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Technical Specification

KT PyeongChang 5G Special Interest Group (KT 5G-SIG); KT 5th Generation Radio Access; Physical Layer; Multiplexing and channel coding (Release 1)

Ericsson, Intel Corp., Nokia, Qualcomm Technologies Inc., Samsung Electronics & KT

Document History

Version	Date	Change
1.0	2016-02-17	First Draft Version
2.1	2016-07-13	Pre-final Version
2.2	2016-08-29	Apply CR for clarification
2.3	2016-09-19	Changes for technical/editorial correction (including DCI format B1 update)

Contents

Foreword

This Technical Specification has been produced by the KT PyeongChang 5G Special Interest Group (KT 5G-SIG).

1 Scope

The present document specifies the coding, multiplexing and mapping to physical channels for 5G Radio Access (5G RA).

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.

[1] TS 5G.201: "5G Radio Access (5G RA); Physical layer; General description".

[2] TS 5G.211: "5G Radio Access (5G RA); Physical channel and modulation".

[3] TS 5G.213: "5G Radio Access (5G RA); Physical layer procedures".

[4] TS 5G.321: “5G Radio Access (5G RA); 5G Medium Access Control Protocol”.

[5] TS 5G.331: “5G Radio Access (5G RA); 5G Radio Resource Control (5G-RRC) Protocol Specification”.

3 Definitions, symbols and abbreviations

3.1 Definitions

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 following abbreviations apply:

BCH	Broadcast channel
BQI	Beam Quality Information
BRS	Beam measurement Reference Signal
CP	Cyclic Prefix
CSI	Channel State Information
DCI	Downlink Control Information
DL-SCH	Downlink Shared channel
FDD	Frequency Division Duplexing
LDPC	Low Density Parity Check
xPBCH	Physical Broadcast channel
xPDCCH	Physical Downlink Control channel
xPDSCH	Physical Downlink Shared channel
PMI	Precoding Matrix Indicator
xPRACH	Physical Random Access channel
xPUSCH	Physical Uplink Shared channel
xRACH	Random Access channel
RI	Rank Indication
SR	Scheduling Request
SRS	Sounding Reference Signal
TDD	Time Division Duplexing
TPMI	Transmitted Precoding Matrix Indicator

UCI Uplink Control Information
UL-SCH Uplink Shared channel

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	xPUSCH
RACH	xPRACH

Table 4.1-2

Control information	Physical Channel
UCI	xPUCCH, xPUSCH

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	xPDSCH
BCH	xPBCH, ePBCH

Table 4.2-2

Control information	Physical Channel
DCI	xPDCCH

5 Channel coding, multiplexing and interleaving

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 Generic procedures

This section contains coding procedures which are used for more than one transport channel or control information type.

5.1.1 CRC calculation

Denote the input bits to the CRC computation by $a_0, a_1, a_2, a_3, ..., a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, ..., p_{L-1}$. 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:

- $g_{CRC24A}(D) = [D^{24} + D^{23} + D^{18} + D^{17} + D^{14} + D^{11} + D^{10} + D^7 + D^6 + D^5 + D^4 + D^3 + D + 1]$ and;
- $g_{CRC16}(D) = [D^{16} + D^{12} + D^5 + 1]$ for a CRC length $L = 16$.

- $g_{CRC8}(D) = [D^8 + D^7 + D^4 + D^3 + D + 1]$ for a CRC length of $L = 8$.

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

$$a_0 D^{A+23} + a_1 D^{A+22} + \ldots + a_{A-1} D^{24} + p_0 D^{23} + p_1 D^{22} + \ldots + p_{22} D^1 + p_{23}$$

yields a remainder equal to 0 when divided by the corresponding length-24 CRC generator polynomial, $g_{CRC24A}(D)$, the polynomial:

$$a_0 D^{A+15} + a_1 D^{A+14} + \ldots + a_{A-1} D^{16} + p_0 D^{15} + p_1 D^{14} + \ldots + p_{14} D^1 + p_{15}$$

yields a remainder equal to 0 when divided by $g_{CRC16}(D)$, and the polynomial:

$$a_0 D^{A+7} + a_1 D^{A+6} + \ldots + a_{A-1} D^8 + p_0 D^7 + p_1 D^6 + \ldots + p_6 D^1 + p_7$$

yields a remainder equal to 0 when divided by $g_{CRC8}(D)$.

