix} = \mathbf{0}$ , where

$\mathbf{c} = [c_0, c_1, c_2, \dots, c_{K-1}]^T$ ;  $\mathbf{0}$  is a column vector of all elements equal to 0. The encoding is performed in GF(2).

For LDPC base graph 1, a matrix of  $\mathbf{H}_{\text{BG}}$  has 46 rows with row indices  $i = 0,1,2,\dots,45$  and 68 columns with column indices  $j = 0,1,2,\dots,67$ . For LDPC base graph 2, a matrix of  $\mathbf{H}_{\text{BG}}$  has 42 rows with row indices  $i = 0,1,2,\dots,41$  and 52 columns with column indices  $j = 0,1,2,\dots,51$ . The elements in  $\mathbf{H}_{\text{BG}}$  with row and column indices given in Table 5.3.2-2 (for LDPC base graph 1) and Table 5.3.2-3 (for LDPC base graph 2) are of value 1, and all other elements in  $\mathbf{H}_{\text{BG}}$  are of value 0.

The matrix  $\mathbf{H}$  is obtained by replacing each element of  $\mathbf{H}_{\text{BG}}$  with a  $Z_c \times Z_c$  matrix, according to the following:

- Each element of value 0 in  $\mathbf{H}_{\text{BG}}$  is replaced by an all zero matrix  $\mathbf{0}$  of size  $Z_c \times Z_c$ ;
- Each element of value 1 in  $\mathbf{H}_{\text{BG}}$  is replaced by a circular permutation matrix  $\mathbf{I}(P_{i,j})$  of size  $Z_c \times Z_c$ , where  $i$  and  $j$  are the row and column indices of the element, and  $\mathbf{I}(P_{i,j})$  is obtained by circularly shifting the identity matrix  $\mathbf{I}$  of size  $Z_c \times Z_c$  to the right  $P_{i,j}$  times. The value of  $P_{i,j}$  is given by  $P_{i,j} = \text{mod}(V_{i,j}, Z_c)$ . The value of  $V_{i,j}$  is given by Tables 5.3.2-2 and 5.3.2-3 according to the set index  $i_{\text{LS}}$  and LDPC base graph.

4) for  $k = K$  to  $N + 2Z_c - 1$

$$d_{k-2Z_c} = w_{k-K};$$

end for

**Table 5.3.2-1: Sets of LDPC lifting size  $Z$**

Set index ( $i_{\text{LS}}$ )	Set of lifting sizes ( $Z$ )
0	{2, 4, 8, 16, 32, 64, 128, 256}
1	{3, 6, 12, 24, 48, 96, 192, 384}
2	{5, 10, 20, 40, 80, 160, 320}
3	{7, 14, 28, 56, 112, 224}
4	{9, 18, 36, 72, 144, 288}
5	{11, 22, 44, 88, 176, 352}
6	{13, 26, 52, 104, 208}
7	{15, 30, 60, 120, 240}

**Table 5.3.2-2: LDPC base graph 1 ( $H_{BG}$ ) and its parity check matrices ( $V_{i,j}$ )**



	21	123	51	267	130	79	258	161	180		13	120	260	105	210	252	95	112	26	
	22	115	157	279	153	144	283	72	180		24	9	90	135	123	173	212	20	105	
6	27	0	0	0	0	0	0	0	0	31	52	0	0	0	0	0	0	0	0	
	0	183	278	289	158	80	294	6	199		1	95	100	222	175	144	101	4	73	
	6	22	257	21	119	144	73	27	22		7	177	215	308	49	144	297	49	149	
	10	28	1	293	113	169	330	163	23		22	172	258	66	177	166	279	125	175	
	11	67	351	13	21	90	99	50	100		25	61	256	162	128	19	222	194	108	
	13	244	92	232	63	59	172	48	92		53	0	0	0	0	0	0	0	0	
	17	11	253	302	51	177	150	24	207		0	221	102	210	192	0	351	6	103	
7	18	157	18	138	136	151	284	38	52	32	12	112	201	22	209	211	265	126	110	
	20	211	225	235	116	108	305	91	13		14	199	175	271	58	36	338	63	151	
	28	0	0	0	0	0	0	0	0		24	121	287	217	30	162	83	20	211	
	0	220	9	12	17	169	3	145	77		54	0	0	0	0	0	0	0	0	
	1	44	62	88	76	189	103	88	146		33	1	2	323	170	114	0	56	10	199
	4	159	316	207	104	154	224	112	209			2	187	8	20	49	0	304	30	132
	7	31	333	50	100	184	297	153	32			11	41	361	140	161	76	141	6	172
8	167	290	25	150	104	215	159	166	21	211		105	33	137	18	101	92	65		
14	104	114	76	158	164	39	76	18	55	0		0	0	0	0	0	0	0		
29	0	0	0	0	0	0	0	0	0	127	230	187	82	197	60	4	161			
8	0	112	307	295	33	54	348	172	181	34	7	167	148	296	186	0	320	153	237	
	1	4	179	133	95	0	75	2	105		15	164	202	5	68	108	112	197	142	
	3	7	165	130	4	252	22	131	141		17	159	312	44	150	0	54	155	180	
	12	211	18	231	217	41	312	141	223		56	0	0	0	0	0	0	0	0	
	16	102	39	296	204	98	224	96	177		35	1	161	320	207	192	199	100	4	231
	19	164	224	110	39	46	17	99	145			6	197	335	158	173	278	210	45	174
	21	109	368	269	58	15	59	101	199			12	207	2	55	26	0	195	168	145
22	241	67	245	44	230	314	35	153	22	103		266	285	187	205	268	185	100		
24	90	170	154	201	54	244	116	38	57	0		0	0	0	0	0	0	0		
30	0	0	0	0	0	0	0	0	0	37	210	259	222	216	135	6	11			
9	0	103	366	189	9	162	156	6	169	36	14	105	313	179	157	16	15	200	207	
	1	182	232	244	37	159	88	10	12		15	51	297	178	0	0	35	177	42	
	10	109	321	36	213	93	293	145	206		18	120	21	160	6	0	188	43	100	
	11	21	133	286	105	134	111	53	221		58	0	0	0	0	0	0	0	0	
	13	142	57	151	89	45	92	201	17		37	1	198	269	298	81	72	319	82	59
	17	14	303	267	185	132	152	4	212			13	220	82	15	195	144	236	2	204
	18	61	63	135	109	76	23	164	92			23	122	115	115	138	0	85	135	161
20	216	82	209	218	209	337	173	205	59	0		0	0	0	0	0	0	0		
31	0	0	0	0	0	0	0	0	0	167		185	151	123	190	164	91	121		
10	1	98	101	14	82	178	175	126	116	38	9	151	177	179	90	0	196	64	90	
	2	149	339	80	165	1	253	77	151		10	157	289	64	73	0	209	198	26	
	4	167	274	211	174	28	27	156	70		12	163	214	181	10	0	246	100	140	
	7	160	111	75	19	267	231	16	230		60	0	0	0	0	0	0	0	0	
	8	49	383	161	194	234	49	12	115		39	1	173	258	102	12	153	236	4	115
	14	58	354	311	103	201	267	70	84			3	139	93	77	77	0	264	28	188
	32	0	0	0	0	0	0	0	0			7	149	346	192	49	165	37	109	168
0	77	48	16	52	55	25	184	45	19	0		297	208	114	117	272	188	52		
1	41	102	147	11	23	322	194	115	61	0		0	0	0	0	0	0	0		
11	12	83	8	290	2	274	200	123	134	40	0	157	175	32	67	216	304	10	4	
	16	182	47	289	35	181	351	16	1		8	137	37	80	45	144	237	84	103	
	21	78	188	177	32	273	166	104	152		17	149	312	197	96	2	135	12	30	
	22	252	334	43	84	39	338	109	165		62	0	0	0	0	0	0	0	0	
	23	22	115	280	201	26	192	124	107		41	1	167	52	154	23	0	123	2	53
	33	0	0	0	0	0	0	0	0			3	173	314	47	215	0	77	75	189
	0	160	77	229	142	225	123	6	186			9	139	139	124	60	0	25	142	215
1	42	186	235	175	162	217	20	215	18	151		288	207	167	183	272	128	24		
10	21	174	169	136	244	142	203	124	63	0		0	0	0	0	0	0	0		
12	11	32	232	48	3	151	110	153	180	42	0	149	113	226	114	27	288	163	222	
	13	234	50	105	28	238	176	104	98		4	157	14	65	91	0	83	10	170	
	18	7	74	52	182	243	76	207	80		24	137	218	126	78	35	17	162	71	
	34	0	0	0	0	0	0	0	0		64	0	0	0	0	0	0	0	0	
	0	177	313	39	81	231	311	52	220		43	1	151	113	228	206	52	210	1	22
	3	248	177	302	56	0	251	147	185			16	163	132	69	22	243	3	163	127
	7	151	266	303	72	216	265	1	154			18	173	114	176	134	0	53	99	49
20	185	115	160	217	47	94	16	178	25	139		168	102	161	270	167	98	125		
23	62	370	37	78	36	81	46	150	65	0		0	0	0	0	0	0	0		
35	0	0	0	0	0	0	0	0	0	139	80	234	84	18	79	4	191			
13	0	206	142	78	14	0	22	1	124	44	7	157	78	227	4	0	244	6	211	
	12	55	248	299	175	186	322	202	144		9	163	163	259	9	0	293	142	187	
	15	206	137	54	211	253	277	118	182		22	173	274	260	12	57	272	3	148	
	16	127	89	61	191	16	156	130	95		66	0	0	0	0	0	0	0	0	
	17	16	347	179	51	0	66	1	72		45	1	149	135	101	184	168	82	181	177
	21	229	12	258	43	79	78	2	76			6	151	149	228	121	0	67	45	114
	36	0	0	0	0	0	0	0	0			10	167	15	126	29	144	235	153	93
0	40	241	229	90	170	176	173	39	67	0		0	0	0	0	0	0	0		

**Table 5.3.2-3: LDPC base graph 2 ( $H_{BG}$ ) and its parity check matrices ( $V_{i,j}$ )**



$H_{BG}$		$V_{i,j}$									
Row index $i$	Column index $j$	Set index $i_{LS}$									
		0	1	2	3	4	5	6	7		
0	0	9	174	0	72	3	156	143	145		
	1	117	97	0	110	26	143	19	131		
	2	204	166	0	23	53	14	176	71		
	3	26	66	0	181	35	3	165	21		
	6	189	71	0	95	115	40	196	23		
	9	205	172	0	8	127	123	13	112		
	10	0	0	0	1	0	0	0	1		
	11	0	0	0	0	0	0	0	0		
	1	0	167	27	137	53	19	17	18	142	
		3	166	36	124	156	94	65	27	174	
		4	253	48	0	115	104	63	3	183	
		5	125	92	0	156	66	1	102	27	
6		226	31	88	115	84	55	185	96		
7		156	187	0	200	98	37	17	23		
8		224	185	0	29	69	171	14	9		
9		252	3	55	31	50	133	180	167		
11		0	0	0	0	0	0	0	0		
12		0	0	0	0	0	0	0	0		
2		0	81	25	20	152	95	98	126	74	
		1	114	114	94	131	106	168	163	31	
	3	44	117	99	46	92	107	47	3		
	4	52	110	9	191	110	82	183	53		
	8	240	114	108	91	111	142	132	155		
	10	1	1	1	0	1	1	1	0		
	12	0	0	0	0	0	0	0	0		
	13	0	0	0	0	0	0	0	0		
	3	1	8	136	38	185	120	53	36	239	
		2	58	175	15	6	121	174	48	171	
		4	158	113	102	36	22	174	18	95	
		5	104	72	146	124	4	127	111	110	
6		209	123	12	124	73	17	203	159		
7		54	118	57	110	49	89	3	199		
8		18	28	53	156	128	17	191	43		
9		128	186	46	133	79	105	160	75		
10		0	0	0	1	0	0	0	1		
13		0	0	0	0	0	0	0	0		
4		0	179	72	0	200	42	86	43	29	
		1	214	74	136	16	24	67	27	140	
	11	71	29	157	101	51	83	117	180		
	14	0	0	0	0	0	0	0	0		
	5	0	231	10	0	185	40	79	136	121	
		1	41	44	131	138	140	84	49	41	
		5	194	121	142	170	84	35	36	169	
		7	159	80	141	219	137	103	132	88	
		11	103	48	64	193	71	60	62	207	
		15	0	0	0	0	0	0	0	0	
		6	0	155	129	0	123	109	47	7	137
			5	228	92	124	55	87	154	34	72
7			45	100	99	31	107	10	198	172	
9			28	49	45	222	133	155	168	124	
11			158	184	148	209	139	29	12	56	
16			0	0	0	0	0	0	0	0	
7	1		129	80	0	103	97	48	163	86	
	5		147	186	45	13	135	125	78	186	
	7		140	16	148	105	35	24	143	87	
	11		3	102	96	150	108	47	107	172	
	13		116	143	78	181	65	55	58	154	
	17		0	0	0	0	0	0	0	0	
	8	0	142	118	0	147	70	53	101	176	
		1	94	70	65	43	69	31	177	169	
		12	230	152	87	152	88	161	22	225	
		18	0	0	0	0	0	0	0	0	
		9	1	203	28	0	2	97	104	186	167
			8	205	132	97	30	40	142	27	238
10			61	185	51	184	24	99	205	48	
11			247	178	85	83	49	64	81	68	
19			0	0	0	0	0	0	0	0	
10			0	11	59	0	174	46	111	125	38
			1	185	104	17	150	41	25	60	217
			6	0	22	156	8	101	174	177	208
	7		117	52	20	56	96	23	51	232	
	20		0	0	0	0	0	0	0	0	
	11		0	11	32	0	99	28	91	39	178
			7	236	92	7	138	30	175	29	214
		9	210	174	4	110	116	24	35	168	
		13	56	154	2	99	64	141	8	51	
		21	0	0	0	0	0	0	0	0	
		12	1	63	39	0	46	33	122	18	124
			3	111	93	113	217	122	11	155	122
11			14	11	48	109	131	4	49	72	
22			0	0	0	0	0	0	0	0	
13			0	83	49	0	37	76	29	32	48
			1	2	125	112	113	37	91	53	57
			8	38	35	102	143	62	27	95	167

	13	222	166	26	140	47	127	186	219		11	38	190	19	46	1	19	191	105
	23	0	0	0	0	0	0	0	0		48	0	0	0	0	0	0	0	0
14	1	115	19	0	36	143	11	91	82	39	0	239	93	0	106	119	109	181	167
	6	145	118	138	95	51	145	20	232		7	172	132	24	181	32	6	157	45
	11	3	21	57	40	130	8	52	204		12	34	57	138	154	142	105	173	189
	13	232	163	27	116	97	166	109	162		49	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0		2	0	103	0	98	6	160	193	78
15	0	51	68	0	116	139	137	174	38	40	10	75	107	36	35	73	156	163	67
	10	175	63	73	200	96	103	108	217		13	120	163	143	36	102	82	179	180
	11	213	81	99	110	128	40	102	157		50	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0		1	129	147	0	120	48	132	191	53
	1	203	87	0	75	48	78	125	170		41	5	229	7	2	101	47	6	197
9	142	177	79	158	9	158	31	23	11	118		60	55	81	19	8	167	230	
11	8	135	111	134	28	17	54	175	51	0		0	0	0	0	0	0	0	
12	242	64	143	97	8	165	176	202											

### 5.3.3 Channel coding of small block lengths

The bit sequence input for a given code block to channel coding is denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits to encode. After encoding the bits are denoted by  $d_0, d_1, d_2, \dots, d_{N-1}$ .

#### 5.3.3.1 Encoding of 1-bit information

For  $K = 1$ , the code block is encoded according to Table 5.3.3.1-1, where  $N = Q_m$  and  $Q_m$  is the modulation order for the code block.

**Table 5.3.3.1-1: Encoding of 1-bit information**

$Q_m$	Encoded bits $d_0, d_1, d_2, \dots, d_{N-1}$
1	$[c_0]$
2	$[c_0 \ y]$
4	$[c_0 \ y \ x \ x]$
6	$[c_0 \ y \ x \ x \ x \ x]$
8	$[c_0 \ y \ x \ x \ x \ x \ x \ x]$

The "x" and "y" in Table 5.3.3.1-1 are placeholders for Subclause 6.3.1.1 of [4, TS 38.211] to scramble the information bits in a way that maximizes the Euclidean distance of the modulation symbols carrying the information bits.

#### 5.3.3.2 Encoding of 2-bit information

For  $K = 2$ , the code block is encoded according to Table 5.3.3-2, where  $c_2 = (c_0 + c_1) \bmod 2$ ,  $N = 3Q_m$ , and  $Q_m$  is the modulation order for the code block.

**Table 5.3.3.2-1: Encoding of 2-bit information**

$Q_m$	Encoded bits $d_0, d_1, d_2, \dots, d_{N-1}$
1	$[c_0 \ c_1 \ c_2]$
2	$[c_0 \ c_1 \ c_2 \ c_0 \ c_1 \ c_2]$
4	$[c_0 \ c_1 \ x \ x \ c_2 \ c_0 \ x \ x \ c_1 \ c_2 \ x \ x]$
6	$[c_0 \ c_1 \ x \ x \ x \ x \ c_2 \ c_0 \ x \ x \ x \ x \ c_1 \ c_2 \ x \ x \ x \ x]$
8	$[c_0 \ c_1 \ x \ x \ x \ x \ x \ x \ c_2 \ c_0 \ x \ x \ x \ x \ x \ x \ c_1 \ c_2 \ x \ x \ x \ x \ x \ x]$

The "x" in Table 5.3.3.2-1 are placeholders for Subclause 6.3.1.1 of [4, TS 38.211] to scramble the information bits in a way that maximizes the Euclidean distance of the modulation symbols carrying the information bits.

#### 5.3.3.3 Encoding of other small block lengths

For  $3 \leq K \leq 11$ , the code block is encoded by  $d_i = \left( \sum_{k=0}^{K-1} c_k \cdot M_{i,k} \right) \bmod 2$ , where  $i = 0, 1, \dots, N-1$ ,  $N = 32$ , and  $M_{i,k}$  represents the basis sequences as defined in Table 5.3.3.3-1.

Table 5.3.3.3-1: Basis sequences for (32,  $K$ ) code

$i$	$M_{i,0}$	$M_{i,1}$	$M_{i,2}$	$M_{i,3}$	$M_{i,4}$	$M_{i,5}$	$M_{i,6}$	$M_{i,7}$	$M_{i,8}$	$M_{i,9}$	$M_{i,10}$
0	1	1	0	0	0	0	0	0	0	0	1
1	1	1	1	0	0	0	0	0	0	1	1
2	1	0	0	1	0	0	1	0	1	1	1
3	1	0	1	1	0	0	0	0	1	0	1
4	1	1	1	1	0	0	0	1	0	0	1
5	1	1	0	0	1	0	1	1	1	0	1
6	1	0	1	0	1	0	1	0	1	1	1
7	1	0	0	1	1	0	0	1	1	0	1
8	1	1	0	1	1	0	0	1	0	1	1
9	1	0	1	1	1	0	1	0	0	1	1
10	1	0	1	0	0	1	1	1	0	1	1
11	1	1	1	0	0	1	1	0	1	0	1
12	1	0	0	1	0	1	0	1	1	1	1
13	1	1	0	1	0	1	0	1	0	1	1
14	1	0	0	0	1	1	0	1	0	0	1
15	1	1	0	0	1	1	1	1	0	1	1
16	1	1	1	0	1	1	1	0	0	1	0
17	1	0	0	1	1	1	0	0	1	0	0
18	1	1	0	1	1	1	1	1	0	0	0
19	1	0	0	0	0	1	1	0	0	0	0
20	1	0	1	0	0	0	1	0	0	0	1
21	1	1	0	1	0	0	0	0	0	1	1
22	1	0	0	0	1	0	0	1	1	0	1
23	1	1	1	0	1	0	0	0	1	1	1
24	1	1	1	1	1	0	1	1	1	1	0
25	1	1	0	0	0	1	1	1	0	0	1
26	1	0	1	1	0	1	0	0	1	1	0
27	1	1	1	1	0	1	0	1	1	1	0
28	1	0	1	0	1	1	1	0	1	0	0
29	1	0	1	1	1	1	1	1	1	0	0
30	1	1	1	1	1	1	1	1	1	1	1
31	1	0	0	0	0	0	0	0	0	0	0

## 5.4 Rate matching

### 5.4.1 Rate matching for Polar code

The rate matching for Polar code is defined per coded block and consists of sub-block interleaving, bit collection, and bit interleaving. The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ . The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

#### 5.4.1.1 Sub-block interleaving

The bits input to the sub-block interleaver are the coded bits  $d_0, d_1, d_2, \dots, d_{N-1}$ . The coded bits  $d_0, d_1, d_2, \dots, d_{N-1}$  are divided into 32 sub-blocks. The bits output from the sub-block interleaver are denoted as  $y_0, y_1, y_2, \dots, y_{N-1}$ , generated as follows:

for  $n = 0$  to  $N - 1$

$$i = \lfloor 32n / N \rfloor;$$

$$J(n) = P(i) \times (N/32) + \text{mod}(n, N/32);$$

$$y_n = d_{J(n)};$$

end for

where the sub-block interleaver pattern  $P(i)$  is given by Table 5.4.1.1-1.

**Table 5.4.1.1-1: Sub-block interleaver pattern  $P(i)$**

$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$	$i$	$P(i)$
0	0	4	3	8	8	12	10	16	12	20	14	24	24	28	27
1	1	5	5	9	16	13	18	17	20	21	22	25	25	29	29
2	2	6	6	10	9	14	11	18	13	22	15	26	26	30	30
3	4	7	7	11	17	15	19	19	21	23	23	27	28	31	31

The sets of bit indices  $\overline{\mathbf{Q}}_I^N$  and  $\overline{\mathbf{Q}}_F^N$  are determined as follows, where  $K$ ,  $n_{PC}$ , and  $\mathbf{Q}_0^{N-1}$  are defined in Subclause 5.3.1

$$\overline{\mathbf{Q}}_{F,imp}^N = \emptyset$$

if  $E < N$

if  $K/E \leq 7/16$  -- puncturing

for  $n = 0$  to  $N - E - 1$

$$\overline{\mathbf{Q}}_{F,imp}^N = \overline{\mathbf{Q}}_{F,imp}^N \cup \{J(n)\};$$

end for

if  $E \geq 3N/4$

$$\overline{\mathbf{Q}}_{F,imp}^N = \overline{\mathbf{Q}}_{F,imp}^N \cup \{0,1,\dots,\lceil 3N/4 - E/2 \rceil - 1\};$$

else

$$\overline{\mathbf{Q}}_{F,imp}^N = \overline{\mathbf{Q}}_{F,imp}^N \cup \{0,1,\dots,\lceil 9N/16 - E/4 \rceil - 1\};$$

end if

else -- shortening

for  $n = E$  to  $N - 1$

$$\overline{\mathbf{Q}}_{F,imp}^N = \overline{\mathbf{Q}}_{F,imp}^N \cup \{J(n)\};$$

end for

end if

end if

$$\overline{\mathbf{Q}}_{I,imp}^N = \mathbf{Q}_0^{N-1} \setminus \overline{\mathbf{Q}}_{F,imp}^N;$$

$\overline{\mathbf{Q}}_I^N$  comprises  $(K + n_{PC})$  most reliable bit indices in  $\overline{\mathbf{Q}}_{I,imp}^N$ ;

$$\overline{\mathbf{Q}}_F^N = \mathbf{Q}_0^{N-1} \setminus \overline{\mathbf{Q}}_I^N;$$

### 5.4.1.2 Bit selection

The bit sequence after the sub-block interleaver  $y_0, y_1, y_2, \dots, y_{N-1}$  from Subclause 5.4.1.1 is written into a circular buffer of length  $N$ .

Denoting by  $E$  the rate matching output sequence length, the bit selection output bit sequence  $e_k$ ,  $k = 0, 1, 2, \dots, E - 1$ , is generated as follows:

```

if  $E \geq N$  -- repetition
  for  $k = 0$  to  $E - 1$ 
     $e_k = y_{\text{mod}(k,N)}$ ;
  end for
else
  if  $K/E \leq 7/16$  -- puncturing
    for  $k = 0$  to  $E - 1$ 
       $e_k = y_{k+N-E}$ ;
    end for
  else -- shortening
    for  $k = 0$  to  $E - 1$ 
       $e_k = y_k$ ;
    end for
  end if
end if

```

### 5.4.1.3 Interleaving of coded bits

The bit sequence  $e_0, e_1, e_2, \dots, e_{E-1}$  is interleaved into bit sequence  $f_0, f_1, f_2, \dots, f_{E-1}$ , as follows:

If  $I_{BL} = 1$

Denote  $T$  as the smallest integer such that  $T(T+1)/2 \geq E$ ;

$k = 0$ ;

for  $i = 0$  to  $T - 1$

for  $j = 0$  to  $T - 1 - i$

if  $k < E$

$v_{i,j} = e_k$ ;

else

$v_{i,j} = \langle \text{NULL} \rangle$ ;

end if

$k = k + 1$ ;

end for

end for

$k = 0$ ;

for  $j = 0$  to  $T - 1$

```

for  $i = 0$  to  $T - 1 - j$ 
    if  $v_{i,j} \neq \langle NULL \rangle$ 
         $f_k = v_{i,j}$ ;
         $k = k + 1$ 
    end if
end for
end for
else
    for  $i = 0$  to  $E - 1$ 
         $f_i = e_i$ ;
    end for
end if

```

The value of  $E$  is no larger than 8192.

## 5.4.2 Rate matching for LDPC code

The rate matching for LDPC code is defined per coded block and consists of bit selection and bit interleaving. The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ . The output bit sequence after rate matching is denoted as

$f_0, f_1, f_2, \dots, f_{E-1}$ .

### 5.4.2.1 Bit selection

The bit sequence after encoding  $d_0, d_1, d_2, \dots, d_{N-1}$  from Subclause 5.3.2 is written into a circular buffer of length  $N_{cb}$  for the  $r$ -th coded block, where  $N$  is defined in Subclause 5.3.2.

For the  $r$ -th code block, let  $N_{cb} = N$  if  $I_{LBRM} = 0$  and  $N_{cb} = \min(N, N_{ref})$  otherwise, where  $N_{ref} = \left\lfloor \frac{TBS_{LBRM}}{C \cdot R_{LBRM}} \right\rfloor$ ,

$R_{LBRM} = 2/3$ ,  $TBS_{LBRM}$  is determined according to Subclause 6.1.4.2 in [6, TS 38.214] for UL-SCH and Subclause 5.1.3.2 in [6, TS 38.214] for DL-SCH/PCH, assuming the following:

- maximum number of layers for one TB for UL-SCH is given by  $X$ , where
  - if the higher layer parameter *maxMIMO-Layers* of *PUSCH-ServingCellConfig* of the serving cell is configured,  $X$  is given by that parameter
  - elseif the higher layer parameter *maxRank* of *pusch-Config* of the serving cell is configured,  $X$  is given by the maximum value of *maxRank* across all BWPs of the serving cell
  - otherwise,  $X$  is given by the maximum number of layers for PUSCH supported by the UE for the serving cell
- maximum number of layers for one TB for DL-SCH/PCH is given by the minimum of  $X$  and 4, where
  - if the higher layer parameter *maxMIMO-Layers* of *PDSCH-ServingCellConfig* of the serving cell is configured,  $X$  is given by that parameter
  - otherwise,  $X$  is given by the maximum number of layers for PDSCH supported by the UE for the serving cell
- maximum modulation order configured for the serving cell, if configured by higher layers; otherwise a maximum modulation order  $Q_m = 6$  is assumed for DL-SCH;
- maximum coding rate of 948/1024;

- $n_{PRB} = n_{PRB,LBRM}$  is given by Table 5.4.2.1-1, where the value of  $n_{PRB,LBRM}$  for DL-SCH is determined according to the initial bandwidth part if there is no other bandwidth part configured to the UE;
- $N_{RE} = 156 \cdot n_{PRB}$ ;
- $C$  is the number of code blocks of the transport block determined according to Subclause 5.2.2.

**Table 5.4.2.1-1: Value of  $n_{PRB,LBRM}$** 

Maximum number of PRBs across all configured BWPs of a carrier	$n_{PRB,LBRM}$
Less than 33	32
33 to 66	66
67 to 107	107
108 to 135	135
136 to 162	162
163 to 217	217
Larger than 217	273

Denoting by  $E_r$  the rate matching output sequence length for the  $r$ -th coded block, where the value of  $E_r$  is determined as follows:

Set  $j = 0$

for  $r = 0$  to  $C - 1$

if the  $r$ -th coded block is not scheduled for transmission as indicated by CBGTI according to Subclause 5.1.7.2 for DL-SCH and 6.1.5.2 for UL-SCH in [6, TS 38.214]

$E_r = 0$ ;

else

if  $j \leq C' - \text{mod}(G / (N_L \cdot Q_m), C') - 1$

$$E_r = N_L \cdot Q_m \cdot \left\lfloor \frac{G}{N_L \cdot Q_m \cdot C'} \right\rfloor;$$

else

$$E_r = N_L \cdot Q_m \cdot \left\lceil \frac{G}{N_L \cdot Q_m \cdot C'} \right\rceil;$$

end if

$j = j + 1$ ;

end if

end for

where

- $N_L$  is the number of transmission layers that the transport block is mapped onto;
- $Q_m$  is the modulation order;
- $G$  is the total number of coded bits available for transmission of the transport block;

- $C' = C$  if CBGTI is not present in the DCI scheduling the transport block and  $C'$  is the number of scheduled code blocks of the transport block if CBGTI is present in the DCI scheduling the transport block.

Denote by  $rv_{id}$  the redundancy version number for this transmission ( $rv_{id} = 0, 1, 2$  or  $3$ ), the rate matching output bit sequence  $e_k$ ,  $k = 0, 1, 2, \dots, E-1$ , is generated as follows, where  $k_0$  is given by Table 5.4.2.1-2 according to the value of  $rv_{id}$  and LDPC base graph:

$k = 0$ ;

$j = 0$ ;

while  $k < E$

if  $d_{(k_0+j) \bmod N_{cb}} \neq \langle NULL \rangle$

$e_k = d_{(k_0+j) \bmod N_{cb}}$ ;

$k = k + 1$ ;

end if

$j = j + 1$ ;

end while

**Table 5.4.2.1-2: Starting position of different redundancy versions,  $k_0$**

$rv_{id}$	$k_0$	
	LDPC base graph 1	LDPC base graph 2
0	0	0
1	$\left\lfloor \frac{17N_{cb}}{66Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{13N_{cb}}{50Z_c} \right\rfloor Z_c$
2	$\left\lfloor \frac{33N_{cb}}{66Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{25N_{cb}}{50Z_c} \right\rfloor Z_c$
3	$\left\lfloor \frac{56N_{cb}}{66Z_c} \right\rfloor Z_c$	$\left\lfloor \frac{43N_{cb}}{50Z_c} \right\rfloor Z_c$

### 5.4.2.2 Bit interleaving

The bit sequence  $e_0, e_1, e_2, \dots, e_{E-1}$  is interleaved to bit sequence  $f_0, f_1, f_2, \dots, f_{E-1}$ , according to the following, where the value of  $Q_m$  is the modulation order.

for  $j = 0$  to  $E/Q_m - 1$

for  $i = 0$  to  $Q_m - 1$

$f_{i+jQ_m} = e_{i+E/Q_m+j}$ ;

end for

end for



### 5.4.3 Rate matching for channel coding of small block lengths

The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ . The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ , where  $E$  is the rate matching output sequence length. The bit sequence  $f_0, f_1, f_2, \dots, f_{E-1}$  is obtained by the following:

for  $k = 0$  to  $E - 1$

$$f_k = d_{k \bmod N};$$

end for

## 5.5 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences  $f_{rk}$ , for  $r = 0, \dots, C - 1$  and  $k = 0, \dots, E_r - 1$ , where  $E_r$  is the number of rate matched bits for the  $r$ -th code block. The output bit sequence from the code block concatenation block is the sequence  $g_k$  for  $k = 0, \dots, G - 1$ .

The code block concatenation consists of sequentially concatenating the rate matching outputs for the different code blocks. Therefore,

Set  $k = 0$  and  $r = 0$

while  $r < C$

Set  $j = 0$

while  $j < E_r$

$$g_k = f_{rj}$$

$$k = k + 1$$

$$j = j + 1$$

end while

$$r = r + 1$$

end while

---

## 6 Uplink transport channels and control information

### 6.1 Random access channel

The sequence index for the random access channel is received from higher layers and is processed according to [4, TS 38.211].

### 6.2 Uplink shared channel

#### 6.2.1 Transport block CRC attachment

Error detection is provided on each UL-SCH transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer 1 by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , and the parity bits by  $p_0, p_1, p_2, p_3, \dots, p_{L-1}$ , where  $A$  is the payload size and  $L$  is the number of parity bits. The lowest order information bit  $a_0$  is mapped to the most significant bit of the transport block as defined in Subclause 6.1.1 of [TS38.321].

The parity bits are computed and attached to the UL-SCH transport block according to Subclause 5.1, by setting  $L$  to 24 bits and using the generator polynomial  $g_{\text{CRC24A}}(D)$  if  $A > 3824$ ; and by setting  $L$  to 16 bits and using the generator polynomial  $g_{\text{CRC16}}(D)$  otherwise.

The bits after CRC attachment are denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$ , where  $B = A + L$ .

## 6.2.2 LDPC base graph selection

For initial transmission of a transport block with coding rate  $R$  indicated by the MCS index according to Subclause 6.1.4.1 in [6, TS 38.214] and subsequent re-transmission of the same transport block, each code block of the transport block is encoded with either LDPC base graph 1 or 2 according to the following:

- if  $A \leq 292$ , or if  $A \leq 3824$  and  $R \leq 0.67$ , or if  $R \leq 0.25$ , LDPC base graph 2 is used;
- otherwise, LDPC base graph 1 is used,

where  $A$  is the payload size as described in Subclause 6.2.1.

## 6.2.3 Code block segmentation and code block CRC attachment

The bits input to the code block segmentation are denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$  where  $B$  is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to Subclause 5.2.2.

The bits after code block segmentation are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $r$  is the code block number and  $K_r$  is the number of bits for code block number  $r$  according to Subclause 5.2.2.

## 6.2.4 Channel coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $r$  is the code block number, and  $K_r$  is the number of bits in code block number  $r$ . The total number of code blocks is denoted by  $C$  and each code block is individually LDPC encoded according to Subclause 5.3.2.

After encoding the bits are denoted by  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$ , where the values of  $N_r$  is given in Subclause 5.3.2.

## 6.2.5 Rate matching

Coded bits for each code block, denoted as  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$ , are delivered to the rate match block, where  $r$  is the code block number, and  $N_r$  is the number of encoded bits in code block number  $r$ . The total number of code blocks is denoted by  $C$  and each code block is individually rate matched according to Subclause 5.4.2 by setting  $I_{\text{LBRM}} = 1$  if higher layer parameter *rateMatching* is set to *limitedBufferRM* and by setting  $I_{\text{LBRM}} = 0$  otherwise.

After rate matching, the bits are denoted by  $f_{r0}, f_{r1}, f_{r2}, f_{r3}, \dots, f_{r(E_r-1)}$ , where  $E_r$  is the number of rate matched bits for code block number  $r$ .

## 6.2.6 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences  $f_{r0}, f_{r1}, f_{r2}, f_{r3}, \dots, f_{r(E_r-1)}$ , for  $r = 0, \dots, C-1$  and where  $E_r$  is the number of rate matched bits for the  $r$ -th code block.

Code block concatenation is performed according to Subclause 5.5.

The bits after code block concatenation are denoted by  $g_0, g_1, g_2, g_3, \dots, g_{G-1}$ , where  $G$  is the total number of coded bits for transmission.

## 6.2.7 Data and control multiplexing

Denote the coded bits for UL-SCH as  $g_0^{\text{UL-SCH}}, g_1^{\text{UL-SCH}}, g_2^{\text{UL-SCH}}, g_3^{\text{UL-SCH}}, \dots, g_{G^{\text{UL-SCH}}-1}^{\text{UL-SCH}}$ .

Denote the coded bits for HARQ-ACK, if any, as  $g_0^{\text{ACK}}, g_1^{\text{ACK}}, g_2^{\text{ACK}}, g_3^{\text{ACK}}, \dots, g_{G^{\text{ACK}}-1}^{\text{ACK}}$ .

Denote the coded bits for CSI part 1, if any, as  $g_0^{\text{CSI-part1}}, g_1^{\text{CSI-part1}}, g_2^{\text{CSI-part1}}, g_3^{\text{CSI-part1}}, \dots, g_{G^{\text{CSI-part1}}-1}^{\text{CSI-part1}}$ .

Denote the coded bits for CSI part 2, if any, as  $g_0^{\text{CSI-part2}}, g_1^{\text{CSI-part2}}, g_2^{\text{CSI-part2}}, g_3^{\text{CSI-part2}}, \dots, g_{G^{\text{CSI-part2}}-1}^{\text{CSI-part2}}$ .

Denote the multiplexed data and control coded bit sequence as  $g_0, g_1, g_2, g_3, \dots, g_{G-1}$ .

Denote  $l$  as the OFDM symbol index of the scheduled PUSCH, starting from 0 to  $N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , where  $N_{\text{sym,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS.

Denote  $k$  as the subcarrier index of the scheduled PUSCH, starting from 0 to  $M_{\text{sc}}^{\text{PUSCH}} - 1$ , where  $M_{\text{sc}}^{\text{PUSCH}}$  is expressed as a number of subcarriers.

Denote  $\Phi_l^{\text{UL-SCH}}$  as the set of resource elements, in ascending order of indices  $k$ , available for transmission of data in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ .

Denote  $M_{\text{sc}}^{\text{UL-SCH}}(l) = |\Phi_l^{\text{UL-SCH}}|$  as the number of elements in set  $\Phi_l^{\text{UL-SCH}}$ . Denote  $\Phi_l^{\text{UL-SCH}}(j)$  as the  $j$ -th element in  $\Phi_l^{\text{UL-SCH}}$ .

Denote  $\Phi_l^{\text{UCI}}$  as the set of resource elements, in ascending order of indices  $k$ , available for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ . Denote  $M_{\text{sc}}^{\text{UCI}}(l) = |\Phi_l^{\text{UCI}}|$  as the number of elements in set  $\Phi_l^{\text{UCI}}$ . Denote  $\Phi_l^{\text{UCI}}(j)$  as the  $j$ -th element in  $\Phi_l^{\text{UCI}}$ . For any OFDM symbol that carries DMRS of the PUSCH,  $\Phi_l^{\text{UCI}} = \emptyset$ . For any OFDM symbol that does not carry DMRS of the PUSCH,  $\Phi_l^{\text{UCI}} = \Phi_l^{\text{UL-SCH}}$ .

If frequency hopping is configured for the PUSCH,

- denote  $l^{(1)}$  as the OFDM symbol index of the first OFDM symbol after the first set of consecutive OFDM symbol(s) carrying DMRS in the first hop;
- denote  $l^{(2)}$  as the OFDM symbol index of the first OFDM symbol after the first set of consecutive OFDM symbol(s) carrying DMRS in the second hop.
- denote  $l_{\text{CSI}}^{(1)}$  as the OFDM symbol index of the first OFDM symbol that does not carry DMRS in the first hop;
- denote  $l_{\text{CSI}}^{(2)}$  as the OFDM symbol index of the first OFDM symbol that does not carry DMRS in the second hop;
- if HARQ-ACK is present for transmission on the PUSCH with UL-SCH, let
  - $G^{\text{ACK}}(1) = N_L \cdot Q_m \cdot \lceil G^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \rceil$  and  $G^{\text{ACK}}(2) = N_L \cdot Q_m \cdot \lceil G^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \rceil$ ;
- if CSI is present for transmission on the PUSCH with UL-SCH, let
  - $G^{\text{CSI-part1}}(1) = N_L \cdot Q_m \cdot \lceil G^{\text{CSI-part1}} / (2 \cdot N_L \cdot Q_m) \rceil$ ;
  - $G^{\text{CSI-part1}}(2) = N_L \cdot Q_m \cdot \lceil G^{\text{CSI-part1}} / (2 \cdot N_L \cdot Q_m) \rceil$ ;

- $G^{\text{CSI-part2}}(1) = N_L \cdot Q_m \cdot \left\lfloor G^{\text{CSI-part2}} / (2 \cdot N_L \cdot Q_m) \right\rfloor$ ; and
- $G^{\text{CSI-part2}}(2) = N_L \cdot Q_m \cdot \left\lceil G^{\text{CSI-part2}} / (2 \cdot N_L \cdot Q_m) \right\rceil$ ;
- if only HARQ-ACK and CSI part 1 are present for transmission on the PUSCH without UL-SCH, let
  - $G^{\text{ACK}}(1) = \min\left(N_L \cdot Q_m \cdot \left\lfloor G^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \right\rfloor, M_3 \cdot N_L \cdot Q_m\right)$ ;
  - $G^{\text{ACK}}(2) = G^{\text{ACK}} - G^{\text{ACK}}(1)$  ;
  - $G^{\text{CSI-part1}}(1) = M_1 \cdot N_L \cdot Q_m - G^{\text{ACK}}(1)$ ; and
  - $G^{\text{CSI-part1}}(2) = G^{\text{CSI-part1}} - G^{\text{CSI-part1}}(1)$  ;
- if HARQ-ACK, CSI part 1 and CSI part 2 are present for transmission on the PUSCH without UL-SCH, let
  - $G^{\text{ACK}}(1) = \min\left(N_L \cdot Q_m \cdot \left\lfloor G^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \right\rfloor, M_3 \cdot N_L \cdot Q_m\right)$ ;
  - $G^{\text{ACK}}(2) = G^{\text{ACK}} - G^{\text{ACK}}(1)$  ;
  - if the number of HARQ-ACK information bits is more than 2,
    - $G^{\text{CSI-part1}}(1) = \min\left(N_L \cdot Q_m \cdot \left\lfloor G^{\text{CSI-part1}} / (2 \cdot N_L \cdot Q_m) \right\rfloor, M_1 \cdot N_L \cdot Q_m - G^{\text{ACK}}(1)\right)$ ; otherwise,
    - $G^{\text{CSI-part1}}(1) = \min\left(N_L \cdot Q_m \cdot \left\lfloor G^{\text{CSI-part1}} / (2 \cdot N_L \cdot Q_m) \right\rfloor, M_1 \cdot N_L \cdot Q_m - G_{\text{rd}}^{\text{ACK}}(1)\right)$
  - $G^{\text{CSI-part1}}(2) = G^{\text{CSI-part1}} - G^{\text{CSI-part1}}(1)$  ;
  - $G^{\text{CSI-part2}}(1) = M_1 \cdot N_L \cdot Q_m - G^{\text{CSI-part1}}(1)$  if the number of HARQ-ACK information bits is no more than 2, and  
 $G^{\text{CSI-part2}}(1) = M_1 \cdot N_L \cdot Q_m - G^{\text{ACK}}(1) - G^{\text{CSI-part1}}(1)$  otherwise; and
  - $G^{\text{CSI-part2}}(2) = M_2 \cdot N_L \cdot Q_m - G^{\text{CSI-part1}}(2)$  if the number of HARQ-ACK information bits is no more than 2, and  
 $G^{\text{CSI-part2}}(2) = M_2 \cdot N_L \cdot Q_m - G^{\text{ACK}}(2) - G^{\text{CSI-part1}}(2)$  otherwise;
- if CSI part 1 and CSI part 2 are present for transmission on the PUSCH without UL-SCH, let
  - $G^{\text{CSI-part1}}(1) = \min\left(N_L \cdot Q_m \cdot \left\lfloor G^{\text{CSI-part1}} / (2 \cdot N_L \cdot Q_m) \right\rfloor, M_1 \cdot N_L \cdot Q_m - G_{\text{rd}}^{\text{ACK}}(1)\right)$ ;
  - $G^{\text{CSI-part1}}(2) = G^{\text{CSI-part1}} - G^{\text{CSI-part1}}(1)$  ;
  - $G^{\text{CSI-part2}}(1) = M_1 \cdot N_L \cdot Q_m - G^{\text{CSI-part1}}(1)$ ; and
  - $G^{\text{CSI-part2}}(2) = M_2 \cdot N_L \cdot Q_m - G^{\text{CSI-part1}}(2)$ ;
- let  $N_{\text{hop}}^{\text{PUSCH}} = 2$ , and denote  $N_{\text{sybm,hop}}^{\text{PUSCH}}(1)$ ,  $N_{\text{sybm,hop}}^{\text{PUSCH}}(2)$  as the number of OFDM symbols of the PUSCH in the first and second hop, respectively;
- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH;
- $M_1 = \sum_{l=0}^{N_{\text{sybm,hop}}^{\text{PUSCH}}(1)-1} M_{\text{SC}}^{\text{UCI}}(l)$ ;
- $M_2 = \sum_{l=N_{\text{sybm,hop}}^{\text{PUSCH}}(1)}^{N_{\text{sybm,hop}}^{\text{PUSCH}}(1)+N_{\text{sybm,hop}}^{\text{PUSCH}}(2)-1} M_{\text{SC}}^{\text{UCI}}(l)$

$$M_3 = \sum_{l=l^{(1)}}^{N_{\text{sym,hop}}^{\text{PUSCH}}(1)-1} M_{\text{sc}}^{\text{UCI}}(l)$$

If frequency hopping is not configured for the PUSCH,

- denote  $l^{(1)}$  as the OFDM symbol index of the first OFDM symbol after the first set of consecutive OFDM symbol(s) carrying DMRS;
- denote  $l_{\text{CSI}}^{(1)}$  as the OFDM symbol index of the first OFDM symbol that does not carry DMRS;
- if HARQ-ACK is present for transmission on the PUSCH, let  $G^{\text{ACK}}(1) = G^{\text{ACK}}$ ;
- if CSI is present for transmission on the PUSCH, let  $G^{\text{CSI-part1}}(1) = G^{\text{CSI-part1}}$  and  $G^{\text{CSI-part2}}(1) = G^{\text{CSI-part2}}$ ;
- let  $N_{\text{hop}}^{\text{PUSCH}} = 1$  and  $N_{\text{sym,hop}}^{\text{PUSCH}}(1) = N_{\text{sym,all}}^{\text{PUSCH}}$ .

The multiplexed data and control coded bit sequence  $g_0, g_1, g_2, g_3, \dots, g_{G-1}$  is obtained according to the following:

**Step 1:**

Set  $\bar{\Phi}_l^{\text{UL-SCH}} = \Phi_l^{\text{UL-SCH}}$  for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

Set  $\bar{M}_{\text{sc}}^{\text{UL-SCH}}(l) = |\bar{\Phi}_l^{\text{UL-SCH}}|$  for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

Set  $\bar{\Phi}_l^{\text{UCI}} = \Phi_l^{\text{UCI}}$  for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

Set  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) = |\bar{\Phi}_l^{\text{UCI}}|$  for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

if the number of HARQ-ACK information bits to be transmitted on PUSCH is 0, 1 or 2 bits

the number of reserved resource elements for potential HARQ-ACK transmission is calculated according to Subclause 6.3.2.4.1.1, by setting  $O_{\text{ACK}} = 2$ ;

denote  $G_{\text{rvd}}^{\text{ACK}}$  as the number of coded bits for potential HARQ-ACK transmission using the reserved resource elements;

if frequency hopping is configured for the PUSCH, let  $G_{\text{rvd}}^{\text{ACK}}(1) = N_L \cdot Q_m \cdot \lfloor G_{\text{rvd}}^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \rfloor$  and

$$G_{\text{rvd}}^{\text{ACK}}(2) = N_L \cdot Q_m \cdot \lceil G_{\text{rvd}}^{\text{ACK}} / (2 \cdot N_L \cdot Q_m) \rceil;$$

if frequency hopping is not configured for the PUSCH, let  $G_{\text{rvd}}^{\text{ACK}}(1) = G_{\text{rvd}}^{\text{ACK}}$ ;

denote  $\bar{\Phi}_l^{\text{rvd}}$  as the set of reserved resource elements for potential HARQ-ACK transmission, in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

Set  $m_{\text{count}}^{\text{ACK}}(1) = 0$ ;

Set  $m_{\text{count}}^{\text{ACK}}(2) = 0$ ;

$\bar{\Phi}_l^{\text{rvd}} = \emptyset$  for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ ;

for  $i = 1$  to  $N_{\text{hop}}^{\text{PUSCH}}$

$$l = l^{(i)};$$

while  $m_{\text{count}}^{\text{ACK}}(i) < G_{\text{rvd}}^{\text{ACK}}(i)$

if  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) > 0$

if  $G_{\text{rvd}}^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) \geq \bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m$

$d = 1$ ;

$m_{\text{count}}^{\text{RE}} = \bar{M}_{\text{sc}}^{\text{UL-SCH}}(l)$ ;

end if

if  $G_{\text{rvd}}^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) < \bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m$

$d = \left\lceil \frac{\bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m}{G_{\text{rvd}}^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)} \right\rceil$ ;

$m_{\text{count}}^{\text{RE}} = \left\lceil \frac{G_{\text{rvd}}^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)}{N_L \cdot Q_m} \right\rceil$ ;

end if

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$\bar{\Phi}_l^{\text{rvd}} = \bar{\Phi}_l^{\text{rvd}} \cup \{\bar{\Phi}_l^{\text{UL-SCH}}(j \cdot d)\}$

$m_{\text{count}}^{\text{ACK}}(i) = m_{\text{count}}^{\text{ACK}}(i) + N_L \cdot Q_m$ ;

end for

end if

$l = l + 1$ ;

end while

end for

else

$$\bar{\Phi}_l^{\text{rvd}} = \emptyset \text{ for } l = 0, 1, 2, \dots, N_{\text{symb,all}}^{\text{PUSCH}} - 1;$$

end if

Denote  $\bar{M}_{\text{sc,rvd}}^{\bar{\Phi}}(l) = |\bar{\Phi}_l^{\text{rvd}}|$  as the number of elements in  $\bar{\Phi}_l^{\text{rvd}}$ .

### **Step 2:**

if HARQ-ACK is present for transmission on the PUSCH and the number of HARQ-ACK information bits is more than 2,

Set  $m_{\text{count}}^{\text{ACK}}(1) = 0$ ;

Set  $m_{\text{count}}^{\text{ACK}}(2) = 0$ ;

Set  $m_{\text{count,all}}^{\text{ACK}} = 0$ ;

for  $i = 1$  to  $N_{\text{hop}}^{\text{PUSCH}}$

$l = l^{(i)}$ ;

while  $m_{\text{count}}^{\text{ACK}}(i) < G^{\text{ACK}}(i)$

if  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) > 0$

if  $G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) \geq \bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m$

$d = 1$ ;

$m_{\text{count}}^{\text{RE}} = \bar{M}_{\text{sc}}^{\text{UCI}}(l)$ ;

end if

if  $G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) < \bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m$

$d = \left\lceil \frac{\bar{M}_{\text{sc}}^{\text{UCI}}(l) \cdot N_L \cdot Q_m}{G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)} \right\rceil$ ;

$m_{\text{count}}^{\text{RE}} = \left\lceil \frac{G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)}{N_L \cdot Q_m} \right\rceil$ ;

end if

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$k = \bar{\Phi}_l^{\text{UCI}}(j \cdot d)$ ;

for  $v = 0$  to  $N_L \cdot Q_m - 1$

$\bar{g}_{l,k,v} = g_{m_{\text{count,all}}^{\text{ACK}}}^{\text{ACK}}$  ;

$m_{\text{count,all}}^{\text{ACK}} = m_{\text{count,all}}^{\text{ACK}} + 1$ ;

$m_{\text{count}}^{\text{ACK}}(i) = m_{\text{count}}^{\text{ACK}}(i) + 1$ ;

end for

end for

$\bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} = \emptyset$ ;

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$\bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} = \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} \cup \bar{\Phi}_l^{\text{UCI}}(j \cdot d)$ ;

end for

$\bar{\Phi}_l^{\text{UCI}} = \bar{\Phi}_l^{\text{UCI}} \setminus \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}}$ ;

$\bar{\Phi}_l^{\text{UL-SCH}} = \bar{\Phi}_l^{\text{UL-SCH}} \setminus \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}}$ ;

$\bar{M}_{\text{sc}}^{\text{UCI}}(l) = |\bar{\Phi}_l^{\text{UCI}}|$ ;

$\bar{M}_{\text{sc}}^{\text{UL-SCH}}(l) = |\bar{\Phi}_l^{\text{UL-SCH}}|$ ;

end if  
 $l = l + 1$ ;  
end while  
end for  
end if

**Step 3:**

if CSI is present for transmission on the PUSCH,

Set  $m_{\text{count}}^{\text{CSI-part1}}(1) = 0$ ;

Set  $m_{\text{count}}^{\text{CSI-part1}}(2) = 0$ ;

Set  $m_{\text{count,all}}^{\text{CSI-part1}} = 0$ ;

for  $i = 1$  to  $N_{\text{hop}}^{\text{PUSCH}}$

$l = l_{\text{CSI}}^{(i)}$ ;

while  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l) \leq 0$

$l = l + 1$ ;

end while

while  $m_{\text{count}}^{\text{CSI-part1}}(i) < G^{\text{CSI-part1}}(i)$

if  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l) > 0$

if  $G^{\text{CSI-part1}}(i) - m_{\text{count}}^{\text{CSI-part1}}(i) \geq (\bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l)) \cdot N_L \cdot Q_m$

$d = 1$ ;

$m_{\text{count}}^{\text{RE}} = \bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l)$ ;

end if

if  $G^{\text{CSI-part1}}(i) - m_{\text{count}}^{\text{CSI-part1}}(i) < (\bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l)) \cdot N_L \cdot Q_m$

$d = \left\lceil \frac{(\bar{M}_{\text{sc}}^{\text{UCI}}(l) - \bar{M}_{\text{sc,rvd}}^{\Phi}(l)) \cdot N_L \cdot Q_m}{(G^{\text{CSI-part1}}(i) - m_{\text{count}}^{\text{CSI-part1}}(i))} \right\rceil$ ;