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

$b_k = a_k$ for k = 0, 1, 2, …, A-1

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

5.1.2 Code block segmentation

The input bit sequence to the code block segmentation is denoted by $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$, where $B > 0$. If B is larger than the maximum code block size K_{max}, segmentation of the input bit sequence is performed.

The maximum and minimum code block sizes depending on the code rate and Coding Type are depicted in Table 5.1.2-1.

Table 5.1.2-1: K_{max} and K_{min}

Coding Type	Code Rate	K_{max}	K_{min}
Type 1	5/6	1620	540
	3/4	1458	486
	2/3	1296	432
	1/2	972	324
Type 2	1/3	1620	540

If the number of filler bits F_r calculated below is not 0, filler bits are added to r-th blocks, where r is the code block number.

Note that if $B < K_{min}$, filler bits are added to the end of the code block.

The filler bits shall be set to <*NULL*> at the input to the encoder.

For a given code rate, total number of code blocks C is determined by:

if $B \leq K_{max}$

Number of code blocks: $C = 1$

else

Number of code blocks: $C = \lceil B/K_{\max} \rceil$.

end if

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

Number of bits in each code block (applicable for $C \neq 0$ only):

if $C = 1$,

$K_0 = \lceil B/K_{min} \rceil \cdot K_{min}$

$F_0 = K_0 - B$

else

$J = \lceil B/C \rceil$

$K^{'} = \lceil J/K_{min} \rceil \cdot K_{min}$

$F^{'} = K^{'} \cdot C - B$

$\gamma = F^{'} \bmod C$

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

if $r \leq C - \gamma - 1$

$F_r = \lfloor F^{'}/C \rfloor$

$K_r = \lceil B/C \rceil + F_r$

else

$F_r = \lceil F^{'}/C \rceil$

$K_r = \lfloor B/C \rfloor + F_r$

end if

end for r

end if

$s = 0$

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

for $k = 0$ to $K_r - F_r - 1$,

$c_{rk} = b_s$

$s = s + 1$

end for k

The filler bits <*NULL*> shall be inserted end of the each code block

for $k = K_r - F_r - 1$ to K_r-1,

c_{rk} = <*NULL*>

end for k

end for r

5.1.3 Channel coding

The bit sequence input for a given code block to channel coding is denoted by $c_0, c_1, c_2, c_3, ..., c_{K-1}$, where K is the number of bits to encode. After encoding the bits are denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)}, ..., d_{D-1}^{(i)}$ and $d_o, d_1, d_2, d_3, ..., d_{D-1}$ for convolutional coding scheme and LDPC coding scheme respectively, where D is the number of encoded bits per output stream and i indexes the encoder output stream. The relation between c_k and $d_k^{(i)}$ and between K and D is dependent on the channel coding scheme.

The following channel coding schemes can be applied to TrCHs:

- Tail biting convolutional coding;
- LDPC coding.

Usage of coding scheme and coding rate for the different types of TrCH is shown in Table 5.1.3-1. Usage of coding scheme and coding rate for the different control information types is shown in Table 5.1.3-2.

The values of D in connection with each coding scheme:

- tail biting convolutional coding with rate 1/3: $D = K$;
- LDPC coding with code rate R: $D = K/R$

The range for the output stream index i is 0, 1 and 2 for tail biting convolutional coding scheme.

Table 5.1.3-1: Usage of channel coding scheme and coding rate for TrCHs.

TrCH	Coding scheme	Coding rate
UL-SCH	LDPC coding	variable
DL-SCH		
BCH	Tail biting convolutional coding	1/3

Table 5.1.3-2: Usage of channel coding scheme and coding rate for control information.

Control Information	Coding scheme	Coding rate
DCI	Tail biting convolutional coding	1/3
UCI	Block code	variable
	Tail biting convolutional coding	1/3

5.1.3.1 Tail biting convolutional coding

A tail biting convolutional code with constraint length 7 and coding rate 1/3 is defined.

The configuration of the convolutional encoder is presented in Figure 5.1.3.1-1.