$m_{\text{count}}^{\text{RE}} = \left\lceil \frac{(G^{\text{CSI-part1}}(i) - m_{\text{count}}^{\text{CSI-part1}}(i))}{(N_L \cdot Q_m)} \right\rceil$ ;

end if

$\bar{\Phi}_l^{\text{temp}} = \bar{\Phi}_l^{\text{UCI}} \setminus \bar{\Phi}_l^{\text{rvd}}$ ;

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$k = \bar{\Phi}_l^{\text{temp}}(j \cdot d)$ ;



for  $v = 0$  to  $N_L \cdot Q_m - 1$

$$\bar{g}_{l,k,v} = g_{m_{\text{count,all}}^{\text{CSI-part1}}};$$

$$m_{\text{count,all}}^{\text{CSI-part1}} = m_{\text{count,all}}^{\text{CSI-part1}} + 1;$$

$$m_{\text{count}}^{\text{CSI-part1}}(i) = m_{\text{count}}^{\text{CSI-part1}}(i) + 1;$$

end for

end for

$$\bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} = \emptyset;$$

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$$\bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} = \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}} \cup \bar{\Phi}_l^{\text{temp}}(j \cdot d);$$

end for

$$\bar{\Phi}_l^{\text{UCI}} = \bar{\Phi}_l^{\text{UCI}} \setminus \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}};$$

$$\bar{\Phi}_l^{\text{UL-SCH}} = \bar{\Phi}_l^{\text{UL-SCH}} \setminus \bar{\Phi}_{l,\text{tmp}}^{\text{UCI}};$$

$$\bar{M}_{\text{sc}}^{\text{UCI}}(l) = |\bar{\Phi}_l^{\text{UCI}}|;$$

$$\bar{M}_{\text{sc}}^{\text{UL-SCH}}(l) = |\bar{\Phi}_l^{\text{UL-SCH}}|;$$

end if

$$l = l + 1;$$

end while

end for

Set  $m_{\text{count}}^{\text{CSI-part2}}(1) = 0$ ;

Set  $m_{\text{count}}^{\text{CSI-part2}}(2) = 0$ ;

Set  $m_{\text{count,all}}^{\text{CSI-part2}} = 0$ ;

for  $i = 1$  to  $N_{\text{hop}}^{\text{PUSCH}}$

$$l = l_{\text{CSI}}^{(i)};$$

while  $\bar{M}_{\text{sc}}^{\text{UCI}}(l) \leq 0$

$$l = l + 1;$$

end while

while  $m_{\text{count}}^{\text{CSI-part2}}(i) < G^{\text{CSI-part2}}(i)$

if  $\bar{M}_{sc}^{UCI}(l) > 0$

if  $G^{CSI-part2}(i) - m_{count}^{CSI-part2}(i) \geq \bar{M}_{sc}^{UCI}(l) \cdot N_L \cdot Q_m$

$d = 1$ ;

$m_{count}^{RE} = \bar{M}_{sc}^{UCI}(l)$ ;

end if

if  $G^{CSI-part2}(i) - m_{count}^{CSI-part2}(i) < \bar{M}_{sc}^{UCI}(l) \cdot N_L \cdot Q_m$

$d = \left\lfloor \frac{\bar{M}_{sc}^{UCI}(l) \cdot N_L \cdot Q_m}{G^{CSI-part2}(i) - m_{count}^{CSI-part2}(i)} \right\rfloor$ ;

$m_{count}^{RE} = \left\lceil \frac{G^{CSI-part2}(i) - m_{count}^{CSI-part2}(i)}{N_L \cdot Q_m} \right\rceil$ ;

end if

for  $j = 0$  to  $m_{count}^{RE} - 1$

$k = \bar{\Phi}_l^{UCI}(j \cdot d)$ ;

for  $v = 0$  to  $N_L \cdot Q_m - 1$

$\bar{g}_{l,k,v} = g_{m_{count,all}^{CSI-part2}}^{CSI-part2}$ ;

$m_{count,all}^{CSI-part2} = m_{count,all}^{CSI-part2} + 1$ ;

$m_{count}^{CSI-part2}(i) = m_{count}^{CSI-part2}(i) + 1$ ;

end for

end for

$\bar{\Phi}_{l,tmp}^{UCI} = \emptyset$ ;

for  $j = 0$  to  $m_{count}^{RE} - 1$

$\bar{\Phi}_{l,tmp}^{UCI} = \bar{\Phi}_{l,tmp}^{UCI} \cup \bar{\Phi}_l^{UCI}(j \cdot d)$ ;

end for

$\bar{\Phi}_l^{UCI} = \bar{\Phi}_l^{UCI} \setminus \bar{\Phi}_{l,tmp}^{UCI}$ ;

$\bar{\Phi}_l^{UL-SCH} = \bar{\Phi}_l^{UL-SCH} \setminus \bar{\Phi}_{l,tmp}^{UCI}$ ;

$\bar{M}_{sc}^{UCI}(l) = |\bar{\Phi}_l^{UCI}|$ ;

$\bar{M}_{sc}^{UL-SCH}(l) = |\bar{\Phi}_l^{UL-SCH}|$ ;

end if

$l = l + 1$ ;

end while

end for

end if

#### **Step 4:**

if UL-SCH is present for transmission on the PUSCH,

Set  $m_{\text{count}}^{\text{UL-SCH}} = 0$ ;

for  $l = 0$  to  $N_{\text{sym,all}}^{\text{PUSCH}} - 1$

if  $\bar{M}_{\text{sc}}^{\text{UL-SCH}}(l) > 0$

for  $j = 0$  to  $\bar{M}_{\text{sc}}^{\text{UL-SCH}}(l) - 1$

$k = \bar{\Phi}_l^{\text{UL-SCH}}(j)$ ;

for  $v = 0$  to  $N_L \cdot Q_m - 1$

$\bar{g}_{l,k,v} = g_{m_{\text{count}}}^{\text{UL-SCH}}$ ;

$m_{\text{count}}^{\text{UL-SCH}} = m_{\text{count}}^{\text{UL-SCH}} + 1$ ;

end for

end for

end if

end for

end if

#### **Step 5:**

if HARQ-ACK is present for transmission on the PUSCH and the number of HARQ-ACK information bits is no more than 2,

Set  $m_{\text{count}}^{\text{ACK}}(1) = 0$ ;

Set  $m_{\text{count}}^{\text{ACK}}(2) = 0$ ;

Set  $m_{\text{count,all}}^{\text{ACK}} = 0$ ;

for  $i = 1$  to  $N_{\text{hop}}^{\text{PUSCH}}$

$l = l^{(i)}$ ;

while  $m_{\text{count}}^{\text{ACK}}(i) < G^{\text{ACK}}(i)$

if  $\bar{M}_{\text{sc,rvd}}^{\bar{\Phi}}(l) > 0$

if  $G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) \geq \bar{M}_{\text{sc,rvd}}^{\bar{\Phi}}(l) \cdot N_L \cdot Q_m$

$d = 1$ ;

$$m_{\text{count}}^{\text{RE}} = \bar{M}_{\text{sc,rvd}}^{\Phi}(l);$$

end if

if  $G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i) < \bar{M}_{\text{sc,rvd}}^{\Phi}(l) \cdot N_L \cdot Q_m$

$$d = \left\lceil \bar{M}_{\text{sc,rvd}}^{\Phi}(l) \cdot N_L \cdot Q_m / (G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)) \right\rceil;$$

$$m_{\text{count}}^{\text{RE}} = \left\lceil (G^{\text{ACK}}(i) - m_{\text{count}}^{\text{ACK}}(i)) / (N_L \cdot Q_m) \right\rceil;$$

end if

for  $j = 0$  to  $m_{\text{count}}^{\text{RE}} - 1$

$$k = \Phi_l^{\text{rvd}}(j \cdot d);$$

for  $v = 0$  to  $N_L \cdot Q_m - 1$

$$\bar{g}_{l,k,v} = g_{m_{\text{count,all}}^{\text{ACK}}};$$

$$m_{\text{count,all}}^{\text{ACK}} = m_{\text{count,all}}^{\text{ACK}} + 1;$$

$$m_{\text{count}}^{\text{ACK}}(i) = m_{\text{count}}^{\text{ACK}}(i) + 1;$$

end for

end for

end if

$$l = l + 1;$$

end while

end for

end if

### **Step 6:**

Set  $t = 0$ ;

for  $l = 0$  to  $N_{\text{symb,all}}^{\text{PUSCH}} - 1$

for  $j = 0$  to  $M_{\text{sc}}^{\text{UL-SCH}}(l) - 1$

$$k = \Phi_l^{\text{UL-SCH}}(j);$$

for  $v = 0$  to  $N_L \cdot Q_m - 1$

$$g_t = \bar{g}_{l,k,v};$$

$$t = t + 1;$$

end for

end for

end for

## 6.3 Uplink control information

### 6.3.1 Uplink control information on PUCCH

The procedure in this subclause applies to PUCCH formats 2/3/4.

#### 6.3.1.1 UCI bit sequence generation

##### 6.3.1.1.1 HARQ-ACK/SR only

If only HARQ-ACK bits are transmitted on a PUCCH, the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  is determined by setting  $a_i = \tilde{o}_i^{ACK}$  for  $i = 0, 1, \dots, O^{ACK} - 1$  and  $A = O^{ACK}$ , where the HARQ-ACK bit sequence  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O^{ACK}-1}^{ACK}$  is given by Subclause 9.1 of [5, TS38.213].

If only HARQ-ACK and SR bits are transmitted on a PUCCH, the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  is determined by setting  $a_i = \tilde{o}_i^{ACK}$  for  $i = 0, 1, \dots, O^{ACK} - 1$ ,  $a_i = \tilde{o}_i^{SR}$  for  $i = O^{ACK}, O^{ACK} + 1, \dots, O^{ACK} + O^{SR} - 1$ , and  $A = O^{ACK} + O^{SR}$ , where the HARQ-ACK bit sequence  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O^{ACK}-1}^{ACK}$  is given by Subclause 9.1 of [5, TS 38.213], and the SR bit sequence  $\tilde{o}_0^{SR}, \tilde{o}_1^{SR}, \dots, \tilde{o}_{O^{SR}-1}^{SR}$  is given by Subclause 9.2.5.1 of [5, TS 38.213].

##### 6.3.1.1.2 CSI only

The bitwidth for PMI of *codebookType=typeI-SinglePanel* with 2 CSI-RS ports is 2 for Rank=1 and 1 for Rank=2, according to Subclause 5.2.2.2.1 in [6, TS 38.214].

The bitwidth for PMI of *codebookType=typeI-SinglePanel* with more than 2 CSI-RS ports is provided in Tables 6.3.1.1.2-1, where the values of  $(N_1, N_2)$  and  $(O_1, O_2)$  are given by Subclause 5.2.2.2.1 in [6, TS 38.214].

**Table 6.3.1.1.2-1: PMI of *codebookType=typeI-SinglePanel***

	Information field $X_1$ for wideband PMI		Information field $X_2$ for wideband PMI or per subband PMI		
	$(i_{1,1}, i_{1,2})$		$i_{1,3}$	$i_2$	
	<i>codebookMode=1</i>	<i>codebookMode=2</i>		<i>codebookMode=1</i>	<i>codebookMode=2</i>
Rank = 1 with >2 CSI-RS ports, $N_2 > 1$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	$\lceil \log_2\left(\frac{N_1 O_1}{2} \cdot \frac{N_2 O_2}{2}\right) \rceil$	N/A	2	4
Rank = 1 with >2 CSI-RS ports, $N_2 = 1$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	$\lceil \log_2\left(\frac{N_1 O_1}{2}\right) \rceil$	N/A	2	4
Rank=2 with 4 CSI-RS ports, $N_2 = 1$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	$\lceil \log_2\left(\frac{N_1 O_1}{2}\right) \rceil$	1	1	3
Rank=2 with >4 CSI-RS ports, $N_2 > 1$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	$\lceil \log_2\left(\frac{N_1 O_1}{2} \cdot \frac{N_2 O_2}{2}\right) \rceil$	2	1	3

Rank=2 with >4 CSI-RS ports, $N_2 = 1$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	$\lceil \log_2\left(\frac{N_1 O_1}{2}\right) \rceil$	2	1	3
Rank=3 or 4, with 4 CSI-RS ports	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$		0	1	
Rank=3 or 4, with 8 or 12 CSI-RS ports	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$		2	1	
Rank=3 or 4, with >=16 CSI-RS ports	$\lceil \log_2\left(\frac{N_1 O_1}{2} \cdot N_2 O_2\right) \rceil$		2	1	
Rank=5 or 6	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$		N/A	1	
Rank=7 or 8, $N_1 = 4, N_2 = 1$	$\lceil \log_2\left(\frac{N_1 O_1}{2} \cdot N_2 O_2\right) \rceil$		N/A	1	
Rank=7 or 8, $N_1 > 2, N_2 = 2$	$\lceil \log_2\left(N_1 O_1 \cdot \frac{N_2 O_2}{2}\right) \rceil$		N/A	1	
Rank=7 or 8, with $N_1 > 4, N_2 = 1$ or $N_1 = 2, N_2 = 2$ or $N_1 > 2, N_2 > 2$	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$		N/A	1	

The bitwidth for PMI of *codebookType= type1-MultiPanel* is provided in Tables 6.3.1.1.2-2, where the values of  $(N_g, N_1, N_2)$  and  $(O_1, O_2)$  are given by Subclause 5.2.2.2.2 in [6, TS 38.214].

**Table 6.3.1.1.2-2: PMI of *codebookType= type1-MultiPanel***

	Information fields $X_1$ for wideband					Information fields $X_2$ for wideband or per subband			
	$(i_{1,1}, i_{1,2})$	$i_{1,3}$	$i_{1,4,1}$	$i_{1,4,2}$	$i_{1,4,3}$	$i_2$	$i_{2,0}$	$i_{2,1}$	$i_{2,2}$
Rank=1 with $N_g = 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	N/A	2	N/A	N/A	2	N/A	N/A	N/A
Rank=1 with $N_g = 4$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	N/A	2	2	2	2	N/A	N/A	N/A
Rank=2 with $N_g = 2,$ $N_1 N_2 = 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	1	2	N/A	N/A	1	N/A	N/A	N/A

Rank=3 or 4 with $N_g = 2$ , $N_1 N_2 = 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	0	2	N/A	N/A	1	N/A	N/A	N/A
Rank=2 or 3 or 4 with $N_g = 2$ , $N_1 N_2 > 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	2	2	N/A	N/A	1	N/A	N/A	N/A
Rank=2 with $N_g = 4$ , $N_1 N_2 = 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	1	2	2	2	1	N/A	N/A	N/A
Rank=3 or 4 with $N_g = 4$ , $N_1 N_2 = 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	0	2	2	2	1	N/A	N/A	N/A
Rank=2 or 3 or 4 with $N_g = 4$ , $N_1 N_2 > 2$ <i>codebookMode=1</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	2	2	2	2	1	N/A	N/A	N/A
Rank=1 with $N_g = 2$ <i>codebookMode=2</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	N/A	2	2	N/A	N/A	2	1	1
Rank=2 with $N_g = 2$ , $N_1 N_2 = 2$ <i>codebookMode=2</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	1	2	2	N/A	N/A	1	1	1
Rank=3 or 4 with $N_g = 2$ , $N_1 N_2 = 2$ <i>codebookMode=2</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	0	2	2	N/A	N/A	1	1	1
Rank=2 or 3 or 4 with $N_g = 2$ , $N_1 N_2 > 2$ <i>codebookMode=2</i>	$\lceil \log_2(N_1 O_1 \cdot N_2 O_2) \rceil$	2	2	2	N/A	N/A	1	1	1

The bitwidth for PMI with 1 CSI-RS port is 0.

The bitwidth for RI/LI/CQI/CRI of *codebookType=typeI-SinglePanel* is provided in Tables 6.3.1.1.2-3.

**Table 6.3.1.1.2-3: RI, LI, CQI, and CRI of *codebookType=typeI-SinglePanel***

Field	Bitwidth				
	1 antenna port	2 antenna ports	4 antenna ports	>4 antenna ports	
				Rank1~4	Rank5~8
Rank Indicator	0	$\min(1, \lceil \log_2 n_{RI} \rceil)$	$\min(2, \lceil \log_2 n_{RI} \rceil)$	$\lceil \log_2 n_{RI} \rceil$	$\lceil \log_2 n_{RI} \rceil$
Layer Indicator	0	$\lceil \log_2 v \rceil$	$\min(2, \lceil \log_2 v \rceil)$	$\min(2, \lceil \log_2 v \rceil)$	$\min(2, \lceil \log_2 v \rceil)$
Wide-band CQI	4	4	4	4	8
Subband differential CQI	2	2	2	2	4
CRI	$\lceil \log_2(K_s^{CSI-RS}) \rceil$	$\lceil \log_2(K_s^{CSI-RS}) \rceil$	$\lceil \log_2(K_s^{CSI-RS}) \rceil$	$\lceil \log_2(K_s^{CSI-RS}) \rceil$	$\lceil \log_2(K_s^{CSI-RS}) \rceil$

$n_{\text{RI}}$  in Table 6.3.1.1.2-3 is the number of allowed rank indicator values according to Subclause 5.2.2.2.1 [6, TS 38.214].  $\nu$  is the value of the rank. The value of  $K_s^{\text{CSI-RS}}$  is the number of CSI-RS resources in the corresponding resource set. The values of the rank indicator field are mapped to allowed rank indicator values with increasing order, where '0' is mapped to the smallest allowed rank indicator value.

The bitwidth for RI/LI/CQI/CRI of *codebookType=typeI-MultiPanel* is provided in Table 6.3.1.1.2-4.

**Table 6.3.1.1.2-4: RI, LI, CQI, and CRI of *codebookType=typeI-MultiPanel***

Field	Bitwidth
Rank Indicator	$\min(2, \lceil \log_2 n_{\text{RI}} \rceil)$
Layer Indicator	$\min(2, \lceil \log_2 \nu \rceil)$
Wide-band CQI	4
Subband differential CQI	2
CRI	$\lceil \log_2 (K_s^{\text{CSI-RS}}) \rceil$

where  $n_{\text{RI}}$  is the number of allowed rank indicator values according to Subclause 5.2.2.2.2 [6, TS 38.214],  $\nu$  is the value of the rank, and  $K_s^{\text{CSI-RS}}$  is the number of CSI-RS resources in the corresponding resource set. The values of the rank indicator field are mapped to allowed rank indicator values with increasing order, where '0' is mapped to the smallest allowed rank indicator value.

The bitwidth for RI/LI/CQI of *codebookType=typeII* or *codebookType=typeII-PortSelection* is provided in Table 6.3.1.1.2-5.

**Table 6.3.1.1.2-5: RI, LI, and CQI of *codebookType=typeII* or *typeII-PortSelection***

Field	Bitwidth
Rank Indicator	$\min(1, \lceil \log_2 n_{\text{RI}} \rceil)$
Layer Indicator	$\min(2, \lceil \log_2 \nu \rceil)$
Wide-band CQI	4
Subband differential CQI	2
Indicator of the number of non-zero wideband amplitude coefficients $M_l$ for layer $l$	$\lceil \log_2 (2L-1) \rceil$

where  $n_{\text{RI}}$  is the number of allowed rank indicator values according to Subclauses 5.2.2.2.3 and 5.2.2.2.4 [6, TS 38.214] and  $\nu$  is the value of the rank. The values of the rank indicator field are mapped to allowed rank indicator values with increasing order, where '0' is mapped to the smallest allowed rank indicator value.

The bitwidth for CRI, SSBRI, RSRP, and differential RSRP are provided in Table 6.3.1.1.2-6.



**Table 6.3.1.1.2-6: CRI, SSBRI, and RSRP**

Field	Bitwidth
CRI	$\lceil \log_2(K_s^{\text{CSI-RS}}) \rceil$
SSBRI	$\lceil \log_2(K_s^{\text{SSB}}) \rceil$
RSRP	7
Differential RSRP	4

where  $K_s^{\text{CSI-RS}}$  is the number of CSI-RS resources in the corresponding resource set, and  $K_s^{\text{SSB}}$  is the configured number of SS/PBCH blocks in the corresponding resource set for reporting 'ssb-Index-RSRP'.

**Table 6.3.1.1.2-7: Mapping order of CSI fields of one CSI report, *pmi-FormatIndicator=widebandPMI* and *cqi-FormatIndicator=widebandCQI***

CSI report number	CSI fields
CSI report #n	CRI as in Tables 6.3.1.1.2-3/4, if reported
	Rank Indicator as in Tables 6.3.1.1.2-3/4, if reported
	Layer Indicator as in Tables 6.3.1.1.2-3/4, if reported
	Zero padding bits $O_p$ , if needed
	PMI wideband information fields $X_1$ , from left to right as in Tables 6.3.1.1.2-1/2, if reported
	PMI wideband information fields $X_2$ , from left to right as in Tables 6.3.1.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214], if reported
	Wideband CQI as in Tables 6.3.1.1.2-3/4, if reported

The number of zero padding bits  $O_p$  in Table 6.3.1.1.2-7 is 0 for 1 CSI-RS port and  $O_p = N_{\max} - N_{\text{reported}}$  for more than 1 CSI-RS port, where

- $N_{\max} = \max_{r \in S_{\text{Rank}}} B(r)$  and  $S_{\text{Rank}}$  is the set of rank values  $r$  that are allowed to be reported;
- $N_{\text{reported}} = B(R)$ , where  $R$  is the reported rank;
- For 2 CSI-RS ports,  $B(r) = N_{\text{PMI}}(r) + N_{\text{CQI}}(r) + N_{\text{LI}}(r)$ ;
- For more than 2 CSI-RS ports,  $B(r) = N_{\text{PMI},i1}(r) + N_{\text{PMI},i2}(r) + N_{\text{CQI}}(r) + N_{\text{LI}}(r)$ ;
- if PMI is reported,  $N_{\text{PMI}}(1) = 2$  and  $N_{\text{PMI}}(2) = 1$ ; otherwise,  $N_{\text{PMI}}(r) = 0$ ;
- if PMI  $i_1$  is reported,  $N_{\text{PMI},i1}(r)$  is obtained according to Tables 6.3.1.1.2-1/2; otherwise,  $N_{\text{PMI},i1}(r) = 0$ ;
- if PMI  $i_2$  is reported,  $N_{\text{PMI},i2}(r)$  is obtained according to Tables 6.3.1.1.2-1/2; otherwise,  $N_{\text{PMI},i2}(r) = 0$ ;
- if CQI is reported,  $N_{\text{CQI}}(r)$  is obtained according to Tables 6.3.1.1.2-3/4; otherwise,  $N_{\text{CQI}}(r) = 0$ ;
- if LI is reported,  $N_{\text{LI}}(r)$  is obtained according to Tables 6.3.1.1.2-3/4; otherwise,  $N_{\text{LI}}(r) = 0$ .

**Table 6.3.1.1.2-8: Mapping order of CSI fields of one report for CRI/RSRP or SSBRI/RSRP reporting**

CSI report number	CSI fields
CSI report #n	CRI or SSBRI #1 as in Table 6.3.1.1.2-6, if reported
	CRI or SSBRI #2 as in Table 6.3.1.1.2-6, if reported
	CRI or SSBRI #3 as in Table 6.3.1.1.2-6, if reported
	CRI or SSBRI #4 as in Table 6.3.1.1.2-6, if reported
	RSRP #1 as in Table 6.3.1.1.2-6, if reported
	Differential RSRP #2 as in Table 6.3.1.1.2-6, if reported
	Differential RSRP #3 as in Table 6.3.1.1.2-6, if reported
	Differential RSRP #4 as in Table 6.3.1.1.2-6, if reported

**Table 6.3.1.1.2-9: Mapping order of CSI fields of one CSI report, CSI part 1, *pmi-FormatIndicator= subbandPMI* or *cqi-FormatIndicator=subbandCQI***

CSI report number	CSI fields
CSI report #n CSI part 1	CRI as in Tables 6.3.1.1.2-3/4, if reported
	Rank Indicator as in Tables 6.3.1.1.2-3/4/5, if reported
	Wideband CQI for the first TB as in Tables 6.3.1.1.2-3/4/5, if reported
	Subband differential CQI for the first TB with increasing order of subband number as in Tables 6.3.1.1.2-3/4/5, if reported
	Indicator of the number of non-zero wideband amplitude coefficients $M_l$ for layer $l$ as in Table 6.3.1.1.2-5, if reported
Note:	Subbands for given CSI report $n$ indicated by the higher layer parameter <i>csi-ReportingBand</i> are numbered continuously in the increasing order with the lowest subband of <i>csi-ReportingBand</i> as subband 0.

**Table 6.3.1.1.2-10: Mapping order of CSI fields of one CSI report, CSI part 2 wideband, *pmi-FormatIndicator= subbandPMI* or *cqi-FormatIndicator=subbandCQI***

CSI report number	CSI fields
CSI report #n CSI part 2 wideband	Wideband CQI for the second TB as in Tables 6.3.1.1.2-3/4/5, if present and reported
	Layer Indicator as in Tables 6.3.1.1.2-3/4/5, if reported
	PMI wideband information fields $X_1$ , from left to right as in Tables 6.3.1.1.2-1/2, if reported
	PMI wideband information fields $X_2$ , from left to right as in Tables 6.3.1.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214], if <i>pmi-FormatIndicator= widebandPMI</i> and if reported

**Table 6.3.1.1.2-11: Mapping order of CSI fields of one CSI report, CSI part 2 subband, *pmi-FormatIndicator= subbandPMI* or *cqi-FormatIndicator=subbandCQI***

CSI report #n Part 2 subband	Subband differential CQI for the second TB of all even subbands with increasing order of subband number, as in Tables 6.3.1.1.2-3/4/5, if <i>cqi-FormatIndicator=subbandCQI</i> and if reported
	PMI subband information fields $X_2$ of all even subbands with increasing order of subband number, from left to right as in Tables 6.3.1.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214] of all even subbands with increasing order of subband number, if <i>pmi-FormatIndicator= subbandPMI</i> and if reported
	Subband differential CQI for the second TB of all odd subbands with increasing order of subband number, as in Tables 6.3.1.1.2-3/4/5, if <i>cqi-FormatIndicator=subbandCQI</i> and if reported
	PMI subband information fields $X_2$ of all odd subbands with increasing order of subband number, from left to right as in Tables 6.3.1.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214] of all odd subbands with increasing order of subband number, if <i>pmi-FormatIndicator= subbandPMI</i> and if reported

Note: Subbands for given CSI report  $n$  indicated by the higher layer parameter *csi-ReportingBand* are numbered continuously in the increasing order with the lowest subband of *csi-ReportingBand* as subband 0.

If none of the CSI reports for transmission on a PUCCH is of two parts, the CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-12, are mapped to the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  starting with  $a_0$ . The most significant bit of each field is mapped to the lowest order information bit for that field, e.g. the most significant bit of the first field is mapped to  $a_0$ .

**Table 6.3.1.1.2-12: Mapping order of CSI reports to UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , without two-part CSI report(s)**

UCI bit sequence	CSI report number
$a_0$	CSI report #1 as in Table 6.3.1.1.2-7/8
$a_1$	CSI report #2 as in Table 6.3.1.1.2-7/8
$a_2$	
$a_3$	...
$\vdots$	
$a_{A-1}$	CSI report #n as in Table 6.3.1.1.2-7/8

If at least one of the CSI reports for transmission on a PUCCH is of two parts, two UCI bit sequences are generated,  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  and  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$ . The CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-13, are mapped to the UCI bit sequence  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  starting with  $a_0^{(1)}$ . The most significant bit of each field is mapped to the lowest order information bit for that field, e.g. the most significant bit of the first field is mapped to  $a_0^{(1)}$ . The CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-14, are mapped to the UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  starting with  $a_0^{(2)}$ . The most significant bit of each field is mapped to the lowest order information bit for that field, e.g. the most significant bit of the first field is mapped to  $a_0^{(2)}$ . If the length of UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  is less than 3 bits, zeros shall be appended to the UCI bit sequence until its length equals 3.

**Table 6.3.1.1.2-13: Mapping order of CSI reports to UCI bit sequence  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$ , with two-part CSI report(s)**

UCI bit sequence	CSI report number
$a_0^{(1)}$	CSI report #1 if CSI report #1 is not of two parts, or CSI report #1, CSI part 1, if CSI report #1 is of two parts, as in Table 6.3.1.1.2-7/8/9
$a_1^{(1)}$	CSI report #2 if CSI report #2 is not of two parts, or CSI report #2, CSI part 1, if CSI report #2 is of two parts, as in Table 6.3.1.1.2-7/8/9
$a_2^{(1)}$	...
$a_3^{(1)}$	...
$\vdots$	...
$a_{A^{(1)}-1}^{(1)}$	CSI report #n if CSI report #n is not of two parts, or CSI report #n, CSI part 1, if CSI report #n is of two parts, as in Table 6.3.1.1.2-7/8/9

where CSI report #1, CSI report #2, ..., CSI report #n in Table 6.3.1.1.2-13 correspond to the CSI reports in increasing order of CSI report priority values according to Subclause 5.2.5 of [6, TS38.214].

**Table 6.3.1.1.2-14: Mapping order of CSI reports to UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$ , with two-part CSI report(s)**

UCI bit sequence	CSI report number
$a_0^{(2)}$ $a_1^{(2)}$ $a_2^{(2)}$ $a_3^{(2)}$ $\vdots$ $a_{A^{(2)}-1}^{(2)}$	CSI report #1, CSI part 2 wideband, as in Table 6.3.1.1.2-10 if CSI part 2 exists for CSI report #1
	CSI report #2, CSI part 2 wideband, as in Table 6.3.1.1.2-10 if CSI part 2 exists for CSI report #2
	...
	CSI report #n, CSI part 2 wideband, as in Table 6.3.1.1.2-10 if CSI part 2 exists for CSI report #n
	CSI report #1, CSI part 2 subband, as in Table 6.3.1.1.2-11 if CSI part 2 exists for CSI report #1
	CSI report #2, CSI part 2 subband, as in Table 6.3.1.1.2-11 if CSI part 2 exists for CSI report #2
	...
	CSI report #n, CSI part 2 subband, as in Table 6.3.1.1.2-11 if CSI part 2 exists for CSI report #n

where CSI report #1, CSI report #2, ..., CSI report #n in Table 6.3.1.1.2-14 correspond to the CSI reports in increasing order of CSI report priority values according to Subclause 5.2.5 of [6, TS38.214].

**6.3.1.1.3 HARQ-ACK/SR and CSI**

If none of the CSI reports for transmission on a PUCCH is of two parts, the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  is generated according to the following, where  $A = O^{\text{ACK}} + O^{\text{SR}} + O^{\text{CSI}}$ :

- if there is HARQ-ACK for transmission on the PUCCH, the HARQ-ACK bits are mapped to the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{O^{\text{ACK}}-1}$ , where  $a_i = \tilde{o}_i^{\text{ACK}}$  for  $i = 0, 1, \dots, O^{\text{ACK}} - 1$ , the HARQ-ACK bit sequence  $\tilde{o}_0^{\text{ACK}}, \tilde{o}_1^{\text{ACK}}, \dots, \tilde{o}_{O^{\text{ACK}}-1}^{\text{ACK}}$  is given by Subclause 9.1 of [5, TS38.213], and  $O^{\text{ACK}}$  is number of HARQ-ACK bits; if there is no HARQ-ACK for transmission on the PUCCH, set  $O^{\text{ACK}} = 0$ ;

- if there is SR for transmission on the PUCCH, set  $a_i = \tilde{o}_i^{SR}$  for  $i = O^{ACK}, O^{ACK} + 1, \dots, O^{ACK} + O^{SR} - 1$ , where the SR bit sequence  $\tilde{o}_0^{SR}, \tilde{o}_1^{SR}, \dots, \tilde{o}_{O^{SR}-1}^{SR}$  is given by Subclause 9.2.5.1 of [5, TS 38.213]; if there is no SR for transmission on the PUCCH, set  $O^{SR} = 0$ ;
- the CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-12, are mapped to the UCI bit sequence  $a_{O^{ACK}+O^{SR}}, a_{O^{ACK}+O^{SR}+1}, \dots, a_{O^{ACK}+O^{SR}+O^{CSI}-1}$  starting with  $a_{O^{ACK}+O^{SR}}$ , where  $O^{CSI}$  is the number of CSI bits.

If at least one of the CSI reports for transmission on a PUCCH is of two parts, two UCI bit sequences are generated,  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  and  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$ , according to the following, where

$$A^{(1)} = O^{ACK} + O^{SR} + O^{CSI-part1} \text{ and } A^{(2)} = O^{CSI-part2};$$

- if there is HARQ-ACK for transmission on the PUCCH, the HARQ-ACK bits are mapped to the UCI bit sequence  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{O^{ACK}-1}^{(1)}$ , where  $a_i^{(1)} = \tilde{o}_i^{ACK}$  for  $i = 0, 1, \dots, O^{ACK} - 1$ , the HARQ-ACK bit sequence  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O^{ACK}-1}^{ACK}$  is given by Subclause 9.1 of [5, TS38.213], and  $O^{ACK}$  is number of HARQ-ACK bits; if there is no HARQ-ACK for transmission on the PUCCH, set  $O^{ACK} = 0$ ;
- if there is SR for transmission on the PUCCH, set  $a_i = \tilde{o}_i^{SR}$  for  $i = O^{ACK}, O^{ACK} + 1, \dots, O^{ACK} + O^{SR} - 1$ , where the SR bit sequence  $\tilde{o}_0^{SR}, \tilde{o}_1^{SR}, \dots, \tilde{o}_{O^{SR}-1}^{SR}$  is given by Subclause 9.2.5.1 of [5, TS 38.213]; if there is no SR for transmission on the PUCCH, set  $O^{SR} = 0$ ;
- the CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-13, are mapped to the UCI bit sequence  $a_{O^{ACK}+O^{SR}}^{(1)}, a_{O^{ACK}+O^{SR}+1}^{(1)}, \dots, a_{O^{ACK}+O^{SR}+O^{CSI-part1}-1}^{(1)}$  starting with  $a_{O^{ACK}+O^{SR}}^{(1)}$ , where  $O^{CSI-part1}$  is the number of CSI bits in CSI part 1 of all CSI reports;
- the CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.1.1.2-14, are mapped to the UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  starting with  $a_0^{(2)}$ , where  $O^{CSI-part2}$  is the number of CSI bits in CSI part 2 of all CSI reports. If the length of UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  is less than 3 bits, zeros shall be appended to the UCI bit sequence until its length equals 3.

### 6.3.1.2 Code block segmentation and CRC attachment

The UCI bit sequence from subclause 6.3.1.1 is denoted by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , where  $A$  is the payload size. The procedure in 6.3.1.2.1 applies for  $A \geq 12$  and the procedure in Subclause 6.3.1.2.2 applies for  $A \leq 11$ .

#### 6.3.1.2.1 UCI encoded by Polar code

If the payload size  $A \geq 12$ , code block segmentation and CRC attachment is performed according to Subclause 5.2.1. If ( $A \geq 360$  and  $E \geq 1088$ ) or if  $A \geq 1013$ ,  $I_{seg} = 1$ ; otherwise  $I_{seg} = 0$ , where  $E$  is the rate matching output sequence length as given in Subclause 6.3.1.4.1.

If  $12 \leq A \leq 19$ , the parity bits  $p_{r0}, p_{r1}, p_{r2}, \dots, p_{r(L-1)}$  in Subclause 5.2.1 are computed by setting  $L$  to 6 bits and using the generator polynomial  $g_{CRC6}(D)$  in Subclause 5.1, resulting in the sequence  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$  where  $r$  is the code block number and  $K_r$  is the number of bits for code block number  $r$ .

If  $A \geq 20$ , the parity bits  $p_{r0}, p_{r1}, p_{r2}, \dots, p_{r(L-1)}$  in Subclause 5.2.1 are computed by setting  $L$  to 11 bits and using the generator polynomial  $g_{CRC11}(D)$  in Subclause 5.1, resulting in the sequence  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$  where  $r$  is the code block number and  $K_r$  is the number of bits for code block number  $r$ .

#### 6.3.1.2.2 UCI encoded by channel coding of small block lengths

If the payload size  $A \leq 11$ , CRC bits are not attached.

The output bit sequence is denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $c_i = a_i$  for  $i = 0, 1, \dots, A-1$  and  $K = A$ .

### 6.3.1.3 Channel coding of UCI

#### 6.3.1.3.1 UCI encoded by Polar code

Information bits are delivered to the channel coding block. They are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $r$  is the code block number, and  $K_r$  is the number of bits in code block number  $r$ . The total number of code blocks is denoted by  $C$  and each code block is individually encoded by the following:

If  $18 \leq K_r \leq 25$ , the information bits are encoded via Polar coding according to Subclause 5.3.1, by setting  $n_{\max} = 10$ ,  $I_{IL} = 0$ ,  $n_{PC} = 3$ ,  $n_{PC}^{wm} = 1$  if  $E_r - K_r + 3 > 192$  and  $n_{PC}^{wm} = 0$  if  $E_r - K_r + 3 \leq 192$ , where  $E_r$  is the rate matching output sequence length as given in Subclause 6.3.1.4.1.

If  $K_r > 30$ , the information bits are encoded via Polar coding according to Subclause 5.3.1, by setting  $n_{\max} = 10$ ,  $I_{IL} = 0$ ,  $n_{PC} = 0$ , and  $n_{PC}^{wm} = 0$ .

After encoding the bits are denoted by  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$ , where  $N_r$  is the number of coded bits in code block number  $r$ .

#### 6.3.1.3.2 UCI encoded by channel coding of small block lengths

Information bits are delivered to the channel coding block. They are denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits.

The information bits are encoded according to Subclause 5.3.3.

After encoding the bits are denoted by  $d_0, d_1, d_2, d_3, \dots, d_{N-1}$ , where  $N$  is the number of coded bits.

### 6.3.1.4 Rate matching

For PUCCH formats 2/3/4, the total rate matching output sequence length  $E_{\text{tot}}$  is given by Table 6.3.1.4-1, where

$N_{\text{symb,UCI}}^{\text{PUCCH2}}$ ,  $N_{\text{symb,UCI}}^{\text{PUCCH3}}$  and  $N_{\text{symb,UCI}}^{\text{PUCCH4}}$  are the number of symbols carrying UCI for PUCCH formats 2/3/4 respectively;  $N_{\text{PRB}}^{\text{PUCCH,2}}$  and  $N_{\text{PRB}}^{\text{PUCCH,3}}$  are the number of PRBs that are determined by the UE for PUCCH formats 2/3 transmission respectively according to Subclause 9.2 of [5, TS38.213]; and  $N_{\text{SF}}^{\text{PUCCH,4}}$  is the spreading factor for PUCCH format 4.

**Table 6.3.1.4-1: Total rate matching output sequence length  $E_{\text{tot}}$**

PUCCH format	Modulation order	
	QPSK	$\pi/2$ -BPSK
PUCCH format 2	$16 \cdot N_{\text{symb,UCI}}^{\text{PUCCH2}} \cdot N_{\text{PRB}}^{\text{PUCCH2}}$	N/A
PUCCH format 3	$24 \cdot N_{\text{symb,UCI}}^{\text{PUCCH3}} \cdot N_{\text{PRB}}^{\text{PUCCH3}}$	$12 \cdot N_{\text{symb,UCI}}^{\text{PUCCH3}} \cdot N_{\text{PRB}}^{\text{PUCCH3}}$
PUCCH format 4	$24 \cdot N_{\text{symb,UCI}}^{\text{PUCCH4}} / N_{\text{SF}}^{\text{PUCCH4}}$	$12 \cdot N_{\text{symb,UCI}}^{\text{PUCCH4}} / N_{\text{SF}}^{\text{PUCCH4}}$

#### 6.3.1.4.1 UCI encoded by Polar code

The input bit sequence to rate matching is  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$  where  $r$  is the code block number, and  $N_r$  is the number of coded bits in code block number  $r$ .

Table 6.3.1.4.1-1: Rate matching output sequence length  $E_{UCI}$ 

UCI(s) for transmission on a PUCCH	UCI for encoding	Value of $E_{UCI}$
HARQ-ACK	HARQ-ACK	$E_{UCI} = E_{tot}$
HARQ-ACK, SR	HARQ-ACK, SR	$E_{UCI} = E_{tot}$
CSI (CSI not of two parts)	CSI	$E_{UCI} = E_{tot}$
HARQ-ACK, CSI (CSI not of two parts)	HARQ-ACK, CSI	$E_{UCI} = E_{tot}$
HARQ-ACK, SR, CSI (CSI not of two parts)	HARQ-ACK, SR, CSI	$E_{UCI} = E_{tot}$
CSI (CSI of two parts)	CSI part 1	$E_{UCI} = \min(E_{tot}, \lceil (O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$
	CSI part 2	$E_{UCI} = E_{tot} - \min(E_{tot}, \lceil (O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$
HARQ-ACK, CSI (CSI of two parts)	HARQ-ACK, CSI part 1	$E_{UCI} = \min(E_{tot}, \lceil (O^{ACK} + O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$
	CSI part 2	$E_{UCI} = E_{tot} - \min(E_{tot}, \lceil (O^{ACK} + O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$
HARQ-ACK, SR, CSI (CSI of two parts)	HARQ-ACK, SR, CSI part 1	$E_{UCI} = \min(E_{tot}, \lceil (O^{ACK} + O^{SR} + O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$
	CSI part 2	$E_{UCI} = E_{tot} - \min(E_{tot}, \lceil (O^{ACK} + O^{SR} + O^{CSI-part1} + L) / R_{UCI}^{max} / Q_m \rceil \cdot Q_m)$

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{BLL} = 1$  and the rate matching output sequence length to  $E_r = \lfloor E_{UCI} / C_{UCI} \rfloor$ , where  $C_{UCI}$  is the number of code blocks for UCI determined according to Subclause 6.3.1.2.1 and the value of  $E_{UCI}$  is given by Table 6.3.1.4.1-1:

- $O^{ACK}$  is the number of bits for HARQ-ACK for transmission on the current PUCCH;
- $O^{SR}$  is the number of bits for SR for transmission on the current PUCCH;
- $O^{CSI-part1}$  is the number of bits for CSI part 1 for transmission on the current PUCCH;
- $O^{CSI-part2}$  is the number of bits for CSI part 2 for transmission on the current PUCCH;
- if  $A \geq 360$ ,  $L = 11$ ; otherwise,  $L$  is the number of CRC bits determined according to subclause 6.3.1.2.1, where  $A$  equals  $O^{CSI-part1}$  for "CSI (CSI of two parts)", equals  $O^{ACK} + O^{CSI-part1}$  for "HARQ-ACK, CSI (CSI of two parts)", and equals  $O^{ACK} + O^{SR} + O^{CSI-part1}$  for "HARQ-ACK, SR, CSI (CSI of two parts)" respectively in Table 6.3.1.4.1-1;
- $R_{UCI}^{max}$  is the configured maximum PUCCH coding rate;
- $E_{tot}$  is given by Table 6.3.1.4-1.

The output bit sequence after rate matching is denoted as  $f_{r0}, f_{r1}, f_{r2}, \dots, f_{r(E_r-1)}$  where  $E_r$  is the length of rate matching output sequence in code block number  $r$ .

#### 6.3.1.4.2 UCI encoded by channel coding of small block lengths

The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ .

The value of  $E_{UCI}$  is determined according to Table 6.3.1.4.1-1 by setting  $L = 0$ .

Rate matching is performed according to Subclause 5.4.3 by setting the rate matching output sequence length  $E = E_{UCI}$ .

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

### 6.3.1.5 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences  $f_{r0}, f_{r1}, f_{r2}, \dots, f_{r(E_r-1)}$ , for  $r = 0, \dots, C-1$  and where  $E_r$  is the number of rate matched bits for the  $r$ -th code block.

Code block concatenation is performed according to Subclause 5.5.

The bits after code block concatenation are denoted by  $g_0, g_1, g_2, g_3, \dots, g_{G-1}$ , where  $G' = \lfloor E_{\text{UCI}} / C_{\text{UCI}} \rfloor \cdot C_{\text{UCI}}$  with the values of  $E_{\text{UCI}}$  and  $C_{\text{UCI}}$  given in Subclause 6.3.1.4.1. Let  $G$  be the total number of coded bits for transmission and  $G = G' + \text{mod}(E_{\text{UCI}}, C_{\text{UCI}})$ . Set  $g_i = 0$  for  $i = G', G'+1, \dots, G-1$ .

### 6.3.1.6 Multiplexing of coded UCI bits to PUCCH

If CSI of two parts are transmitted on a PUCCH, the coded bits corresponding to UCI bit sequence

$a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  is denoted by  $g_0^{(1)}, g_1^{(1)}, g_2^{(1)}, g_3^{(1)}, \dots, g_{G^{(1)}-1}^{(1)}$  and the coded bits corresponding to UCI bit

sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  is denoted by  $g_0^{(2)}, g_1^{(2)}, g_2^{(2)}, g_3^{(2)}, \dots, g_{G^{(2)}-1}^{(2)}$ . The coded bit sequence

$g_0, g_1, g_2, g_3, \dots, g_{G-1}$ , where  $G = G^{(1)} + G^{(2)}$ , is generated according to the following.

**Table 6.3.1.6-1: PUCCH DMRS and UCI symbols**

PUCCH duration (symbols)	PUCCH DMRS symbol indices	Number of UCI symbol indices sets $N_{\text{UCI}}^{\text{set}}$	1 <sup>st</sup> UCI symbol indices set $S_{\text{UCI}}^{(1)}$	2 <sup>nd</sup> UCI symbol indices set $S_{\text{UCI}}^{(2)}$	3 <sup>rd</sup> UCI symbol indices set $S_{\text{UCI}}^{(3)}$
4	{1}	2	{0,2}	{3}	-
4	{0,2}	1	{1,3}	-	-
5	{0, 3}	1	{1, 2, 4}	-	-
6	{1, 4}	1	{0, 2, 3, 5}	-	-
7	{1, 4}	2	{0, 2, 3, 5}	{6}	-
8	{1, 5}	2	{0, 2, 4, 6}	{3, 7}	-
9	{1, 6}	2	{0, 2, 5, 7}	{3, 4, 8}	-
10	{2, 7}	2	{1, 3, 6, 8}	{0, 4, 5, 9}	-
10	{1, 3, 6, 8}	1	{0,2,4,5,7,9}	-	-
11	{2, 7}	3	{1,3,6,8}	{0,4,5,9}	{10}
11	{1,3,6,9}	1	{0,2,4,5,7,8,10}	-	-
12	{2, 8}	3	{1,3,7,9}	{0,4,6,10}	{5, 11}
12	{1,4,7,10}	1	{0,2,3,5,6,8,9,11}	-	-
13	{2, 9}	3	{1,3,8,10}	{0,4,7,11}	{5,6,12}
13	{1,4,7,11}	2	{0,2,3,5,6,8,10,12}	{9}	-
14	{3, 10}	3	{2,4,9,11}	{1,5,8,12}	{0,6,7,13}
14	{1,5,8,12}	2	{0,2,4,6,7,9,11,13}	{3, 10}	-

Denote  $s_i$  as UCI OFDM symbol index. Denote  $N_{\text{UCI}}^{(i)}$  as the number of elements in UCI symbol indices set  $S_{\text{UCI}}^{(i)}$  for  $i = 1, \dots, N_{\text{UCI}}^{\text{set}}$ , where  $S_{\text{UCI}}^{(i)}$  and  $N_{\text{UCI}}^{\text{set}}$  are given by Table 6.3.1.6-1 according to the PUCCH duration and the PUCCH

DMRS configuration. Denote  $N_{\text{symb,UCI}}^{\text{PUCCH}} = \sum_{i=1}^{N_{\text{UCI}}^{\text{set}}} N_{\text{UCI}}^{(i)}$  as the number of OFDM symbols carrying UCI in the PUCCH.

Denote  $Q_m$  as the modulation order of the PUCCH.

For PUCCH format 3, set  $N_{\text{UCI}}^{\text{symbol}} = 12 \cdot N_{\text{PRB}}^{\text{PUCCH},3}$ , where  $N_{\text{PRB}}^{\text{PUCCH},3}$  is the number of PRBs that is determined by the UE for PUCCH format 3 transmission according to Subclause 9.2 of [5, TS 38.213].

For PUCCH format 4, set  $N_{\text{UCI}}^{\text{symbol}} = 12 / N_{\text{SF}}^{\text{PUCCH},4}$ , where  $N_{\text{SF}}^{\text{PUCCH},4}$  is the spreading factor for PUCCH format 4.

Find the smallest  $j > 0$  such that  $\left( \sum_{i=1}^j N_{\text{UCI}}^{(i)} \right) \cdot N_{\text{UCI}}^{\text{symbol}} \cdot Q_m \geq G^{(1)}$ .



Set  $n_1 = 0$ ;

Set  $n_2 = 0$ ;

Set  $\bar{N}_{\text{UCI}}^{\text{symbol}} = \left\lfloor \left( G^{(1)} - \left( \sum_{i=1}^{j-1} N_{\text{UCI}}^{(i)} \right) \cdot N_{\text{UCI}}^{\text{symbol}} \cdot Q_m \right) / \left( N_{\text{UCI}}^{(j)} \cdot Q_m \right) \right\rfloor$ ;

Set  $M = \text{mod} \left( \left( G^{(1)} - \left( \sum_{i=1}^{j-1} N_{\text{UCI}}^{(i)} \right) \cdot N_{\text{UCI}}^{\text{symbol}} \cdot Q_m \right) / Q_m, N_{\text{UCI}}^{(j)} \right)$ ;

for  $l = 0$  to  $N_{\text{symb,UCI}}^{\text{PUCCH}} - 1$

if  $s_l \in \bigcup_{i=1}^{j-1} S_{\text{UCI}}^{(i)}$

for  $k = 0$  to  $N_{\text{UCI}}^{\text{symbol}} - 1$

for  $v = 0$  to  $Q_m - 1$

$\bar{g}_{l,k,v} = g_{n_1}^{(1)}$ ;

$n_1 = n_1 + 1$ ;

end for

end for

elseif  $s_l \in S_{\text{UCI}}^{(j)}$

if  $M > 0$

$\gamma = 1$ ;

else

$\gamma = 0$ ;

end if

$M = M - 1$ ;

for  $k = 0$  to  $\bar{N}_{\text{UCI}}^{\text{symbol}} + \gamma - 1$

for  $v = 0$  to  $Q_m - 1$

$\bar{g}_{l,k,v} = g_{n_1}^{(1)}$ ;

$n_1 = n_1 + 1$ ;

end for

end for

for  $k = \bar{N}_{\text{UCI}}^{\text{symbol}} + \gamma$  to  $N_{\text{UCI}}^{\text{symbol}} - 1$

for  $v = 0$  to  $Q_m - 1$

```

 $\bar{g}_{l,k,v} = g_{n_2}^{(2)};$ 
 $n_2 = n_2 + 1;$ 
end for
end for
else
for  $k = 0$  to  $N_{\text{UCI}}^{\text{symbol}} - 1$ 
for  $v = 0$  to  $Q_m - 1$ 
 $\bar{g}_{l,k,v} = g_{n_2}^{(2)};$ 
 $n_2 = n_2 + 1;$ 
end for
end for
end if
end for
Set  $n = 0$ 
for  $l = 0$  to  $N_{\text{symp,UCI}}^{\text{PUCCH}} - 1$ 
for  $k = 0$  to  $N_{\text{UCI}}^{\text{symbol}} - 1$ 
for  $v = 0$  to  $Q_m - 1$ 
 $g_n = \bar{g}_{l,k,v};$ 
 $n = n + 1;$ 
end for
end for
end for

```

## 6.3.2 Uplink control information on PUSCH

### 6.3.2.1 UCI bit sequence generation

#### 6.3.2.1.1 HARQ-ACK

If HARQ-ACK bits are transmitted on a PUSCH, the UCI bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  is determined as follows:

- If UCI is transmitted on PUSCH without UL-SCH and the UCI includes CSI part 1 without CSI part 2,
- if there is no HARQ-ACK bit given by Subclause 9.1 of [5, TS 38.213], set  $a_0 = 0$ ,  $a_1 = 0$ , and  $A = 2$ ;
- if there is only one HARQ-ACK bit  $\tilde{o}_0^{\text{ACK}}$  given by Subclause 9.1 of [5, TS 38.213], set  $a_0 = \tilde{o}_0^{\text{ACK}}$ ,  $a_1 = 0$ , and  $A = 2$ ;

- otherwise, set  $a_i = \tilde{o}_i^{ACK}$  for  $i = 0, 1, \dots, O^{ACK} - 1$  and  $A = O^{ACK}$ , where the HARQ-ACK bit sequence  $\tilde{o}_0^{ACK}, \tilde{o}_1^{ACK}, \dots, \tilde{o}_{O^{ACK}-1}^{ACK}$  is given by Subclause 9.1 of [5, TS 38.213].

6.3.2.1.2 CSI

The bitwidth for PMI of *codebookType=typeI-SinglePanel* and *codebookType=typeI-MultiPanel* is specified in Subclause 6.3.1.1.2.

The bitwidth for RI/LI/CQI/CRI of *codebookType=typeI-SinglePanel* and *codebookType=typeI-MultiPanel* is specified in Subclause 6.3.1.1.2.

The bitwidth for PMI of *codebookType=typeII* is provided in Tables 6.3.2.1.2-1, where the values of  $(N_1, N_2)$ ,  $(O_1, O_2)$ ,  $L$ ,  $N_{PSK}$ ,  $M_1$ ,  $M_2$ , and  $K^{(2)}$  are given by Subclause 5.2.2.2.3 in [6, TS 38.214].

**Table 6.3.2.1.2-1: PMI of *codebookType= typeII***

	Information fields $X_1$ for wideband PMI						Information fields $X_2$ for wideband PMI or per subband PMI			
	$i_{1,1}$	$i_{1,2}$	$i_{1,3,1}$	$i_{1,4,1}$	$i_{1,3,2}$	$i_{1,4,2}$	$i_{2,1,1}$	$i_{2,1,2}$	$i_{2,2,1}$	$i_{2,2,2}$
Rank=1 SBAmpon off	$\lceil \log_2(O_1 O_2) \rceil$	$\lceil \log_2 \left( \frac{N_1 N_2}{L} \right) \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	N/A	N/A	$(M_1 - 1) \cdot \log_2 N_{PSK}$	N/A	N/A	N/A
Rank=2 SBAmpon off	$\lceil \log_2(O_1 O_2) \rceil$	$\lceil \log_2 \left( \frac{N_1 N_2}{L} \right) \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$(M_1 - 1) \cdot \log_2 N_{PSK}$	$(M_2 - 1) \cdot \log_2 N_{PSK}$	N/A	N/A
Rank=1 SBAmpon on	$\lceil \log_2(O_1 O_2) \rceil$	$\lceil \log_2 \left( \frac{N_1 N_2}{L} \right) \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	N/A	N/A	$\min(M_1, K^{(2)}) \cdot \log_2 N_{PSK} - \log_2 N_{PSK} + 2 \cdot (M_1 - \min(M_1, K^{(2)}))$	N/A	$\min(M_1, K^{(2)}) - 1$	N/A
Rank=2 SBAmpon on	$\lceil \log_2(O_1 O_2) \rceil$	$\lceil \log_2 \left( \frac{N_1 N_2}{L} \right) \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\min(M_1, K^{(2)}) \cdot \log_2 N_{PSK} - \log_2 N_{PSK} + 2 \cdot (M_1 - \min(M_1, K^{(2)}))$	$\min(M_2, K^{(2)}) \cdot \log_2 N_{PSK} - \log_2 N_{PSK} + 2 \cdot (M_2 - \min(M_2, K^{(2)}))$	$\min(M_1, K^{(2)}) - 1$	$\min(M_2, K^{(2)}) - 1$

The bitwidth for PMI of *codebookType= typeII-PortSelection* is provided in Tables 6.3.2.1.2-2, where the values of  $P_{CSI-RS}$ ,  $d$ ,  $L$ ,  $N_{PSK}$ ,  $M_1$ ,  $M_2$ , and  $K^{(2)}$  are given by Subclause 5.2.2.2.4 in [6, TS 38.214].

**Table 6.3.2.1.2-2: PMI of *codebookType= typeII-PortSelection***

	Information fields $X_1$ for wideband PMI					Information fields $X_2$ for wideband PMI or per subband PMI			
	$i_{1,1}$	$i_{1,3,1}$	$i_{1,4,1}$	$i_{1,3,2}$	$i_{1,4,2}$	$i_{2,1,1}$	$i_{2,1,2}$	$i_{2,2,1}$	$i_{2,2,2}$
Rank=1 SBAmpon off	$\lceil \log_2 \left\lceil \frac{P_{CSI-RS}}{2d} \right\rceil \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	N/A	N/A	$(M_1 - 1) \cdot \log_2 N_{PSK}$	N/A	N/A	N/A
Rank=2 SBAmpon off	$\lceil \log_2 \left\lceil \frac{P_{CSI-RS}}{2d} \right\rceil \rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$(M_1 - 1) \cdot \log_2 N_{PSK}$	$(M_2 - 1) \cdot \log_2 N_{PSK}$	N/A	N/A

Rank=1 SBAmpon	$\left\lceil \log_2 \left\lceil \frac{P_{CSI-RS}}{2d} \right\rceil \right\rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	N/A	N/A	$\min(M_1, K^{(2)}) \cdot \log_2 N_{\text{PSK}} - \log_2 N_{\text{PSK}} + 2 \cdot (M_1 - \min(M_1, K^{(2)}))$	N/A	$\min(M_1, K^{(2)}) - 1$	N/A
Rank=2 SBAmpon	$\left\lceil \log_2 \left\lceil \frac{P_{CSI-RS}}{2d} \right\rceil \right\rceil$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\lceil \log_2(2L) \rceil$	$3(2L-1)$	$\min(M_1, K^{(2)}) \cdot \log_2 N_{\text{PSK}} - \log_2 N_{\text{PSK}} + 2 \cdot (M_1 - \min(M_1, K^{(2)}))$	$\min(M_2, K^{(2)}) \cdot \log_2 N_{\text{PSK}} - \log_2 N_{\text{PSK}} + 2 \cdot (M_2 - \min(M_2, K^{(2)}))$	$\min(M_1, K^{(2)}) - 1$	$\min(M_2, K^{(2)}) - 1$

For CSI on PUSCH, two UCI bit sequences are generated,  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  and  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$ . The CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.2.1.2-6, are mapped to the UCI bit sequence  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$  starting with  $a_0^{(1)}$ . The CSI fields of all CSI reports, in the order from upper part to lower part in Table 6.3.2.1.2-7, are mapped to the UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$  starting with  $a_0^{(2)}$ .

**Table 6.3.2.1.2-3: Mapping order of CSI fields of one CSI report, CSI part 1**

CSI report number	CSI fields
CSI report #n CSI part 1	CRI or SSBRI as in Tables 6.3.1.1.2-3/4/6, if reported
	Rank Indicator as in Tables 6.3.1.1.2-3/4/5, if reported
	Wideband CQI for the first TB as in Tables 6.3.1.1.2-3/4/5, if reported
	Subband differential CQI for the first TB with increasing order of subband number as in Tables 6.3.1.1.2-3/4/5, if reported
	Indicator of the number of non-zero wideband amplitude coefficients $M_l$ for layer $l$ as in Table 6.3.1.1.2-5, if reported
	RSRP as in Table 6.3.1.1.2-6, if reported
	Differential RSRP as in Table 6.3.1.1.2-6, if reported
Note:	Subbands for given CSI report $n$ indicated by the higher layer parameter <i>csi-ReportingBand</i> are numbered continuously in the increasing order with the lowest subband of <i>csi-ReportingBand</i> as subband 0.

**Table 6.3.2.1.2-4: Mapping order of CSI fields of one CSI report, CSI part 2 wideband**

CSI report number	CSI fields
CSI report #n CSI part 2 wideband	Wideband CQI for the second TB as in Tables 6.3.1.1.2-3/4/5, if present and reported
	Layer Indicator as in Tables 6.3.1.1.2-3/4/5, if reported
	PMI wideband information fields $X_1$ , from left to right as in Tables 6.3.1.1.2-1/2 or 6.3.2.1.2-1/2, if reported
	PMI wideband information fields $X_2$ , from left to right as in Tables 6.3.1.1.2-1/2 or 6.3.2.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214], if <i>pmi-FormatIndicator</i> = <i>widebandPMI</i> and if reported

**Table 6.3.2.1.2-5: Mapping order of CSI fields of one CSI report, CSI part 2 subband**

CSI report #n Part 2 subband	Subband differential CQI for the second TB of all even subbands with increasing order of subband number, as in Tables 6.3.1.1.2-3/4/5, if <i>cqi-FormatIndicator= subbandCQI</i> and if reported
	PMI subband information fields $X_2$ of all even subbands with increasing order of subband number, from left to right as in Tables 6.3.1.1.2-1/2 or 6.3.2.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214] of all even subbands with increasing order of subband number, if <i>pmi-FormatIndicator= subbandPMI</i> and if reported
	Subband differential CQI for the second TB of all odd subbands with increasing order of subband number, as in Tables 6.3.1.1.2-3/4/5, if <i>cqi-FormatIndicator= subbandCQI</i> and if reported
	PMI subband information fields $X_2$ of all odd subbands with increasing order of subband number, from left to right as in Tables 6.3.1.1.2-1/2 or 6.3.2.1.2-1/2, or codebook index for 2 antenna ports according to Subclause 5.2.2.2.1 in [6, TS38.214] of all odd subbands with increasing order of subband number, if <i>pmi-FormatIndicator= subbandPMI</i> and if reported

Note: Subbands for given CSI report  $n$  indicated by the higher layer parameter *csi-ReportingBand* are numbered continuously in the increasing order with the lowest subband of *csi-ReportingBand* as subband 0.

**Table 6.3.2.1.2-6: Mapping order of CSI reports to UCI bit sequence  $a_0^{(1)}, a_1^{(1)}, a_2^{(1)}, a_3^{(1)}, \dots, a_{A^{(1)}-1}^{(1)}$ , with two-part CSI report(s)**

UCI bit sequence	CSI report number
$a_0^{(1)}$	CSI part 1 of CSI report #1 as in Table 6.3.2.1.2-3
$a_1^{(1)}$	CSI part 1 of CSI report #2 as in Table 6.3.2.1.2-3
$a_2^{(1)}$	
$a_3^{(1)}$	...
$\vdots$	
$a_{A^{(1)}-1}^{(1)}$	CSI part 1 of CSI report #n as in Table 6.3.2.1.2-3

where CSI report #1, CSI report #2, ..., CSI report #n in Table 6.3.2.1.2-6 correspond to the CSI reports in increasing order of CSI report priority values according to Subclause 5.2.5 of [6, TS38.214].

**Table 6.3.2.1.2-7: Mapping order of CSI reports to UCI bit sequence  $a_0^{(2)}, a_1^{(2)}, a_2^{(2)}, a_3^{(2)}, \dots, a_{A^{(2)}-1}^{(2)}$ , with two-part CSI report(s)**

UCI bit sequence	CSI report number
$a_0^{(2)}$ $a_1^{(2)}$ $a_2^{(2)}$ $a_3^{(2)}$ $\vdots$ $a_{A^{(2)}-1}^{(2)}$	CSI report #1, CSI part 2 wideband, as in Table 6.3.2.1.2-4 if CSI part 2 exists for CSI report #1
	CSI report #2, CSI part 2 wideband, as in Table 6.3.2.1.2-4 if CSI part 2 exists for CSI report #2
	...
	CSI report #n, CSI part 2 wideband, as in Table 6.3.2.1.2-4 if CSI part 2 exists for CSI report #n
	CSI report #1, CSI part 2 subband, as in Table 6.3.2.1.2-5 if CSI part 2 exists for CSI report #1
	CSI report #2, CSI part 2 subband, as in Table 6.3.2.1.2-5 if CSI part 2 exists for CSI report #2
	...
	CSI report #n, CSI part 2 subband, as in Table 6.3.2.1.2-5 if CSI part 2 exists for CSI report #n

where CSI report #1, CSI report #2, ..., CSI report #n in Table 6.3.2.1.2-7 correspond to the CSI reports in increasing order of CSI report priority values according to Subclause 5.2.5 of [6, TS38.214].

### 6.3.2.2 Code block segmentation and CRC attachment

Denote the bits of the payload by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , where  $A$  is the payload size. The procedure in 6.3.2.2.1 applies for  $A \geq 12$  and the procedure in Subclause 6.3.2.2.2 applies for  $A \leq 11$ .

#### 6.3.2.2.1 UCI encoded by Polar code

Code block segmentation and CRC attachment is performed according to Subclause 6.3.1.2.1.

#### 6.3.2.2.2 UCI encoded by channel coding of small block lengths

The procedure in Subclause 6.3.1.2.2 applies.

### 6.3.2.3 Channel coding of UCI

#### 6.3.2.3.1 UCI encoded by Polar code

Channel coding is performed according to Subclause 6.3.1.3.1, except that the rate matching output sequence length  $E_r$  is given in Subclause 6.3.2.4.1.

#### 6.3.2.3.2 UCI encoded by channel coding of small block lengths

Information bits are delivered to the channel coding block. They are denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits.

The information bits are encoded according to Subclause 5.3.3.

After encoding the bits are denoted by  $d_0, d_1, d_2, d_3, \dots, d_{N-1}$ , where  $N$  is the number of coded bits.

### 6.3.2.4 Rate matching

#### 6.3.2.4.1 UCI encoded by Polar code

##### 6.3.2.4.1.1 HARQ-ACK

For HARQ-ACK transmission on PUSCH with UL-SCH, the number of coded modulation symbols per layer for HARQ-ACK transmission, denoted as  $Q'_{\text{ACK}}$ , is determined as follows:

$$Q'_{\text{ACK}} = \min \left\{ \left[ \frac{(O_{\text{ACK}} + L_{\text{ACK}}) \cdot \beta_{\text{offset}}^{\text{PUSCH}} \cdot \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l)}{\sum_{r=0}^{C_{\text{UL-SCH}}-1} K_r} \right], \left[ \alpha \cdot \sum_{l=l_0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l) \right] \right\}$$

where

- $O_{\text{ACK}}$  is the number of HARQ-ACK bits;
- if  $O_{\text{ACK}} \geq 360$ ,  $L_{\text{ACK}} = 11$ ; otherwise  $L_{\text{ACK}}$  is the number of CRC bits for HARQ-ACK determined according to Subclause 6.3.1.2.1;
- $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{HARQ-ACK}}$ ;
- $C_{\text{UL-SCH}}$  is the number of code blocks for UL-SCH of the PUSCH transmission;
- if the DCI format scheduling the PUSCH transmission includes a CBGTI field indicating that the UE shall not transmit the  $r$ -th code block,  $K_r = 0$ ; otherwise,  $K_r$  is the  $r$ -th code block size for UL-SCH of the PUSCH transmission;
- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{sym,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
  - for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
  - for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ ;
- $\alpha$  is configured by higher layer parameter *scaling*;
- $l_0$  is the symbol index of the first OFDM symbol that does not carry DMRS of the PUSCH, after the first DMRS symbol(s), in the PUSCH transmission.

For HARQ-ACK transmission on PUSCH without UL-SCH, the number of coded modulation symbols per layer for HARQ-ACK transmission, denoted as  $Q'_{\text{ACK}}$ , is determined as follows:

$$Q'_{\text{ACK}} = \min \left\{ \left[ \frac{(O_{\text{ACK}} + L_{\text{ACK}}) \cdot \beta_{\text{offset}}^{\text{PUSCH}}}{R \cdot Q_m} \right], \left[ \alpha \cdot \sum_{l=l_0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l) \right] \right\}$$

where

- $O_{\text{ACK}}$  is the number of HARQ-ACK bits;
- if  $O_{\text{ACK}} \geq 360$ ,  $L_{\text{ACK}} = 11$ ; otherwise  $L_{\text{ACK}}$  is the number of CRC bits for HARQ-ACK defined according to Subclause 6.3.1.2.1;
- $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{HARQ-ACK}}$ ;
- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{symb,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{symb,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
- for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
- for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ ;
- $l_0$  is the symbol index of the first OFDM symbol that does not carry DMRS of the PUSCH, after the first DMRS symbol(s), in the PUSCH transmission;
- $R$  is the code rate of the PUSCH, determined according to Subclause 6.1.4.1 of [6, TS38.214];
- $Q_m$  is the modulation order of the PUSCH;
- $\alpha$  is configured by higher layer parameter *scaling*.

The input bit sequence to rate matching is  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$  where  $r$  is the code block number, and  $N_r$  is the number of coded bits in code block number  $r$ .

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{\text{BL}} = 1$  and the rate matching output sequence length to  $E_r = \lfloor E_{\text{UCI}} / C_{\text{UCI}} \rfloor$ , where

- $C_{\text{UCI}}$  is the number of code blocks for UCI determined according to Subclause 5.2.1;
- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH;
- $E_{\text{UCI}} = N_L \cdot Q'_{\text{ACK}} \cdot Q_m$ .

The output bit sequence after rate matching is denoted as  $f_{r0}, f_{r1}, f_{r2}, \dots, f_{r(E_r-1)}$  where  $E_r$  is the length of rate matching output sequence in code block number  $r$ .

#### 6.3.2.4.1.2 CSI part 1

For CSI part 1 transmission on PUSCH with UL-SCH, the number of coded modulation symbols per layer for CSI part 1 transmission, denoted as  $Q'_{\text{CSI-part1}}$ , is determined as follows:



$$Q'_{\text{CSI-1}} = \min \left\{ \left[ \frac{(O_{\text{CSI-1}} + L_{\text{CSI-1}}) \cdot \beta_{\text{offset}}^{\text{PUSCH}} \cdot \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}} - 1} M_{\text{sc}}^{\text{UCI}}(l)}{\sum_{r=0}^{C_{\text{UL-SCH}} - 1} K_r} \right], \left[ \alpha \cdot \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}} - 1} M_{\text{sc}}^{\text{UCI}}(l) \right] - Q'_{\text{ACK}} \right\}$$

where

- $O_{\text{CSI-1}}$  is the number of bits for CSI part 1;
- if  $O_{\text{CSI-1}} \geq 360$ ,  $L_{\text{CSI-1}} = 11$ ; otherwise  $L_{\text{CSI-1}}$  is the number of CRC bits for CSI part 1 determined according to Subclause 6.3.1.2.1;
- $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{CSI-part1}}$ ;
- $C_{\text{UL-SCH}}$  is the number of code blocks for UL-SCH of the PUSCH transmission;
- if the DCI format scheduling the PUSCH transmission includes a CBGTI field indicating that the UE shall not transmit the  $r$ -th code block,  $K_r = 0$ ; otherwise,  $K_r$  is the  $r$ -th code block size for UL-SCH of the PUSCH transmission;
- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $Q'_{\text{ACK}}$  is the number of coded modulation symbols per layer for HARQ-ACK transmitted on the PUSCH if number of HARQ-ACK information bits is more than 2, and  $Q'_{\text{ACK}} = \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}} - 1} \bar{M}_{\text{sc,rvd}}^{\text{ACK}}(l)$  if the number of HARQ-ACK information bits is no more than 2 bits, where  $\bar{M}_{\text{sc,rvd}}^{\text{ACK}}(l)$  is the number of reserved resource elements for potential HARQ-ACK transmission in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission, defined in Subclause 6.2.7;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{sym,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
  - for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
  - for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ ;
- $\alpha$  is configured by higher layer parameter *scaling*.

For CSI part 1 transmission on PUSCH without UL-SCH, the number of coded modulation symbols per layer for CSI part 1 transmission, denoted as  $Q'_{\text{CSI-part1}}$ , is determined as follows:

if there is CSI part 2 to be transmitted on the PUSCH,

$$Q'_{\text{CSI-1}} = \min \left\{ \left[ \frac{(O_{\text{CSI-1}} + L_{\text{CSI-1}}) \cdot \beta_{\text{offset}}^{\text{PUSCH}}}{R \cdot Q_m} \right], \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}} - 1} M_{\text{sc}}^{\text{UCI}}(l) - Q'_{\text{ACK}} \right\}$$

else

$$Q'_{\text{CSI-1}} = \sum_{l=0}^{N_{\text{symb,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l) - Q'_{\text{ACK}}$$

end if

where

- $O_{\text{CSI-1}}$  is the number of bits for CSI part 1;
- if  $O_{\text{CSI-1}} \geq 360$ ,  $L_{\text{CSI-1}} = 11$ ; otherwise  $L_{\text{CSI-1}}$  is the number of CRC bits for CSI part 1 determined according to Subclause 6.3.1.2.1;
- $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{CSI-part1}}$ ;
- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $Q'_{\text{ACK}}$  is the number of coded modulation symbols per layer for HARQ-ACK transmitted on the PUSCH if number of HARQ-ACK information bits is more than 2, and  $Q'_{\text{ACK}} = \sum_{l=0}^{N_{\text{symb,all}}^{\text{PUSCH}}-1} \bar{M}_{\text{sc,rvd}}^{\text{ACK}}(l)$  if the number of HARQ-ACK information bits is no more than 2 bits, where  $\bar{M}_{\text{sc,rvd}}^{\text{ACK}}(l)$  is the number of reserved resource elements for potential HARQ-ACK transmission in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{symb,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission, defined in Subclause 6.2.7;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{symb,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{symb,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
  - for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
  - for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ ;
- $R$  is the code rate of the PUSCH, determined according to Subclause 6.1.4.1 of [6, TS38.214];
- $Q_m$  is the modulation order of the PUSCH.

The input bit sequence to rate matching is  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$  where  $r$  is the code block number, and  $N_r$  is the number of coded bits in code block number  $r$ .

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{\text{BL}} = 1$  and the rate matching output sequence length to  $E_r = \lfloor E_{\text{UCI}} / C_{\text{UCI}} \rfloor$ , where

- $C_{\text{UCI}}$  is the number of code blocks for UCI determined according to Subclause 5.2.1;
- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH;
- $E_{\text{UCI}} = N_L \cdot Q'_{\text{CSI-1}} \cdot Q_m$ .

The output bit sequence after rate matching is denoted as  $f_{r0}, f_{r1}, f_{r2}, \dots, f_{r(E_r-1)}$  where  $E_r$  is the length of rate matching output sequence in code block number  $r$ .

### 6.3.2.4.1.3 CSI part 2

For CSI part 2 transmission on PUSCH with UL-SCH, the number of coded modulation symbols per layer for CSI part 2 transmission, denoted as  $Q'_{\text{CSI-part2}}$ , is determined as follows:

$$Q'_{\text{CSI-2}} = \min \left\{ \left[ \frac{(O_{\text{CSI-2}} + L_{\text{CSI-2}}) \cdot \beta_{\text{offset}}^{\text{PUSCH}} \cdot \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l)}{\sum_{r=0}^{C_{\text{UL-SCH}}-1} K_r} \right], \left[ \alpha \cdot \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l) \right] - Q'_{\text{ACK}} - Q'_{\text{CSI-1}} \right\}$$

where

- $O_{\text{CSI-2}}$  is the number of bits for CSI part 2;
- if  $O_{\text{CSI-2}} \geq 360$ ,  $L_{\text{CSI-2}} = 11$ ; otherwise  $L_{\text{CSI-2}}$  is the number of CRC bits for CSI part 2 determined according to Subclause 6.3.1.2.1;
- $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{CSI-part2}}$ ;
- $C_{\text{UL-SCH}}$  is the number of code blocks for UL-SCH of the PUSCH transmission;
- if the DCI format scheduling the PUSCH transmission includes a CBGTI field indicating that the UE shall not transmit the  $r$ -th code block,  $K_r = 0$ ; otherwise,  $K_r$  is the  $r$ -th code block size for UL-SCH of the PUSCH transmission;
- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $Q'_{\text{ACK}}$  is the number of coded modulation symbols per layer for HARQ-ACK transmitted on the PUSCH if number of HARQ-ACK information bits is more than 2, and  $Q'_{\text{ACK}} = 0$  if the number of HARQ-ACK information bits is 1 or 2 bits;
- $Q'_{\text{CSI-1}}$  is the number of coded modulation symbols per layer for CSI part 1 transmitted on the PUSCH;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{sym,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
  - for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
  - for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ .
- $\alpha$  is configured by higher layer parameter *scaling*.

For CSI part 2 transmission on PUSCH without UL-SCH, the number of coded modulation symbols per layer for CSI part 2 transmission, denoted as  $Q'_{\text{CSI-part2}}$ , is determined as follows:

$$Q'_{\text{CSI-2}} = \sum_{l=0}^{N_{\text{sym,all}}^{\text{PUSCH}}-1} M_{\text{sc}}^{\text{UCI}}(l) - Q'_{\text{ACK}} - Q'_{\text{CSI-1}}$$

where

- $M_{\text{sc}}^{\text{PUSCH}}$  is the scheduled bandwidth of the PUSCH transmission, expressed as a number of subcarriers;
- $M_{\text{sc}}^{\text{PT-RS}}(l)$  is the number of subcarriers in OFDM symbol  $l$  that carries PTRS, in the PUSCH transmission;
- $Q'_{\text{ACK}}$  is the number of coded modulation symbols per layer for HARQ-ACK transmitted on the PUSCH if number of HARQ-ACK information bits is more than 2, and  $Q'_{\text{ACK}} = 0$  if the number of HARQ-ACK information bits is 1 or 2 bits;
- $Q'_{\text{CSI-1}}$  is the number of coded modulation symbols per layer for CSI part 1 transmitted on the PUSCH;
- $M_{\text{sc}}^{\text{UCI}}(l)$  is the number of resource elements that can be used for transmission of UCI in OFDM symbol  $l$ , for  $l = 0, 1, 2, \dots, N_{\text{sym,all}}^{\text{PUSCH}} - 1$ , in the PUSCH transmission and  $N_{\text{sym,all}}^{\text{PUSCH}}$  is the total number of OFDM symbols of the PUSCH, including all OFDM symbols used for DMRS;
  - for any OFDM symbol that carries DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = 0$ ;
  - for any OFDM symbol that does not carry DMRS of the PUSCH,  $M_{\text{sc}}^{\text{UCI}}(l) = M_{\text{sc}}^{\text{PUSCH}} - M_{\text{sc}}^{\text{PT-RS}}(l)$ .

The input bit sequence to rate matching is  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$  where  $r$  is the code block number, and  $N_r$  is the number of coded bits in code block number  $r$ .

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{\text{BL}} = 1$  and the rate matching output sequence length to  $E_r = \lfloor E_{\text{UCI}} / C_{\text{UCI}} \rfloor$ , where

- $C_{\text{UCI}}$  is the number of code blocks for UCI determined according to Subclause 5.2.1;
- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH;
- $E_{\text{UCI}} = N_L \cdot Q'_{\text{CSI-2}} \cdot Q_m$ .

The output bit sequence after rate matching is denoted as  $f_{r0}, f_{r1}, f_{r2}, \dots, f_{r(E_r-1)}$  where  $E_r$  is the length of rate matching output sequence in code block number  $r$ .

### 6.3.2.4.2 UCI encoded by channel coding of small block lengths

#### 6.3.2.4.2.1 HARQ-ACK

For HARQ-ACK transmission on PUSCH, the number of coded modulation symbols per layer for HARQ-ACK transmission, denoted as  $Q'_{\text{ACK}}$ , is determined according to Subclause 6.3.2.4.1.1, by setting the number of CRC bits  $L = 0$ .

The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ .

Rate matching is performed according to Subclause 5.4.3, by setting the rate matching output sequence length  $E = N_L \cdot Q'_{\text{ACK}} \cdot Q_m$ , where

- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH.

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

#### 6.3.2.4.2.2 CSI part 1

For CSI part 1 transmission on PUSCH, the number of coded modulation symbols per layer for CSI part 1 transmission, denoted as  $Q'_{\text{CSI},1}$ , is determined according to Subclause 6.3.2.4.1.2, by setting the number of CRC bits  $L = 0$ .

Rate matching is performed according to Subclause 5.4.3, by setting the rate matching output sequence length  $E = N_L \cdot Q'_{\text{CSI},1} \cdot Q_m$ , where

- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH.

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

#### 6.3.2.4.2.3 CSI part 2

For CSI part 2 transmission on PUSCH, the number of coded modulation symbols per layer for CSI part 2 transmission, denoted as  $Q'_{\text{CSI},2}$ , is determined according to Subclause 6.3.2.4.1.3, by setting the number of CRC bits  $L = 0$ .

Rate matching is performed according to Subclause 5.4.3, by setting the rate matching output sequence length  $E = N_L \cdot Q'_{\text{CSI},2} \cdot Q_m$ , where

- $N_L$  is the number of transmission layers of the PUSCH;
- $Q_m$  is the modulation order of the PUSCH.

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

#### 6.3.2.5 Code block concatenation

Code block concatenation is performed according to Subclause 6.3.1.5, except that the values of  $E_{\text{UCI}}$  and  $C_{\text{UCI}}$  given in Subclause 6.3.2.4.1.

#### 6.3.2.6 Multiplexing of coded UCI bits to PUSCH

The coded UCI bits are multiplexed onto PUSCH according to the procedures in Subclause 6.2.7.

## 7 Downlink transport channels and control information

### 7.1 Broadcast channel

Data arrives to the coding unit in the form of a maximum of one transport block every 80ms. The following coding steps can be identified:

- Payload generation
- Scrambling

- Transport block CRC attachment
- Channel coding
- Rate matching

### 7.1.1 PBCH payload generation

Denote the bits in a transport block delivered to layer 1 by  $\bar{a}_0, \bar{a}_1, \bar{a}_2, \bar{a}_3, \dots, \bar{a}_{\bar{A}-1}$ , where  $\bar{A}$  is the payload size generated by higher layers. The lowest order information bit  $\bar{a}_0$  is mapped to the most significant bit of the transport block as defined in Subclause [6.1.4] of [8, TS 38.321].

Generate the following additional timing related PBCH payload bits  $\bar{a}_{\bar{A}}, \bar{a}_{\bar{A}+1}, \bar{a}_{\bar{A}+2}, \bar{a}_{\bar{A}+3}, \dots, \bar{a}_{\bar{A}+7}$ , where:

- $\bar{a}_{\bar{A}}, \bar{a}_{\bar{A}+1}, \bar{a}_{\bar{A}+2}, \bar{a}_{\bar{A}+3}$  are the 4<sup>th</sup>, 3<sup>rd</sup>, 2<sup>nd</sup>, and 1<sup>st</sup> LSB of SFN, respectively;
- $\bar{a}_{\bar{A}+4}$  is the half frame bit  $\bar{a}_{\text{HRF}}$ ;
- if  $L_{\text{max}} = 64$

$\bar{a}_{\bar{A}+5}, \bar{a}_{\bar{A}+6}, \bar{a}_{\bar{A}+7}$  are the 6<sup>th</sup>, 5<sup>th</sup>, and 4<sup>th</sup> bits of SS/PBCH block index, respectively.

else

$\bar{a}_{\bar{A}+5}$  is the MSB of  $k_{\text{SSB}}$  as defined in Subclause 7.4.3.1 of [4, TS 38.211].

$\bar{a}_{\bar{A}+6}, \bar{a}_{\bar{A}+7}$  are reserved.

end if

Let  $A = \bar{A} + 8$ ;  $j_{\text{SFN}} = 0$ ;  $j_{\text{HRF}} = 10$ ;  $j_{\text{SSB}} = 11$ ;  $j_{\text{other}} = 14$ ;

for  $i = 0$  to  $A - 1$

if  $\bar{a}_i$  is an SFN bit

$$a_{G(j_{\text{SFN}})} = \bar{a}_i;$$

$$j_{\text{SFN}} = j_{\text{SFN}} + 1;$$

elseif  $\bar{a}_i$  is the half radio frame bit

$$a_{G(j_{\text{HRF}})} = \bar{a}_i$$

elseif  $\bar{A} + 5 \leq i \leq \bar{A} + 7$

$$a_{G(j_{\text{SSB}})} = \bar{a}_i;$$

$$j_{\text{SSB}} = j_{\text{SSB}} + 1;$$

else

$$a_{G(j_{\text{Other}})} = \bar{a}_i;$$

$$j_{\text{Other}} = j_{\text{Other}} + 1;$$

end if

end for

where  $L_{\text{max}}$  is the number of candidate SS/PBCH blocks in a half frame according to Subclause 4.1 of [5, TS38.213], and the value of  $G(j)$  is given by Table 7.1.1-1.

**Table 7.1.1-1: Value of PBCH payload interleaver pattern  $G(j)$**

$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$	$j$	$G(j)$
0	16	4	8	8	24	12	3	16	9	20	14	24	21	28	27
1	23	5	30	9	7	13	2	17	11	21	15	22	22	29	28
2	18	6	10	10	0	14	1	18	12	22	19	26	25	30	29
3	17	7	6	11	5	15	4	19	13	23	20	27	26	31	31

## 7.1.2 Scrambling

For PBCH transmission in a frame, the bit sequence  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$  is scrambled into a bit sequence

$a'_0, a'_1, a'_2, a'_3, \dots, a'_{A-1}$ , where  $a'_i = (a_i + s_i) \bmod 2$  for  $i = 0, 1, \dots, A-1$  and  $s_0, s_1, s_2, s_3, \dots, s_{A-1}$  is generated according to the following:

$$i = 0;$$

$$j = 0;$$

while  $i < A$

if  $a_i$  corresponds to any one of the bits belonging to the SS/PBCH block index, the half frame index, and 2<sup>nd</sup> and 3<sup>rd</sup> least significant bits of the system frame number

$$s_i = 0;$$

else

$$s_i = c(j + \nu M);$$

$$j = j + 1;$$

end if

$$i = i + 1;$$

end while

The scrambling sequence  $c(i)$  is given by Subclause 5.2.1 of [4, TS38.211] and initialized with  $c_{\text{init}} = N_{\text{ID}}^{\text{cell}}$  at the start of each SFN satisfying  $\text{mod}(\text{SFN}, 8) = 0$ ;  $M = A - 3$  for  $L_{\text{max}} = 4$  or  $L_{\text{max}} = 8$ , and  $M = A - 6$  for  $L_{\text{max}} = 64$ , where  $L_{\text{max}}$  is the number of candidate SS/PBCH blocks in a half frame according to Subclause 4.1 of [5, TS38.213]; and  $\nu$  is determined according to Table 7.1.2-1 using the 3<sup>rd</sup> and 2<sup>nd</sup> LSB of the SFN in which the PBCH is transmitted.

**Table 7.1.2-1: Value of  $\nu$  for PBCH scrambling**

(3 <sup>rd</sup> LSB of SFN, 2 <sup>nd</sup> LSB of SFN)	Value of $\nu$
(0, 0)	0
(0, 1)	1
(1, 0)	2
(1, 1)	3

### 7.1.3 Transport block CRC attachment

Error detection is provided on BCH transport blocks through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. The input bit sequence is denoted by  $a'_0, a'_1, a'_2, a'_3, \dots, a'_{A-1}$ , and the parity bits by  $p_0, p_1, p_2, p_3, \dots, p_{L-1}$ , where  $A$  is the payload size and  $L$  is the number of parity bits.

The parity bits are computed and attached to the BCH transport block according to Subclause 5.1 by setting  $L$  to 24 bits and using the generator polynomial  $g_{\text{CRC24C}}(D)$ , resulting in the sequence  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$ , where  $B = A + L$ .

The bit sequence  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$  is the input bit sequence  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$  to the channel encoder, where  $c_i = b_i$  for  $i = 0, 1, \dots, B-1$  and  $K = B$ .

### 7.1.4 Channel coding

Information bits are delivered to the channel coding block. They are denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits, and they are encoded via Polar coding according to Subclause 5.3.1, by setting  $n_{\text{max}} = 9$ ,  $I_{\text{LL}} = 1$ ,  $n_{\text{PC}} = 0$ , and  $n_{\text{PC}}^{\text{wm}} = 0$ .

After encoding the bits are denoted by  $d_0, d_1, d_2, d_3, \dots, d_{N-1}$ , where  $N$  is the number of coded bits.

### 7.1.5 Rate matching

The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ .

The rate matching output sequence length  $E = 864$ .

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{\text{BL}} = 0$ .

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

## 7.2 Downlink shared channel and paging channel

### 7.2.1 Transport block CRC attachment

Error detection is provided on each transport block through a Cyclic Redundancy Check (CRC).

The entire transport block is used to calculate the CRC parity bits. Denote the bits in a transport block delivered to layer 1 by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , and the parity bits by  $p_0, p_1, p_2, p_3, \dots, p_{L-1}$ , where  $A$  is the payload size and  $L$  is the number of parity bits. The lowest order information bit  $a_0$  is mapped to the most significant bit of the transport block as defined in Subclause 6.1.1 of [TS38.321].

The parity bits are computed and attached to the DL-SCH transport block according to Subclause 5.1, by setting  $L$  to 24 bits and using the generator polynomial  $g_{\text{CRC24A}}(D)$  if  $A > 3824$ ; and by setting  $L$  to 16 bits and using the generator polynomial  $g_{\text{CRC16}}(D)$  otherwise.

The bits after CRC attachment are denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$ , where  $B = A + L$ .

### 7.2.2 LDPC base graph selection

For initial transmission of a transport block with coding rate  $R$  indicated by the MCS index according to Subclause 5.1.3.1 in [6, TS 38.214] and subsequent re-transmission of the same transport block, each code block of the transport block is encoded with either LDPC base graph 1 or 2 according to the following:

- if  $A \leq 292$ , or if  $A \leq 3824$  and  $R \leq 0.67$ , or if  $R \leq 0.25$ , LDPC base graph 2 is used;
- otherwise, LDPC base graph 1 is used,



where  $A$  is the payload size in Subclause 7.2.1.

### 7.2.3 Code block segmentation and code block CRC attachment

The bits input to the code block segmentation are denoted by  $b_0, b_1, b_2, b_3, \dots, b_{B-1}$  where  $B$  is the number of bits in the transport block (including CRC).

Code block segmentation and code block CRC attachment are performed according to Subclause 5.2.2.

The bits after code block segmentation are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $r$  is the code block number and  $K_r$  is the number of bits for code block number  $r$  according to Subclause 5.2.2.

### 7.2.4 Channel coding

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by  $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \dots, c_{r(K_r-1)}$ , where  $r$  is the code block number, and  $K_r$  is the number of bits in code block number  $r$ . The total number of code blocks is denoted by  $C$  and each code block is individually LDPC encoded according to Subclause 5.3.2.

After encoding the bits are denoted by  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$ , where the values of  $N_r$  is given in Subclause 5.3.2.

### 7.2.5 Rate matching

Coded bits for each code block, denoted as  $d_{r0}, d_{r1}, d_{r2}, d_{r3}, \dots, d_{r(N_r-1)}$ , are delivered to the rate match block, where  $r$  is the code block number, and  $N_r$  is the number of encoded bits in code block number  $r$ . The total number of code blocks is denoted by  $C$  and each code block is individually rate matched according to Subclause 5.4.2 by setting  $I_{LBRM} = 1$ .

After rate matching, the bits are denoted by  $f_{r0}, f_{r1}, f_{r2}, f_{r3}, \dots, f_{r(E_r-1)}$ , where  $E_r$  is the number of rate matched bits for code block number  $r$ .

### 7.2.6 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences  $f_{r0}, f_{r1}, f_{r2}, f_{r3}, \dots, f_{r(E_r-1)}$ , for  $r = 0, \dots, C-1$  and where  $E_r$  is the number of rate matched bits for the  $r$ -th code block.

Code block concatenation is performed according to Subclause 5.5.

The bits after code block concatenation are denoted by  $g_0, g_1, g_2, g_3, \dots, g_{G-1}$ , where  $G$  is the total number of coded bits for transmission.

## 7.3 Downlink control information

A DCI transports downlink control information for one or more cells with one RNTI.

The following coding steps can be identified:

- Information element multiplexing
- CRC attachment
- Channel coding
- Rate matching

### 7.3.1 DCI formats

The DCI formats defined in table 7.3.1-1 are supported.

**Table 7.3.1-1: DCI formats**

DCI format	Usage
0_0	Scheduling of PUSCH in one cell
0_1	Scheduling of PUSCH in one cell
1_0	Scheduling of PDSCH in one cell
1_1	Scheduling of PDSCH in one cell
2_0	Notifying a group of UEs of the slot format
2_1	Notifying a group of UEs of the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE
2_2	Transmission of TPC commands for PUCCH and PUSCH
2_3	Transmission of a group of TPC commands for SRS transmissions by one or more UEs

The fields defined in the DCI formats below are mapped to the information bits  $a_0$  to  $a_{A-1}$  as follows.

Each field is mapped in the order in which it appears in the description, including the zero-padding bit(s), if any, with the first field mapped to the lowest order information bit  $a_0$  and each successive field mapped to higher order information bits. The most significant bit of each field is mapped to the lowest order information bit for that field, e.g. the most significant bit of the first field is mapped to  $a_0$ .

If the number of information bits in a DCI format is less than 12 bits, zeros shall be appended to the DCI format until the payload size equals 12.

The size of each DCI format shall be adjusted as described in clause 7.3.1.0 if necessary.

### 7.3.1.0 DCI size alignment

If necessary, padding or truncation shall be applied to the DCI formats according to the following steps executed in the order below:

Step 0:

- Determine DCI format 0\_0 monitored in a common search space according to clause 7.3.1.1.1 where  $N_{RB}^{UL,BWP}$  is the size of the initial UL bandwidth part.
- Determine DCI format 1\_0 monitored in a common search space according to clause 7.3.1.2.1 where  $N_{RB}^{DL,BWP}$  is given by
  - the size of CORESET 0 if CORESET 0 is configured for the cell; and
  - the size of initial DL bandwidth part if CORESET 0 is not configured for the cell.
- If DCI format 0\_0 is monitored in common search space and if the number of information bits in the DCI format 0\_0 prior to padding is less than the payload size of the DCI format 1\_0 monitored in common search space for scheduling the same serving cell, a number of zero padding bits are generated for the DCI format 0\_0 until the payload size equals that of the DCI format 1\_0.
- If DCI format 0\_0 is monitored in common search space and if the number of information bits in the DCI format 0\_0 prior to truncation is larger than the payload size of the DCI format 1\_0 monitored in common search space for scheduling the same serving cell, the bitwidth of the frequency domain resource assignment field in the DCI format 0\_0 is reduced by truncating the first few most significant bits such that the size of DCI format 0\_0 equals the size of the DCI format 1\_0.

Step 1:

- Determine DCI format 0\_0 monitored in a UE-specific search space according to clause 7.3.1.1.1 where  $N_{RB}^{UL,BWP}$  is the size of the active UL bandwidth part.

- Determine DCI format 1\_0 monitored in a UE-specific search space according to clause 7.3.1.2.1 where  $N_{RB}^{DL,BWP}$  is the size of the active DL bandwidth part.
- If DCI format 0\_0 is monitored in UE-specific search space and if the number of information bits in the DCI format 0\_0 prior to padding is less than the payload size of the DCI format 1\_0 monitored in UE-specific search space for scheduling the same serving cell, a number of zero padding bits are generated for the DCI format 0\_0 until the payload size equals that of the DCI format 1\_0.
- If DCI format 1\_0 is monitored in UE-specific search space and if the number of information bits in the DCI format 1\_0 prior to padding is less than the payload size of the DCI format 0\_0 monitored in UE-specific search space for scheduling the same serving cell, zeros shall be appended to the DCI format 1\_0 until the payload size equals that of the DCI format 0\_0

## Step 2:

- If the size of DCI format 0\_1 monitored in a UE-specific search space equals that of a DCI format 0\_0/1\_0 monitored in another UE-specific search space, one bit of zero padding shall be appended to DCI format 0\_1.
- If the size of DCI format 1\_1 monitored in a UE-specific search space equals that of a DCI format 0\_0/1\_0 monitored in another UE-specific search space, one bit of zero padding shall be appended to DCI format 1\_1.

## Step 3:

- If both of the following conditions are fulfilled the size alignment procedure is complete
  - the total number of different DCI sizes configured to monitor is no more than 4 for the cell
  - the total number of different DCI sizes with C-RNTI configured to monitor is no more than 3 for the cell

## Step 4:

- Otherwise
  - Remove the padding bit (if any) introduced in step 2 above.
  - Determine DCI format 1\_0 monitored in a UE-specific search space according to clause 7.3.1.2.1 where  $N_{RB}^{DL,BWP}$  is given by
    - the size of CORESET 0 if CORESET 0 is configured for the cell; and
    - the size of initial DL bandwidth part if CORESET 0 is not configured for the cell.
  - Determine DCI format 0\_0 monitored in a UE-specific search space according to clause 7.3.1.1.1 where  $N_{RB}^{UL,BWP}$  is the size of the initial UL bandwidth part.
  - If the number of information bits in the DCI format 0\_0 monitored in a UE-specific search space prior to padding is less than the payload size of the DCI format 1\_0 monitored in UE-specific search space for scheduling the same serving cell, a number of zero padding bits are generated for the DCI format 0\_0 monitored in a UE-specific search space until the payload size equals that of the DCI format 1\_0 monitored in a UE-specific search space.
  - If the number of information bits in the DCI format 0\_0 monitored in a UE-specific search space prior to truncation is larger than the payload size of the DCI format 1\_0 monitored in UE-specific search space for scheduling the same serving cell, the bitwidth of the frequency domain resource assignment field in the DCI format 0\_0 is reduced by truncating the first few most significant bits such that the size of DCI format 0\_0 monitored in a UE-specific search space equals the size of the DCI format 1\_0 monitored in a UE-specific search space.

The UE is not expected to handle a configuration that, after applying the above steps, results in

- the total number of different DCI sizes configured to monitor is more than 4 for the cell; or
- the total number of different DCI sizes with C-RNTI configured to monitor is more than 3 for the cell; or

- the size of DCI format 0\_0 in a UE-specific search space is equal to DCI format 0\_1 in another UE-specific search space; or
- the size of DCI format 1\_0 in a UE-specific search space is equal to DCI format 1\_1 in another UE-specific search space

### 7.3.1.1 DCI formats for scheduling of PUSCH

#### 7.3.1.1.1 Format 0\_0

DCI format 0\_0 is used for the scheduling of PUSCH in one cell.

The following information is transmitted by means of the DCI format 0\_0 with CRC scrambled by C-RNTI or CS-RNTI or MCS-C-RNTI:

- Identifier for DCI formats – 1 bit
  - The value of this bit field is always set to 0, indicating an UL DCI format
- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  bits where  $N_{RB}^{UL,BWP}$  is defined in subclause 7.3.1.0
  - For PUSCH hopping with resource allocation type 1:
    - $N_{UL\_hop}$  MSB bits are used to indicate the frequency offset according to Subclause 6.3 of [6, TS 38.214], where  $N_{UL\_hop} = 1$  if the higher layer parameter *frequencyHoppingOffsetLists* contains two offset values and  $N_{UL\_hop} = 2$  if the higher layer parameter *frequencyHoppingOffsetLists* contains four offset values
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil - N_{UL\_hop}$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]
  - For non-PUSCH hopping with resource allocation type 1:
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]
- Time domain resource assignment – 4 bits as defined in Subclause 6.1.2.1 of [6, TS 38.214]
- Frequency hopping flag – 1 bit according to Table 7.3.1.1.1-3, as defined in Subclause 6.3 of [6, TS 38.214]
- Modulation and coding scheme – 5 bits as defined in Subclause 6.1.4.1 of [6, TS 38.214]
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- HARQ process number – 4 bits
- TPC command for scheduled PUSCH – 2 bits as defined in Subclause 7.1.1 of [5, TS 38.213]
- Padding bits, if required.
- UL/SUL indicator – 1 bit for UEs configured with *supplementaryUplink* in *ServingCellConfig* in the cell as defined in Table 7.3.1.1.1-1 and the number of bits for DCI format 1\_0 before padding is larger than the number of bits for DCI format 0\_0 before padding; 0 bit otherwise. The UL/SUL indicator, if present, locates in the last bit position of DCI format 0\_0, after the padding bit(s).
  - If the UL/SUL indicator is present in DCI format 0\_0 and the higher layer parameter *pusch-Config* is not configured on both UL and SUL the UE ignores the UL/SUL indicator field in DCI format 0\_0, and the corresponding PUSCH scheduled by the DCI format 0\_0 is for the UL or SUL for which high layer parameter *pucch-Config* is configured;

- If the UL/SUL indicator is not present in DCI format 0\_0, the corresponding PUSCH scheduled by the DCI format 0\_0 is for the UL or SUL for which high layer parameter *pucch-Config* is configured.

The following information is transmitted by means of the DCI format 0\_0 with CRC scrambled by TC-RNTI:

- Identifier for DCI formats – 1 bit
- The value of this bit field is always set to 0, indicating an UL DCI format
- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  bits where
  - $N_{RB}^{UL,BWP}$  is the size of the initial UL bandwidth part.
  - For PUSCH hopping with resource allocation type 1:
    - $N_{UL\_hop}$  MSB bits are used to indicate the frequency offset according to Subclause 6.3 of [6, TS 38.214], where  $N_{UL\_hop} = 1$  if  $N_{RB}^{UL,BWP} < 50$  and  $N_{UL\_hop} = 2$  otherwise
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil - N_{UL\_hop}$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]
  - For non-PUSCH hopping with resource allocation type 1:
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]
- Time domain resource assignment – 4 bits as defined in Subclause 6.1.2.1 of [6, TS 38.214]
- Frequency hopping flag – 1 bit according to Table 7.3.1.1.1-3, as defined in Subclause 6.3 of [6, TS 38.214]
- Modulation and coding scheme – 5 bits as defined in Subclause 6.1.4.1 of [6, TS 38.214]
- New data indicator – 1 bit, reserved
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- HARQ process number – 4 bits, reserved
- TPC command for scheduled PUSCH – 2 bits as defined in Subclause 7.1.1 of [5, TS 38.213]
- Padding bits, if required.
- UL/SUL indicator – 1 bit if the cell has two ULs and the number of bits for DCI format 1\_0 before padding is larger than the number of bits for DCI format 0\_0 before padding; 0 bit otherwise. The UL/SUL indicator, if present, locates in the last bit position of DCI format 0\_0, after the padding bit(s).
- If 1 bit, reserved, and the corresponding PUSCH is always on the same UL carrier as the previous transmission of the same TB

**Table 7.3.1.1.1-1: UL/SUL indicator**

Value of UL/SUL indicator	Uplink
0	The non-supplementary uplink
1	The supplementary uplink

**Table 7.3.1.1.1-2: Redundancy version**

Value of the Redundancy version field	Value of $rv_{id}$ to be applied
00	0
01	1
10	2
11	3

**Table 7.3.1.1.1-3: Frequency hopping indication**

Bit field mapped to index	PUSCH frequency hopping
0	Disabled
1	Enabled

### 7.3.1.1.2 Format 0\_1

DCI format 0\_1 is used for the scheduling of PUSCH in one cell.

The following information is transmitted by means of the DCI format 0\_1 with CRC scrambled by C-RNTI or CS-RNTI or SP-CSI-RNTI or MCS-C-RNTI:

- Identifier for DCI formats – 1 bit
  - The value of this bit field is always set to 0, indicating an UL DCI format
- Carrier indicator – 0 or 3 bits, as defined in Subclause 10.1 of [5, TS38.213].
- UL/SUL indicator – 0 bit for UEs not configured with *supplementaryUplink* in *ServingCellConfig* in the cell or UEs configured with *supplementaryUplink* in *ServingCellConfig* in the cell but only PUCCH carrier in the cell is configured for PUSCH transmission; otherwise, 1 bit as defined in Table 7.3.1.1.1-1.
- Bandwidth part indicator – 0, 1 or 2 bits as determined by the number of UL BWPs  $n_{\text{BWP,RRC}}$  configured by higher layers, excluding the initial UL bandwidth part. The bitwidth for this field is determined as  $\lceil \log_2(n_{\text{BWP}}) \rceil$  bits, where
  - $n_{\text{BWP}} = n_{\text{BWP,RRC}} + 1$  if  $n_{\text{BWP,RRC}} \leq 3$ , in which case the bandwidth part indicator is equivalent to the ascending order of the higher layer parameter *BWP-Id*;
  - otherwise  $n_{\text{BWP}} = n_{\text{BWP,RRC}}$ , in which case the bandwidth part indicator is defined in Table 7.3.1.1.2-1;

If a UE does not support active BWP change via DCI, the UE ignores this bit field.

- Frequency domain resource assignment – number of bits determined by the following, where  $N_{\text{RB}}^{\text{UL,BWP}}$  is the size of the active UL bandwidth part:
  - $N_{\text{RBG}}$  bits if only resource allocation type 0 is configured, where  $N_{\text{RBG}}$  is defined in Subclause 6.1.2.2.1 of [6, TS 38.214],
  - $\lceil \log_2(N_{\text{RB}}^{\text{UL,BWP}}(N_{\text{RB}}^{\text{UL,BWP}} + 1)/2) \rceil$  bits if only resource allocation type 1 is configured, or  $\max(\lceil \log_2(N_{\text{RB}}^{\text{UL,BWP}}(N_{\text{RB}}^{\text{UL,BWP}} + 1)/2) \rceil, N_{\text{RBG}}) + 1$  bits if both resource allocation type 0 and 1 are configured.
  - If both resource allocation type 0 and 1 are configured, the MSB bit is used to indicate resource allocation type 0 or resource allocation type 1, where the bit value of 0 indicates resource allocation type 0 and the bit value of 1 indicates resource allocation type 1.
  - For resource allocation type 0, the  $N_{\text{RBG}}$  LSBs provide the resource allocation as defined in Subclause 6.1.2.2.1 of [6, TS 38.214].

- For resource allocation type 1, the  $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  LSBs provide the resource allocation as follows:
  - For PUSCH hopping with resource allocation type 1:
    - $N_{UL\_hop}$  MSB bits are used to indicate the frequency offset according to Subclause 6.3 of [6, TS 38.214], where  $N_{UL\_hop} = 1$  if the higher layer parameter *frequencyHoppingOffsetLists* contains two offset values and  $N_{UL\_hop} = 2$  if the higher layer parameter *frequencyHoppingOffsetLists* contains four offset values
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil - N_{UL\_hop}$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]
  - For non-PUSCH hopping with resource allocation type 1:
    - $\lceil \log_2(N_{RB}^{UL,BWP}(N_{RB}^{UL,BWP} + 1)/2) \rceil$  bits provides the frequency domain resource allocation according to Subclause 6.1.2.2.2 of [6, TS 38.214]

If "Bandwidth part indicator" field indicates a bandwidth part other than the active bandwidth part and if both resource allocation type 0 and 1 are configured for the indicated bandwidth part, the UE assumes resource allocation type 0 for the indicated bandwidth part if the bitwidth of the "Frequency domain resource assignment" field of the active bandwidth part is smaller than the bitwidth of the "Frequency domain resource assignment" field of the indicated bandwidth part.

- Time domain resource assignment – 0, 1, 2, 3, or 4 bits as defined in Subclause 6.1.2.1 of [6, TS38.214]. The bitwidth for this field is determined as  $\lceil \log_2(I) \rceil$  bits, where  $I$  is the number of entries in the higher layer parameter *pusch-TimeDomainAllocationList* if the higher layer parameter is configured; otherwise  $I$  is the number of entries in the default table.
- Frequency hopping flag – 0 or 1 bit:
  - 0 bit if only resource allocation type 0 is configured or if the higher layer parameter *frequencyHopping* is not configured;
  - 1 bit according to Table 7.3.1.1.1-3 otherwise, only applicable to resource allocation type 1, as defined in Subclause 6.3 of [6, TS 38.214].
- Modulation and coding scheme – 5 bits as defined in Subclause 6.1.4.1 of [6, TS 38.214]
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- HARQ process number – 4 bits
- 1<sup>st</sup> downlink assignment index – 1 or 2 bits:
  - 1 bit for semi-static HARQ-ACK codebook;
  - 2 bits for dynamic HARQ-ACK codebook.
- 2<sup>nd</sup> downlink assignment index – 0 or 2 bits:
  - 2 bits for dynamic HARQ-ACK codebook with two HARQ-ACK sub-codebooks;
  - 0 bit otherwise.
- TPC command for scheduled PUSCH – 2 bits as defined in Subclause 7.1.1 of [5, TS38.213]

- SRS resource indicator –  $\left\lceil \log_2 \left( \sum_{k=1}^{\min\{L_{\max}, N_{\text{SRS}}\}} \binom{N_{\text{SRS}}}{k} \right) \right\rceil$  or  $\lceil \log_2(N_{\text{SRS}}) \rceil$  bits, where  $N_{\text{SRS}}$  is the number of configured SRS resources in the SRS resource set associated with the higher layer parameter *usage* of value 'codeBook' or 'nonCodeBook',
- $\left\lceil \log_2 \left( \sum_{k=1}^{\min\{L_{\max}, N_{\text{SRS}}\}} \binom{N_{\text{SRS}}}{k} \right) \right\rceil$  bits according to Tables 7.3.1.1.2-28/29/30/31 if the higher layer parameter *txConfig* = *nonCodebook*, where  $N_{\text{SRS}}$  is the number of configured SRS resources in the SRS resource set associated with the higher layer parameter *usage* of value 'nonCodeBook' and
  - if UE supports operation with *maxMIMO-Layers* and the higher layer parameter *maxMIMO-Layers* of *PUSCH-ServingCellConfig* of the serving cell is configured,  $L_{\max}$  is given by that parameter
  - otherwise,  $L_{\max}$  is given by the maximum number of layers for PUSCH supported by the UE for the serving cell for non-codebook based operation.
- $\lceil \log_2(N_{\text{SRS}}) \rceil$  bits according to Tables 7.3.1.1.2-32 if the higher layer parameter *txConfig* = *codebook*, where  $N_{\text{SRS}}$  is the number of configured SRS resources in the SRS resource set associated with the higher layer parameter *usage* of value 'codeBook'.
- Precoding information and number of layers – number of bits determined by the following:
  - 0 bits if the higher layer parameter *txConfig* = *nonCodeBook*;
  - 0 bits for 1 antenna port and if the higher layer parameter *txConfig* = *codebook*;
  - 4, 5, or 6 bits according to Table 7.3.1.1.2-2 for 4 antenna ports, if *txConfig* = *codebook*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters *maxRank*, and *codebookSubset*;
  - 2, 4, or 5 bits according to Table 7.3.1.1.2-3 for 4 antenna ports, if *txConfig* = *codebook*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters *maxRank*, and *codebookSubset*;
  - 2 or 4 bits according to Table 7.3.1.1.2-4 for 2 antenna ports, if *txConfig* = *codebook*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters *maxRank* and *codebookSubset*;
  - 1 or 3 bits according to Table 7.3.1.1.2-5 for 2 antenna ports, if *txConfig* = *codebook*, and according to whether transform precoder is enabled or disabled, and the values of higher layer parameters *maxRank* and *codebookSubset*.
- Antenna ports – number of bits determined by the following
  - 2 bits as defined by Tables 7.3.1.1.2-6, if transform precoder is enabled, *dmrs-Type*=1, and *maxLength*=1;
  - 4 bits as defined by Tables 7.3.1.1.2-7, if transform precoder is enabled, *dmrs-Type*=1, and *maxLength*=2;
  - 3 bits as defined by Tables 7.3.1.1.2-8/9/10/11, if transform precoder is disabled, *dmrs-Type*=1, and *maxLength*=1, and the value of rank is determined according to the SRS resource indicator field if the higher layer parameter *txConfig* = *nonCodebook* and according to the Precoding information and number of layers field if the higher layer parameter *txConfig* = *codebook*;
  - 4 bits as defined by Tables 7.3.1.1.2-12/13/14/15, if transform precoder is disabled, *dmrs-Type*=1, and *maxLength*=2, and the value of rank is determined according to the SRS resource indicator field if the higher layer parameter *txConfig* = *nonCodebook* and according to the Precoding information and number of layers field if the higher layer parameter *txConfig* = *codebook*;
  - 4 bits as defined by Tables 7.3.1.1.2-16/17/18/19, if transform precoder is disabled, *dmrs-Type*=2, and *maxLength*=1, and the value of rank is determined according to the SRS resource indicator field if the higher layer parameter *txConfig* = *nonCodebook* and according to the Precoding information and number of layers field if the higher layer parameter *txConfig* = *codebook*;



- 5 bits as defined by Tables 7.3.1.1.2-20/21/22/23, if transform precoder is disabled,  $dmrs\text{-}Type=2$ , and  $maxLength=2$ , and the value of rank is determined according to the SRS resource indicator field if the higher layer parameter  $txConfig = nonCodebook$  and according to the Precoding information and number of layers field if the higher layer parameter  $txConfig = codebook$ .

where the number of CDM groups without data of values 1, 2, and 3 in Tables 7.3.1.1.2-6 to 7.3.1.1.2-23 refers to CDM groups {0}, {0,1}, and {0, 1,2} respectively.

If a UE is configured with both  $dmrs\text{-}UplinkForPUSCH\text{-}MappingTypeA$  and  $dmrs\text{-}UplinkForPUSCH\text{-}MappingTypeB$ , the bitwidth of this field equals  $\max\{x_A, x_B\}$ , where  $x_A$  is the "Antenna ports" bitwidth derived according to  $dmrs\text{-}UplinkForPUSCH\text{-}MappingTypeA$  and  $x_B$  is the "Antenna ports" bitwidth derived according to  $dmrs\text{-}UplinkForPUSCH\text{-}MappingTypeB$ . A number of  $|x_A - x_B|$  zeros are padded in the MSB of this field, if the mapping type of the PUSCH corresponds to the smaller value of  $x_A$  and  $x_B$ .

- SRS request – 2 bits as defined by Table 7.3.1.1.2-24 for UEs not configured with  $supplementaryUplink$  in  $ServingCellConfig$  in the cell; 3 bits for UEs configured with  $supplementaryUplink$  in  $ServingCellConfig$  in the cell where the first bit is the non-SUL/SUL indicator as defined in Table 7.3.1.1.1-1 and the second and third bits are defined by Table 7.3.1.1.2-24. This bit field may also indicate the associated CSI-RS according to Subclause 6.1.1.2 of [6, TS 38.214].
- CSI request – 0, 1, 2, 3, 4, 5, or 6 bits determined by higher layer parameter  $reportTriggerSize$ .
- CBG transmission information (CBGTI) – 0, 2, 4, 6, or 8 bits determined by higher layer parameter  $maxCodeBlockGroupsPerTransportBlock$  for PUSCH.
- PTRS-DMRS association – number of bits determined as follows
  - 0 bit if  $PTRS\text{-}UplinkConfig$  is not configured and transform precoder is disabled, or if transform precoder is enabled, or if  $maxRank=1$ ;
  - 2 bits otherwise, where Table 7.3.1.1.2-25 and 7.3.1.1.2-26 are used to indicate the association between PTRS port(s) and DMRS port(s) for transmission of one PT-RS port and two PT-RS ports respectively, and the DMRS ports are indicated by the Antenna ports field.

If "Bandwidth part indicator" field indicates a bandwidth part other than the active bandwidth part and the "PTRS-DMRS association" field is present for the indicated bandwidth part but not present for the active bandwidth part, the UE assumes the "PTRS-DMRS association" field is not present for the indicated bandwidth part.

- beta\_offset indicator – 0 if the higher layer parameter  $betaOffsets = semiStatic$ ; otherwise 2 bits as defined by Table 9.3-3 in [5, TS 38.213].
- DMRS sequence initialization – 0 bit if transform precoder is enabled; 1 bit if transform precoder is disabled.
- UL-SCH indicator – 1 bit. A value of "1" indicates UL-SCH shall be transmitted on the PUSCH and a value of "0" indicates UL-SCH shall not be transmitted on the PUSCH. A UE is not expected to receive a DCI format 0\_1 with UL-SCH indicator of "0" and CSI request of all zero(s).

For a UE configured with  $supplementaryUplink$  in  $ServingCellConfig$  in a cell, if PUSCH is configured to be transmitted on both the SUL and the non-SUL of the cell and if the number of information bits in format 0\_1 for the SUL is not equal to the number of information bits in format 0\_1 for the non-SUL, zeros shall be appended to smaller format 0\_1 until the payload size equals that of the larger format 0\_1.

A UE does not expect that the bit width of a field in DCI format 0\_1 with CRC scrambled by CS-RNTI is larger than corresponding bit width of same field in DCI format 0\_1 with CRC scrambled by C-RNTI for the same serving cell. If the bit width of a field in the DCI format 0\_1 with CRC scrambled by CS-RNTI is not equal to that of the corresponding field in the DCI format 0\_1 with CRC scrambled by C-RNTI for the same serving cell, a number of most significant bits with value set to '0' are inserted to the field in DCI format 0\_1 with CRC scrambled by CS-RNTI until the bit width equals that of the corresponding field in the DCI format 0\_1 with CRC scrambled by C-RNTI for the same serving cell.

**Table 7.3.1.1.2-1: Bandwidth part indicator**

Value of BWP indicator field 2 bits	Bandwidth part
00	Configured BWP with BWP-Id = 1
01	Configured BWP with BWP-Id = 2
10	Configured BWP with BWP-Id = 3
11	Configured BWP with BWP-Id = 4

**Table 7.3.1.1.2-2: Precoding information and number of layers, for 4 antenna ports, if transform precoder is disabled and *maxRank* = 2 or 3 or 4**

Bit field mapped to index	<i>codebookSubset = fullyAndPartialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = partialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = nonCoherent</i>
0	1 layer: TPMI=0	0	1 layer: TPMI=0	0	1 layer: TPMI=0
1	1 layer: TPMI=1	1	1 layer: TPMI=1	1	1 layer: TPMI=1
...	...	...	...	...	...
3	1 layer: TPMI=3	3	1 layer: TPMI=3	3	1 layer: TPMI=3
4	2 layers: TPMI=0	4	2 layers: TPMI=0	4	2 layers: TPMI=0
...	...	...	...	...	...
9	2 layers: TPMI=5	9	2 layers: TPMI=5	9	2 layers: TPMI=5
10	3 layers: TPMI=0	10	3 layers: TPMI=0	10	3 layers: TPMI=0
11	4 layers: TPMI=0	11	4 layers: TPMI=0	11	4 layers: TPMI=0
12	1 layer: TPMI=4	12	1 layer: TPMI=4	12-15	reserved
...	...	...	...		
19	1 layer: TPMI=11	19	1 layer: TPMI=11		
20	2 layers: TPMI=6	20	2 layers: TPMI=6		
...	...	...	...		
27	2 layers: TPMI=13	27	2 layers: TPMI=13		
28	3 layers: TPMI=1	28	3 layers: TPMI=1		
29	3 layers: TPMI=2	29	3 layers: TPMI=2		
30	4 layers: TPMI=1	30	4 layers: TPMI=1		
31	4 layers: TPMI=2	31	4 layers: TPMI=2		
32	1 layers: TPMI=12				
...	...				
47	1 layers: TPMI=27				
48	2 layers: TPMI=14				
...	...				
55	2 layers: TPMI=21				
56	3 layers: TPMI=3				
...	...				
59	3 layers: TPMI=6				
60	4 layers: TPMI=3				
61	4 layers: TPMI=4				
62-63	reserved				

**Table 7.3.1.1.2-3: Precoding information and number of layers for 4 antenna ports, if transform precoder is enabled, or if transform precoder is disabled and *maxRank* = 1**

Bit field mapped to index	<i>codebookSubset = fullyAndPartialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = partialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = nonCoherent</i>
0	1 layer: TPMI=0	0	1 layer: TPMI=0	0	1 layer: TPMI=0
1	1 layer: TPMI=1	1	1 layer: TPMI=1	1	1 layer: TPMI=1
...	...	...	...	...	...
3	1 layer: TPMI=3	3	1 layer: TPMI=3	3	1 layer: TPMI=3
4	1 layer: TPMI=4	4	1 layer: TPMI=4		
...	...	...	...		
11	1 layer: TPMI=11	11	1 layer: TPMI=11		
12	1 layers: TPMI=12	12-15	reserved		
...	...				
27	1 layers: TPMI=27				
28-31	reserved				

**Table 7.3.1.1.2-4: Precoding information and number of layers, for 2 antenna ports, if transform precoder is disabled and *maxRank* = 2**

Bit field mapped to index	<i>codebookSubset = fullyAndPartialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = nonCoherent</i>
0	1 layer: TPMI=0	0	1 layer: TPMI=0
1	1 layer: TPMI=1	1	1 layer: TPMI=1
2	2 layers: TPMI=0	2	2 layers: TPMI=0
3	1 layer: TPMI=2	3	reserved
4	1 layer: TPMI=3		
5	1 layer: TPMI=4		
6	1 layer: TPMI=5		
7	2 layers: TPMI=1		
8	2 layers: TPMI=2		
9-15	reserved		

**Table 7.3.1.1.2-5: Precoding information and number of layers, for 2 antenna ports, if transform precoder is enabled, or if transform precoder is disabled and *maxRank* = 1**

Bit field mapped to index	<i>codebookSubset = fullyAndPartialAndNonCoherent</i>	Bit field mapped to index	<i>codebookSubset = nonCoherent</i>
0	1 layer: TPMI=0	0	1 layer: TPMI=0
1	1 layer: TPMI=1	1	1 layer: TPMI=1
2	1 layer: TPMI=2		
3	1 layer: TPMI=3		
4	1 layer: TPMI=4		
5	1 layer: TPMI=5		
6-7	reserved		

**Table 7.3.1.1.2-6: Antenna port(s), transform precoder is enabled, *dmrs-Type*=1, *maxLength*=1**

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	2	0
1	2	1
2	2	2
3	2	3

**Table 7.3.1.1.2-7: Antenna port(s), transform precoder is enabled, *dmrs-Type=1*, *maxLength=2***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	2	0	1
1	2	1	1
2	2	2	1
3	2	3	1
4	2	0	2
5	2	1	2
6	2	2	2
7	2	3	2
8	2	4	2
9	2	5	2
10	2	6	2
11	2	7	2
12-15	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-8: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=1*, rank = 1**

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0
1	1	1
2	2	0
3	2	1
4	2	2
5	2	3
6-7	Reserved	Reserved

**Table 7.3.1.1.2-9: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=1*, rank = 2**

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0,1
1	2	0,1
2	2	2,3
3	2	0,2
4-7	Reserved	Reserved

**Table 7.3.1.1.2-10: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=1*, rank = 3**

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	2	0-2
2-7	Reserved	Reserved

**Table 7.3.1.1.2-11: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=1*, rank = 4**

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	2	0-3
2-7	Reserved	Reserved

Table 7.3.1.1.2-12: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=2*, rank = 1

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0	1
1	1	1	1
2	2	0	1
3	2	1	1
4	2	2	1
5	2	3	1
6	2	0	2
7	2	1	2
8	2	2	2
9	2	3	2
10	2	4	2
11	2	5	2
12	2	6	2
13	2	7	2
14-15	Reserved	Reserved	Reserved

Table 7.3.1.1.2-13: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=2*, rank = 2

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0,1	1
1	2	0,1	1
2	2	2,3	1
3	2	0,2	1
4	2	0,1	2
5	2	2,3	2
6	2	4,5	2
7	2	6,7	2
8	2	0,4	2
9	2	2,6	2
10-15	Reserved	Reserved	Reserved

Table 7.3.1.1.2-14: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=2*, rank = 3

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	2	0-2	1
1	2	0,1,4	2
2	2	2,3,6	2
3-15	Reserved	Reserved	Reserved

Table 7.3.1.1.2-15: Antenna port(s), transform precoder is disabled, *dmrs-Type=1*, *maxLength=2*, rank = 4

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	2	0-3	1
1	2	0,1,4,5	2
2	2	2,3,6,7	2
3	2	0,2,4,6	2
4-15	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-16: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=1*, *rank=1***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0
1	1	1
2	2	0
3	2	1
4	2	2
5	2	3
6	3	0
7	3	1
8	3	2
9	3	3
10	3	4
11	3	5
12-15	Reserved	Reserved

**Table 7.3.1.1.2-17: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=1*, *rank=2***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0,1
1	2	0,1
2	2	2,3
3	3	0,1
4	3	2,3
5	3	4,5
6	2	0,2
7-15	Reserved	Reserved

**Table 7.3.1.1.2-18: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=1*, *rank=3***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	2	0-2
1	3	0-2
2	3	3-5
3-15	Reserved	Reserved

**Table 7.3.1.1.2-19: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=1*, *rank=4***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	2	0-3
1	3	0-3
2-15	Reserved	Reserved

**Table 7.3.1.1.2-20: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=2*, *rank=1***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0	1
1	1	1	1
2	2	0	1
3	2	1	1
4	2	2	1
5	2	3	1
6	3	0	1
7	3	1	1
8	3	2	1
9	3	3	1
10	3	4	1
11	3	5	1
12	3	0	2
13	3	1	2
14	3	2	2
15	3	3	2
16	3	4	2
17	3	5	2
18	3	6	2
19	3	7	2
20	3	8	2
21	3	9	2
22	3	10	2
23	3	11	2
24	1	0	2
25	1	1	2
26	1	6	2
27	1	7	2
28-31	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-21: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=2*, *rank=2***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0,1	1
1	2	0,1	1
2	2	2,3	1
3	3	0,1	1
4	3	2,3	1
5	3	4,5	1
6	2	0,2	1
7	3	0,1	2
8	3	2,3	2
9	3	4,5	2
10	3	6,7	2
11	3	8,9	2
12	3	10,11	2
13	1	0,1	2
14	1	6,7	2
15	2	0,1	2
16	2	2,3	2
17	2	6,7	2
18	2	8,9	2
19-31	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-22: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=2*, *rank=3***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	2	0-2	1
1	3	0-2	1
2	3	3-5	1
3	3	0,1,6	2
4	3	2,3,8	2
5	3	4,5,10	2
6-31	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-23: Antenna port(s), transform precoder is disabled, *dmrs-Type=2*, *maxLength=2*, *rank=4***

Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	2	0-3	1
1	3	0-3	1
2	3	0,1,6,7	2
3	3	2,3,8,9	2
4	3	4,5,10,11	2
5-31	Reserved	Reserved	Reserved

**Table 7.3.1.1.2-24: SRS request**

Value of SRS request field	Triggered aperiodic SRS resource set(s) for DCI format 0_1, 1_0, and 2_3 configured with higher layer parameter <i>srs-TPC-PDCCH-Group</i> set to 'typeB'	Triggered aperiodic SRS resource set(s) for DCI format 2_3 configured with higher layer parameter <i>srs-TPC-PDCCH-Group</i> set to 'typeA'
00	No aperiodic SRS resource set triggered	No aperiodic SRS resource set triggered
01	SRS resource set(s) configured with higher layer parameter <i>aperiodicSRS-ResourceTrigger</i> set to 1	SRS resource set(s) configured with higher layer parameter <i>SRS-SetUse</i> set to 'antenna switching' and <i>resourceType</i> in <i>SRS-ResourceSet</i> set to 'aperiodic' for a 1 <sup>st</sup> set of serving cells configured by higher layers
10	SRS resource set(s) configured with higher layer parameter <i>aperiodicSRS-ResourceTrigger</i> set to 2	SRS resource set(s) configured with higher layer parameter <i>SRS-SetUse</i> set to 'antenna switching' and <i>resourceType</i> in <i>SRS-ResourceSet</i> set to 'aperiodic' for a 2 <sup>nd</sup> set of serving cells configured by higher layers
11	SRS resource set(s) configured with higher layer parameter <i>aperiodicSRS-ResourceTrigger</i> set to 3	SRS resource set(s) configured with higher layer parameter <i>SRS-SetUse</i> set to 'antenna switching' and <i>resourceType</i> in <i>SRS-ResourceSet</i> set to 'aperiodic' for a 3 <sup>rd</sup> set of serving cells configured by higher layers

**Table 7.3.1.1.2-25: PTRS-DMRS association for UL PTRS port 0**

Value	DMRS port
0	1 <sup>st</sup> scheduled DMRS port
1	2 <sup>nd</sup> scheduled DMRS port
2	3 <sup>rd</sup> scheduled DMRS port
3	4 <sup>th</sup> scheduled DMRS port



**Table 7.3.1.1.2-26: PTRS-DMRS association for UL PTRS ports 0 and 1**

Value of MSB	DMRS port	Value of LSB	DMRS port
0	1 <sup>st</sup> DMRS port which shares PTRS port 0	0	1 <sup>st</sup> DMRS port which shares PTRS port 1
1	2 <sup>nd</sup> DMRS port which shares PTRS port 0	1	2 <sup>nd</sup> DMRS port which shares PTRS port 1

**Table 7.3.1.1.2-27: void**

**Table 7.3.1.1.2-28: SRI indication for non-codebook based PUSCH transmission,  $L_{\max} = 1$**

Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 2$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 3$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 4$
0	0	0	0	0	0
1	1	1	1	1	1
		2	2	2	2
		3	reserved	3	3

**Table 7.3.1.1.2-29: SRI indication for non-codebook based PUSCH transmission,  $L_{\max} = 2$**

Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 2$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 3$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 4$
0	0	0	0	0	0
1	1	1	1	1	1
2	0,1	2	2	2	2
3	reserved	3	0,1	3	3
		4	0,2	4	0,1
		5	1,2	5	0,2
		6-7	reserved	6	0,3
				7	1,2
				8	1,3
				9	2,3
				10-15	reserved

**Table 7.3.1.1.2-30: SRI indication for non-codebook based PUSCH transmission,  $L_{\max} = 3$**

Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 2$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 3$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 4$
0	0	0	0	0	0
1	1	1	1	1	1
2	0,1	2	2	2	2
3	reserved	3	0,1	3	3
		4	0,2	4	0,1
		5	1,2	5	0,2
		6	0,1,2	6	0,3
		7	reserved	7	1,2
				8	1,3
				9	2,3
				10	0,1,2
				11	0,1,3
				12	0,2,3
				13	1,2,3
				14-15	reserved

**Table 7.3.1.1.2-31: SRI indication for non-codebook based PUSCH transmission,  $L_{\max} = 4$** 

Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 2$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 3$	Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 4$
0	0	0	0	0	0
1	1	1	1	1	1
2	0,1	2	2	2	2
3	reserved	3	0,1	3	3
		4	0,2	4	0,1
		5	1,2	5	0,2
		6	0,1,2	6	0,3
		7	reserved	7	1,2
				8	1,3
				9	2,3
				10	0,1,2
				11	0,1,3
				12	0,2,3
				13	1,2,3
				14	0,1,2,3
				15	reserved

**Table 7.3.1.1.2-32: SRI indication for codebook based PUSCH transmission**

Bit field mapped to index	SRI(s), $N_{\text{SRS}} = 2$
0	0
1	1

**Table 7.3.1.1.2-33: VRB-to-PRB mapping**

Bit field mapped to index	VRB-to-PRB mapping
0	Non-interleaved
1	Interleaved

## 7.3.1.2 DCI formats for scheduling of PDSCH

### 7.3.1.2.1 Format 1\_0

DCI format 1\_0 is used for the scheduling of PDSCH in one DL cell.

The following information is transmitted by means of the DCI format 1\_0 with CRC scrambled by C-RNTI or CS-RNTI or MCS-C-RNTI:

- Identifier for DCI formats – 1 bits
  - The value of this bit field is always set to 1, indicating a DL DCI format
- Frequency domain resource assignment –  $\lceil \log_2(N_{\text{RB}}^{\text{DL,BWP}}(N_{\text{RB}}^{\text{DL,BWP}} + 1)/2) \rceil$  bits where  $N_{\text{RB}}^{\text{DL,BWP}}$  is given by subclause 7.3.1.0

If the CRC of the DCI format 1\_0 is scrambled by C-RNTI and the "Frequency domain resource assignment" field are of all ones, the DCI format 1\_0 is for random access procedure initiated by a PDCCH order, with all remaining fields set as follows:

- Random Access Preamble index – 6 bits according to *ra-PreambleIndex* in Subclause 5.1.2 of [8, TS38.321]
- UL/SUL indicator – 1 bit. If the value of the "Random Access Preamble index" is not all zeros and if the UE is configured with *supplementaryUplink* in *ServingCellConfig* in the cell, this field indicates which UL carrier in the cell to transmit the PRACH according to Table 7.3.1.1.1-1; otherwise, this field is reserved

- SS/PBCH index – 6 bits. If the value of the "Random Access Preamble index" is not all zeros, this field indicates the SS/PBCH that shall be used to determine the RACH occasion for the PRACH transmission; otherwise, this field is reserved.
- PRACH Mask index – 4 bits. If the value of the "Random Access Preamble index" is not all zeros, this field indicates the RACH occasion associated with the SS/PBCH indicated by "SS/PBCH index" for the PRACH transmission, according to Subclause 5.1.1 of [8, TS38.321]; otherwise, this field is reserved
- Reserved bits – 10 bits

Otherwise, all remaining fields are set as follows:

- Time domain resource assignment – 4 bits as defined in Subclause 5.1.2.1 of [6, TS 38.214]
- VRB-to-PRB mapping – 1 bit according to Table 7.3.1.1.2-33
- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3 of [6, TS 38.214]
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- HARQ process number – 4 bits
- Downlink assignment index – 2 bits as defined in Subclause 9.1.3 of [5, TS 38.213], as counter DAI
- TPC command for scheduled PUCCH – 2 bits as defined in Subclause 7.2.1 of [5, TS 38.213]
- PUCCH resource indicator – 3 bits as defined in Subclause 9.2.3 of [5, TS 38.213]
- PDSCH-to-HARQ\_feedback timing indicator – 3 bits as defined in Subclause 9.2.3 of [5, TS38.213]

The following information is transmitted by means of the DCI format 1\_0 with CRC scrambled by P-RNTI:

- Short Messages Indicator – 2 bits according to Table 7.3.1.2.1-1.
- Short Messages – 8 bits, according to Subclause 6.5 of [9, TS38.331]. If only the scheduling information for Paging is carried, this bit field is reserved.
- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{DL,BWP}(N_{RB}^{DL,BWP} + 1)/2) \rceil$  bits. If only the short message is carried, this bit field is reserved.
  - $N_{RB}^{DL,BWP}$  is the size of CORESET 0
- Time domain resource assignment – 4 bits as defined in Subclause 5.1.2.1 of [6, TS38.214]. If only the short message is carried, this bit field is reserved.
- VRB-to-PRB mapping – 1 bit according to Table 7.3.1.1.2-33. If only the short message is carried, this bit field is reserved.
- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3 of [6, TS38.214], using Table 5.1.3.1-1. If only the short message is carried, this bit field is reserved.
- TB scaling – 2 bits as defined in Subclause 5.1.3.2 of [6, TS38.214]. If only the short message is carried, this bit field is reserved.
- Reserved bits – 6 bits

The following information is transmitted by means of the DCI format 1\_0 with CRC scrambled by SI-RNTI:

- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{DL,BWP}(N_{RB}^{DL,BWP} + 1)/2) \rceil$  bits

- $N_{RB}^{DL,BWP}$  is the size of CORESET 0
- Time domain resource assignment – 4 bits as defined in Subclause 5.1.2.1 of [6, TS38.214]
- VRB-to-PRB mapping – 1 bit according to Table 7.3.1.1.2-33
- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3 of [6, TS38.214], using Table 5.1.3.1-1
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- System information indicator – 1 bit as defined in Table 7.3.1.2.1-2
- Reserved bits – [15] bits

The following information is transmitted by means of the DCI format 1\_0 with CRC scrambled by RA-RNTI:

- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{DL,BWP}(N_{RB}^{DL,BWP} + 1)/2) \rceil$  bits
- $N_{RB}^{DL,BWP}$  is the size of CORESET 0 if CORESET 0 is configured for the cell and  $N_{RB}^{DL,BWP}$  is the size of initial DL bandwidth part if CORESET 0 is not configured for the cell
- Time domain resource assignment – 4 bits as defined in Subclause 5.1.2.1 of [6, TS38.214]
- VRB-to-PRB mapping – 1 bit according to Table 7.3.1.1.2-33
- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3 of [6, TS38.214], using Table 5.1.3.1-1
- TB scaling – 2 bits as defined in Subclause 5.1.3.2 of [6, TS38.214]
- Reserved bits – 16 bits

The following information is transmitted by means of the DCI format 1\_0 with CRC scrambled by TC-RNTI:

- Identifier for DCI formats – 1 bit
  - The value of this bit field is always set to 1, indicating a DL DCI format
- Frequency domain resource assignment –  $\lceil \log_2(N_{RB}^{DL,BWP}(N_{RB}^{DL,BWP} + 1)/2) \rceil$  bits
- $N_{RB}^{DL,BWP}$  is the size of CORESET 0
- Time domain resource assignment – 4 bits as defined in Subclause 5.1.2.1 of [6, TS38.214]
- VRB-to-PRB mapping – 1 bit according to Table 7.3.1.1.2-33
- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3 of [6, TS38.214], using Table 5.1.3.1-1
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2
- HARQ process number – 4 bits
- Downlink assignment index – 2 bits, reserved
- TPC command for scheduled PUCCH – 2 bits as defined in Subclause 7.2.1 of [5, TS38.213]
- PUCCH resource indicator – 3 bits as defined in Subclause 9.2.3 of [5, TS38.213]
- PDSCH-to-HARQ<sub>feedback</sub> timing indicator – 3 bits as defined in Subclause 9.2.3 of [5, TS38.213]

**Table 7.3.1.2.1-1: Short Message indicator**

Bit field	Short Message indicator
00	Reserved
01	Only scheduling information for Paging is present in the DCI
10	Only short message is present in the DCI
11	Both scheduling information for Paging and short message are present in the DCI

**Table 7.3.1.2.1-2: System information indicator**

Bit field	System information indicator
0	SIB1 [9, TS38.331, Subclause 5.2.1]
1	SI message [9, TS38.331, Subclause 5.2.1]

### 7.3.1.2.2 Format 1\_1

DCI format 1\_1 is used for the scheduling of PDSCH in one cell.

The following information is transmitted by means of the DCI format 1\_1 with CRC scrambled by C-RNTI or CS-RNTI or MCS-C-RNTI:

- Identifier for DCI formats – 1 bits
  - The value of this bit field is always set to 1, indicating a DL DCI format
- Carrier indicator – 0 or 3 bits as defined in Subclause 10.1 of [5, TS 38.213].
- Bandwidth part indicator – 0, 1 or 2 bits as determined by the number of DL BWPs  $n_{\text{BWP,RRC}}$  configured by higher layers, excluding the initial DL bandwidth part. The bitwidth for this field is determined as  $\lceil \log_2(n_{\text{BWP}}) \rceil$  bits, where
  - $n_{\text{BWP}} = n_{\text{BWP,RRC}} + 1$  if  $n_{\text{BWP,RRC}} \leq 3$ , in which case the bandwidth part indicator is equivalent to the ascending order of the higher layer parameter *BWP-Id*;
  - otherwise  $n_{\text{BWP}} = n_{\text{BWP,RRC}}$ , in which case the bandwidth part indicator is defined in Table 7.3.1.1.2-1;

If a UE does not support active BWP change via DCI, the UE ignores this bit field.

- Frequency domain resource assignment – number of bits determined by the following, where  $N_{\text{RB}}^{\text{DL,BWP}}$  is the size of the active DL bandwidth part:
  - $N_{\text{RB}}$  bits if only resource allocation type 0 is configured, where  $N_{\text{RB}}$  is defined in Subclause 5.1.2.2.1 of [6, TS38.214],
  - $\lceil \log_2(N_{\text{RB}}^{\text{DL,BWP}}(N_{\text{RB}}^{\text{DL,BWP}} + 1)/2) \rceil$  bits if only resource allocation type 1 is configured, or
  - $\max\left(\lceil \log_2(N_{\text{RB}}^{\text{DL,BWP}}(N_{\text{RB}}^{\text{DL,BWP}} + 1)/2) \rceil, N_{\text{RB}}\right) + 1$  bits if both resource allocation type 0 and 1 are configured.
  - If both resource allocation type 0 and 1 are configured, the MSB bit is used to indicate resource allocation type 0 or resource allocation type 1, where the bit value of 0 indicates resource allocation type 0 and the bit value of 1 indicates resource allocation type 1.
  - For resource allocation type 0, the  $N_{\text{RB}}$  LSBs provide the resource allocation as defined in Subclause 5.1.2.2.1 of [6, TS 38.214].
  - For resource allocation type 1, the  $\lceil \log_2(N_{\text{RB}}^{\text{DL,BWP}}(N_{\text{RB}}^{\text{DL,BWP}} + 1)/2) \rceil$  LSBs provide the resource allocation as defined in Subclause 5.1.2.2.2 of [6, TS 38.214]

If "Bandwidth part indicator" field indicates a bandwidth part other than the active bandwidth part and if both resource allocation type 0 and 1 are configured for the indicated bandwidth part, the UE assumes resource allocation type 0 for the indicated bandwidth part if the bitwidth of the "Frequency domain resource assignment" field of the active bandwidth part is smaller than the bitwidth of the "Frequency domain resource assignment" field of the indicated bandwidth part.

- Time domain resource assignment – 0, 1, 2, 3, or 4 bits as defined in Subclause 5.1.2.1 of [6, TS 38.214]. The bitwidth for this field is determined as  $\lceil \log_2(I) \rceil$  bits, where  $I$  is the number of entries in the higher layer parameter *pdsch-TimeDomainAllocationList* if the higher layer parameter is configured; otherwise  $I$  is the number of entries in the default table.
- VRB-to-PRB mapping – 0 or 1 bit:
  - 0 bit if only resource allocation type 0 is configured or if interleaved VRB-to-PRB mapping is not configured by high layers;
  - 1 bit according to Table 7.3.1.1.2-33 otherwise, only applicable to resource allocation type 1, as defined in Subclause 7.3.1.6 of [4, TS 38.211].
- PRB bundling size indicator – 0 bit if the higher layer parameter *prb-BundlingType* is not configured or is set to 'static', or 1 bit if the higher layer parameter *prb-BundlingType* is set to 'dynamic' according to Subclause 5.1.2.3 of [6, TS 38.214].
- Rate matching indicator – 0, 1, or 2 bits according to higher layer parameters *rateMatchPatternGroup1* and *rateMatchPatternGroup2*, where the MSB is used to indicate *rateMatchPatternGroup1* and the LSB is used to indicate *rateMatchPatternGroup2* when there are two groups.
- ZP CSI-RS trigger – 0, 1, or 2 bits as defined in Subclause 5.1.4.2 of [6, TS 38.214]. The bitwidth for this field is determined as  $\lceil \log_2(n_{ZP} + 1) \rceil$  bits, where  $n_{ZP}$  is the number of aperiodic ZP CSI-RS resource sets configured by higher layer.

For transport block 1:

- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3.1 of [6, TS 38.214]
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2

For transport block 2 (only present if *maxNrofCodeWordsScheduledByDCI* equals 2):

- Modulation and coding scheme – 5 bits as defined in Subclause 5.1.3.1 of [6, TS 38.214]
- New data indicator – 1 bit
- Redundancy version – 2 bits as defined in Table 7.3.1.1.1-2

If "Bandwidth part indicator" field indicates a bandwidth part other than the active bandwidth part and the value of *maxNrofCodeWordsScheduledByDCI* for the indicated bandwidth part equals 2 and the value of *maxNrofCodeWordsScheduledByDCI* for the active bandwidth part equals 1, the UE assumes zeros are padded when interpreting the "Modulation and coding scheme", "New data indicator", and "Redundancy version" fields of transport block 2 according to Subclause 12 of [5, TS38.213], and the UE ignores the "Modulation and coding scheme", "New data indicator", and "Redundancy version" fields of transport block 2 for the indicated bandwidth part.

- HARQ process number – 4 bits
- Downlink assignment index – number of bits as defined in the following
  - 4 bits if more than one serving cell are configured in the DL and the higher layer parameter *pdsch-HARQ-ACK-Codebook=dynamic*, where the 2 MSB bits are the counter DAI and the 2 LSB bits are the total DAI;
  - 2 bits if only one serving cell is configured in the DL and the higher layer parameter *pdsch-HARQ-ACK-Codebook=dynamic*, where the 2 bits are the counter DAI;

- 0 bits otherwise.
- TPC command for scheduled PUCCH – 2 bits as defined in Subclause 7.2.1 of [5, TS 38.213]
- PUCCH resource indicator – 3 bits as defined in Subclause 9.2.3 of [5, TS 38.213]
- PDSCH-to-HARQ\_feedback timing indicator – 0, 1, 2, or 3 bits as defined in Subclause 9.2.3 of [5, TS 38.213]. The bitwidth for this field is determined as  $\lceil \log_2(I) \rceil$  bits, where  $I$  is the number of entries in the higher layer parameter *dl-DataToUL-ACK*.
- Antenna port(s) – 4, 5, or 6 bits as defined by Tables 7.3.1.2.2-1/2/3/4, where the number of CDM groups without data of values 1, 2, and 3 refers to CDM groups {0}, {0,1}, and {0, 1,2} respectively. The antenna ports  $\{p_0, \dots, p_{v-1}\}$  shall be determined according to the ordering of DMRS port(s) given by Tables 7.3.1.2.2-1/2/3/4.

If a UE is configured with both *dmrs-DownlinkForPDSCH-MappingTypeA* and *dmrs-DownlinkForPDSCH-MappingTypeB*, the bitwidth of this field equals  $\max\{x_A, x_B\}$ , where  $x_A$  is the "Antenna ports" bitwidth derived according to *dmrs-DownlinkForPDSCH-MappingTypeA* and  $x_B$  is the "Antenna ports" bitwidth derived according to *dmrs-DownlinkForPDSCH-MappingTypeB*. A number of  $|x_A - x_B|$  zeros are padded in the MSB of this field, if the mapping type of the PDSCH corresponds to the smaller value of  $x_A$  and  $x_B$ .

- Transmission configuration indication – 0 bit if higher layer parameter *tc-PresentInDCI* is not enabled; otherwise 3 bits as defined in Subclause 5.1.5 of [6, TS38.214].

If "Bandwidth part indicator" field indicates a bandwidth part other than the active bandwidth part,

- if the higher layer parameter *tc-PresentInDCI* is not enabled for the CORESET used for the PDCCH carrying the DCI format 1\_1,
  - the UE assumes *tc-PresentInDCI* is not enabled for all CORESETs in the indicated bandwidth part;
- otherwise,
  - the UE assumes *tc-PresentInDCI* is enabled for all CORESETs in the indicated bandwidth part.
- SRS request – 2 bits as defined by Table 7.3.1.1.2-24 for UEs not configured with *supplementaryUplink* in *ServingCellConfig* in the cell; 3 bits for UEs configured with *supplementaryUplink* in *ServingCellConfig* in the cell where the first bit is the non-SUL/SUL indicator as defined in Table 7.3.1.1.1-1 and the second and third bits are defined by Table 7.3.1.1.2-24. This bit field may also indicate the associated CSI-RS according to Subclause 6.1.1.2 of [6, TS 38.214].
- CBG transmission information (CBGTI) – 0, 2, 4, 6, or 8 bits as defined in Subclause 5.1.7 of [6, TS38.214], determined by the higher layer parameters *maxCodeBlockGroupsPerTransportBlock* and *Number-MCS-HARQ-DL-DCI* for the PDSCH.
- CBG flushing out information (CBGFI) – 0 or 1 bit as defined in Subclause 5.1.7 of [6, TS38.214], determined by higher layer parameter *codeBlockGroupFlushIndicator*.
- DMRS sequence initialization – 1 bit.

If DCI formats 1\_1 are monitored in multiple search spaces associated with multiple CORESETs in a BWP for scheduling the same serving cell, zeros shall be appended until the payload size of the DCI formats 1\_1 monitored in the multiple search spaces equal to the maximum payload size of the DCI format 1\_1 monitored in the multiple search spaces.

**Table 7.3.1.2.2-1: Antenna port(s) (1000 + DMRS port), *dmrs-Type=1*, *maxLength=1***

One Codeword: Codeword 0 enabled, Codeword 1 disabled		
Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0
1	1	1
2	1	0,1
3	2	0
4	2	1
5	2	2
6	2	3
7	2	0,1
8	2	2,3
9	2	0-2
10	2	0-3
11	2	0,2
12-15	Reserved	Reserved

**Table 7.3.1.2.2-2: Antenna port(s) (1000 + DMRS port), *dmrs-Type=1*, *maxLength=2***

One Codeword: Codeword 0 enabled, Codeword 1 disabled				Two Codewords: Codeword 0 enabled, Codeword 1 enabled			
Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols	Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0	1	0	2	0-4	2
1	1	1	1	1	2	0,1,2,3,4,6	2
2	1	0,1	1	2	2	0,1,2,3,4,5,6	2
3	2	0	1	3	2	0,1,2,3,4,5,6,7	2
4	2	1	1	4-31	reserved	reserved	reserved
5	2	2	1				
6	2	3	1				
7	2	0,1	1				
8	2	2,3	1				
9	2	0-2	1				
10	2	0-3	1				
11	2	0,2	1				
12	2	0	2				
13	2	1	2				
14	2	2	2				
15	2	3	2				
16	2	4	2				
17	2	5	2				
18	2	6	2				
19	2	7	2				
20	2	0,1	2				
21	2	2,3	2				
22	2	4,5	2				
23	2	6,7	2				
24	2	0,4	2				
25	2	2,6	2				
26	2	0,1,4	2				
27	2	2,3,6	2				
28	2	0,1,4,5	2				
29	2	2,3,6,7	2				
30	2	0,2,4,6	2				
31	Reserved	Reserved	Reserved				



Table 7.3.1.2.2-3: Antenna port(s) (1000 + DMRS port), *dmrs-Type=2*, *maxLength=1*

One codeword: Codeword 0 enabled, Codeword 1 disabled			Two codewords: Codeword 0 enabled, Codeword 1 enabled		
Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0	0	3	0-4
1	1	1	1	3	0-5
2	1	0,1	2-31	reserved	reserved
3	2	0			
4	2	1			
5	2	2			
6	2	3			
7	2	0,1			
8	2	2,3			
9	2	0-2			
10	2	0-3			
11	3	0			
12	3	1			
13	3	2			
14	3	3			
15	3	4			
16	3	5			
17	3	0,1			
18	3	2,3			
19	3	4,5			
20	3	0-2			
21	3	3-5			
22	3	0-3			
23	2	0,2			
24-31	Reserved	Reserved			

**Table 7.3.1.2.2-4: Antenna port(s) (1000 + DMRS port), *dmrs-Type=2*, *maxLength=2***

One codeword: Codeword 0 enabled, Codeword 1 disabled				Two Codewords: Codeword 0 enabled, Codeword 1 enabled			
Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols	Value	Number of DMRS CDM group(s) without data	DMRS port(s)	Number of front-load symbols
0	1	0	1	0	3	0-4	1
1	1	1	1	1	3	0-5	1
2	1	0,1	1	2	2	0,1,2,3,6	2
3	2	0	1	3	2	0,1,2,3,6,8	2
4	2	1	1	4	2	0,1,2,3,6,7,8	2
5	2	2	1	5	2	0,1,2,3,6,7,8,9	2
6	2	3	1	6-63	Reserved	Reserved	Reserved
7	2	0,1	1				
8	2	2,3	1				
9	2	0-2	1				
10	2	0-3	1				
11	3	0	1				
12	3	1	1				
13	3	2	1				
14	3	3	1				
15	3	4	1				
16	3	5	1				
17	3	0,1	1				
18	3	2,3	1				
19	3	4,5	1				
20	3	0-2	1				
21	3	3-5	1				
22	3	0-3	1				
23	2	0,2	1				
24	3	0	2				
25	3	1	2				
26	3	2	2				
27	3	3	2				
28	3	4	2				
29	3	5	2				
30	3	6	2				
31	3	7	2				
32	3	8	2				
33	3	9	2				
34	3	10	2				
35	3	11	2				
36	3	0,1	2				
37	3	2,3	2				
38	3	4,5	2				
39	3	6,7	2				
40	3	8,9	2				
41	3	10,11	2				
42	3	0,1,6	2				
43	3	2,3,8	2				
44	3	4,5,10	2				
45	3	0,1,6,7	2				
46	3	2,3,8,9	2				
47	3	4,5,10,11	2				
48	1	0	2				
49	1	1	2				
50	1	6	2				
51	1	7	2				
52	1	0,1	2				
53	1	6,7	2				
54	2	0,1	2				
55	2	2,3	2				
56	2	6,7	2				

57	2	8,9	2				
58-63	Reserved	Reserved	Reserved				

### 7.3.1.3 DCI formats for other purposes

#### 7.3.1.3.1 Format 2\_0

DCI format 2\_0 is used for notifying the slot format.

The following information is transmitted by means of the DCI format 2\_0 with CRC scrambled by SFI-RNTI:

- Slot format indicator 1, Slot format indicator 2, ..., Slot format indicator  $N$ .

The size of DCI format 2\_0 is configurable by higher layers up to 128 bits, according to Subclause 11.1.1 of [5, TS 38.213].

#### 7.3.1.3.2 Format 2\_1

DCI format 2\_1 is used for notifying the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE.

The following information is transmitted by means of the DCI format 2\_1 with CRC scrambled by INT-RNTI:

- Pre-emption indication 1, Pre-emption indication 2, ..., Pre-emption indication  $N$ .

The size of DCI format 2\_1 is configurable by higher layers up to 126 bits, according to Subclause 11.2 of [5, TS 38.213]. Each pre-emption indication is 14 bits.

#### 7.3.1.3.3 Format 2\_2

DCI format 2\_2 is used for the transmission of TPC commands for PUCCH and PUSCH.

The following information is transmitted by means of the DCI format 2\_2 with CRC scrambled by TPC-PUSCH-RNTI or TPC-PUCCH-RNTI:

- block number 1, block number 2, ..., block number  $N$

The parameter *tpc-PUSCH* or *tpc-PUCCH* provided by higher layers determines the index to the block number for an UL of a cell, with the following fields defined for each block:

- Closed loop indicator – 0 or 1 bit.
  - For DCI format 2\_2 with TPC-PUSCH-RNTI, 0 bit if the UE is not configured with high layer parameter *twoPUSCH-PC-AdjustmentStates*, in which case UE assumes each block in the DCI format 2\_2 is of 2 bits; 1 bit otherwise, in which case UE assumes each block in the DCI format 2\_2 is of 3 bits;
  - For DCI format 2\_2 with TPC-PUCCH-RNTI, 0 bit if the UE is not configured with high layer parameter *twoPUCCH-PC-AdjustmentStates*, in which case UE assumes each block in the DCI format 2\_2 is of 2 bits; 1 bit otherwise, in which case UE assumes each block in the DCI format 2\_2 is of 3 bits;
- TPC command – 2 bits

The number of information bits in format 2\_2 shall be equal to or less than the payload size of format 1\_0 monitored in common search space in the same serving cell. If the number of information bits in format 2\_2 is less than the payload size of format 1\_0 monitored in common search space in the same serving cell, zeros shall be appended to format 2\_2 until the payload size equals that of format 1\_0 monitored in common search space in the same serving cell.

#### 7.3.1.3.4 Format 2\_3

DCI format 2\_3 is used for the transmission of a group of TPC commands for SRS transmissions by one or more UEs. Along with a TPC command, a SRS request may also be transmitted.

The following information is transmitted by means of the DCI format 2\_3 with CRC scrambled by TPC-SRS-RNTI:

- block number 1, block number 2, ..., block number  $B$

where the starting position of a block is determined by the parameter *startingBitOfFormat2-3* or *startingBitOfFormat2-3SUL-v1530* provided by higher layers for the UE configured with the block.

If the UE is configured with higher layer parameter *srs-TPC-PDCCH-Group = typeA* for an UL without PUCCH and PUSCH or an UL on which the SRS power control is not tied with PUSCH power control, one block is configured for the UE by higher layers, with the following fields defined for the block:

- SRS request – 0 or 2 bits. The presence of this field is according to the definition in Subclause 11.4 of [5, TS38.213]. If present, this field is interpreted as defined by Table 7.3.1.1.2-24.
- TPC command number 1, TPC command number 2, ..., TPC command number  $N$ , where each TPC command applies to a respective UL carrier provided by higher layer parameter *cc-IndexInOneCC-Set*

If the UE is configured with higher layer parameter *srs-TPC-PDCCH-Group = typeB* for an UL without PUCCH and PUSCH or an UL on which the SRS power control is not tied with PUSCH power control, one block or more blocks is configured for the UE by higher layers where each block applies to an UL carrier, with the following fields defined for each block:

- SRS request – 0 or 2 bits. The presence of this field is according to the definition in Subclause 11.4 of [5, TS38.213]. If present, this field is interpreted as defined by Table 7.3.1.1.2-24.
- TPC command – 2 bits

The number of information bits in format 2\_3 shall be equal to or less than the payload size of format 1\_0 monitored in common search space in the same serving cell. If the number of information bits in format 2\_3 is less than the payload size of format 1\_0 monitored in common search space in the same serving cell, zeros shall be appended to format 2\_3 until the payload size equals that of format 1\_0 monitored in common search space in the same serving cell.

### 7.3.2 CRC attachment

Error detection is provided on DCI transmissions through a Cyclic Redundancy Check (CRC).

The entire payload is used to calculate the CRC parity bits. Denote the bits of the payload by  $a_0, a_1, a_2, a_3, \dots, a_{A-1}$ , and the parity bits by  $p_0, p_1, p_2, p_3, \dots, p_{L-1}$ , where  $A$  is the payload size and  $L$  is the number of parity bits. Let  $a'_0, a'_1, a'_2, a'_3, \dots, a'_{A+L-1}$  be a bit sequence such that  $a'_i = 1$  for  $i = 0, 1, \dots, L-1$  and  $a'_i = a_{i-L}$  for  $i = L, L+1, \dots, A+L-1$ . The parity bits are computed with input bit sequence  $a'_0, a'_1, a'_2, a'_3, \dots, a'_{A+L-1}$  and attached according to Subclause 5.1 by setting  $L$  to 24 bits and using the generator polynomial  $g_{\text{CRC24C}}(D)$ . The output bit  $b_0, b_1, b_2, b_3, \dots, b_{K-1}$  is

$$b_k = a_k \quad \text{for } k = 0, 1, 2, \dots, A-1$$

$$b_k = p_{k-A} \quad \text{for } k = A, A+1, A+2, \dots, A+L-1,$$

where  $K = A + L$ .

After attachment, the CRC parity bits are scrambled with the corresponding RNTI  $x_{rnti,0}, x_{rnti,1}, \dots, x_{rnti,15}$ , where  $x_{rnti,0}$  corresponds to the MSB of the RNTI, to form the sequence of bits  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ . The relation between  $c_k$  and  $b_k$  is:

$$c_k = b_k \quad \text{for } k = 0, 1, 2, \dots, A+7$$

$$c_k = (b_k + x_{rnti,k-A-8}) \bmod 2 \quad \text{for } k = A+8, A+9, A+10, \dots, A+23.$$

### 7.3.3 Channel coding

Information bits are delivered to the channel coding block. They are denoted by  $c_0, c_1, c_2, c_3, \dots, c_{K-1}$ , where  $K$  is the number of bits, and they are encoded via Polar coding according to Subclause 5.3.1, by setting  $n_{\text{max}} = 9$ ,  $I_{LL} = 1$ ,  $n_{PC} = 0$ , and  $n_{PC}^{\text{wm}} = 0$ .

After encoding the bits are denoted by  $d_0, d_1, d_2, d_3, \dots, d_{N-1}$ , where  $N$  is the number of coded bits.

### 7.3.4 Rate matching

The input bit sequence to rate matching is  $d_0, d_1, d_2, \dots, d_{N-1}$ .

Rate matching is performed according to Subclause 5.4.1 by setting  $I_{BL} = 0$ .

The output bit sequence after rate matching is denoted as  $f_0, f_1, f_2, \dots, f_{E-1}$ .

## Annex <A> (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2017-05	RAN1#89	R1-1707082				Draft skeleton	0.0.0
2017-07	AH_NR2	R1-1712014				Inclusion of LDPC related agreements	0.0.1
2017-08	RAN1#90	R1-1714564				Inclusion of Polar coding related agreements	0.0.2
2017-08	RAN1#90	R1-1714659				Endorsed version by RAN1#90 as basis for further updates	0.1.0
2017-09	RAN1#90	R1-1715322				Capturing additional agreements on LDPC and Polar code from RAN1 #90	0.1.1
2017-09	RAN#77	RP-171991				For information to plenary	1.0.0
2017-09	RAN1#90b	R1-1716928				Capturing additional agreements on LDPC and Polar code from RAN1 NR AH#3	1.0.1
2017-10	RAN1#90b	R1-1719106				Endorsed as v1.1.0	1.1.0
2017-11	RAN1#91	R1-1719225				Capturing additional agreements on channel coding, etc.	1.1.1
2017-11	RAN1#91	R1-1719245				Capturing additional agreements on DCI format, channel coding, etc.	1.1.2
2017-11	RAN1#91	R1-1721049				Endorsed as v1.2.0	1.2.0
2017-12	RAN1#91	R1-1721342				Capturing additional agreements on UCI, DCI, channel coding, etc.	1.2.1
2017-12	RAN#78	RP-172668				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
2018-04	RAN#79					MCC: correction of typo in DCI format 0_1 (time domain resource assignment) – higher layer parameter should be <i>pusch-AllocationList</i>	15.1.1
2018-06	RAN#80	RP-181172	0002	1	F	CR to 38.212 capturing the RAN1#92bis and RAN1#93 meeting agreements	15.2.0
2018-06	RAN#80	RP-181257	0003	-	B	CR to 38.212 capturing the RAN1#92bis and RAN1#93 meeting agreements related to URLLC	15.2.0
2018-09	RAN#81	RP-181789	0004	-	F	CR to 38.212 capturing the RAN1#94 meeting agreements	15.3.0
2018-12	RAN#82	RP-182523	0005	3	F	Combined CR of all essential corrections to 38.212 from RAN1#94bis and RAN1#95	15.4.0
2019-03	RAN#83	RP-190448	0006	-	F	Correction of wrong implementation on frequency domain resource assignment bitwidth	15.5.0
2019-03	RAN#83	RP-190448	0008	-	F	Correction to UCI multiplexing	15.5.0
2019-03	RAN#83	RP-190448	0009	-	F	Correction on DCI format 2_3 for SUL cell in TS 38.212	15.5.0
2019-03	RAN#83	RP-190448	0010	-	F	Corrections to TS38.212	15.5.0
2019-03	RAN#83	RP-190448	0011	-	F	On bitwidth calculation for DCI fields using RRC parameter indicating maximum number of MIMO layers per serving cell	15.5.0
2019-03	RAN#83	RP-190448	0012	-	F	CR on zero-padding of DCI 1_1 in cross-carrier scheduling case	15.5.0
2019-03	RAN#83	RP-190448	0013	-	F	Clarification on UL_SUL indicator field and SRS request field	15.5.0

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## History

<b>Document history</b>		
V15.2.0	July 2018	Publication
V15.3.0	October 2018	Publication
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V15.5.0	May 2019	Publication