The initial value of the shift register of the encoder shall be set to the values corresponding to the last 6 information bits in the input stream so that the initial and final states of the shift register are the same. Therefore, denoting the shift register of the encoder by $s_0, s_1, s_2, ..., s_5$, then the initial value of the shift register shall be set to

$$s_i = c_{(K-1-i)}$$

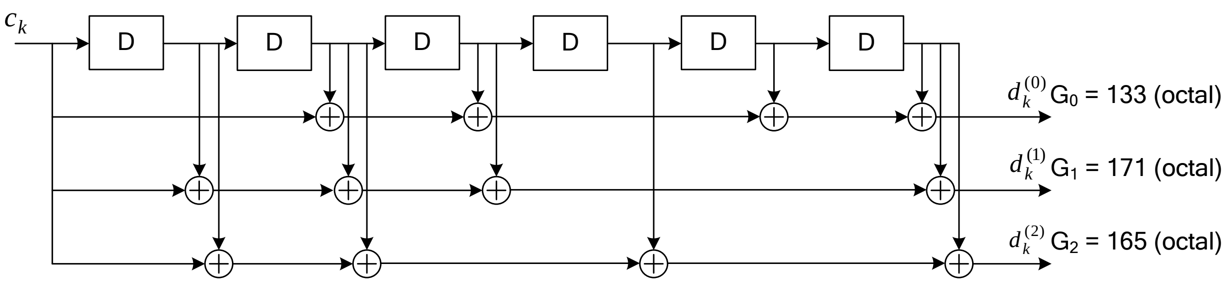

Figure 5.1.3.1-1: Rate 1/3 tail biting convolutional encoder.

The encoder output streams $d_k^{(0)}$, $d_k^{(1)}$ and $d_k^{(2)}$ correspond to the first, second and third parity streams, respectively as shown in Figure 5.1.3.1-1.

5.1.3.2 LDPC encoder

The K bits including filler bits (c_0, c_1, c_2, …, c_{K-1}) are encoded based on D-K by D parity check matrix (H), where D is number of encoded bits and D - K is the number of parity check bits. The parity check bits (p_0, p_1, p_2, … , p_{D-K-1}) are obtained so that $H\cdot \mathbf{d}^T = 0$, where $\mathbf{d}$ =(c_0,c_1,c_2, … ,c_{K-1}, p_0, p_1, p_2, … , p_{D-K-1}) is coded bits stream.

The parity check matrix H is defined as:

$$H = \begin{bmatrix} P^{a_{0,0}} & P^{a_{0,1}} & P^{a_{0,2}} & & P^{a_{0,N_{ldpc\_b}-2}} & P^{a_{0,N_{ldpc\_b}-1}} \\ P^{a_{1,0}} & P^{a_{1,1}} & P^{a_{1,2}} & \cdots & P^{a_{1,N_{ldpc\_b}-2}} & P^{a_{1,N_{ldpc\_b}-1}} \\ P^{a_{2,0}} & P^{a_{2,1}} & P^{a_{2,2}} & & P^{a_{2,N_{ldpc\_b}-2}} & P^{a_{2,N_{ldpc\_b}-1}} \\ & \vdots & & \ddots & & \vdots \\ P^{a_{N_{parity\_b}-1,0}} & P^{a_{N_{parity\_b}-1,1}} & P^{a_{N_{parity\_b}-1,2}} & \cdots & P^{a_{N_{parity\_b}-1,N_{ldpc\_b}-2}} & P^{a_{N_{parity\_b}-1,N_{ldpc\_b}-1}} \end{bmatrix}$$

where $P^{a_{ij}}$ ($0 \le i < N_{parity\_b}$, $0 \le j < N_{ldpc\_b}$) is cyclic-permutation matrix obtained from the zero matrix and the Z by Z identity matrix by cyclically shifted the columns to the right by a_{ij} elements. The value of Z is shift size obtained by $Z = \lceil K/K_{min} \rceil \cdot 27$ where K_{min} is given in Table 5.1.2-1.

The matrix $P^{a_{ij}}$ is Z by Z zero matrix when a_{ij} is -1. The codeword length D, information length K and number of parity bits D-K is equal to N_{ldpc_b} x Z, K_{ldpc_b} x Z and N_{pairty_b} x Z, respectively. The parameters N_{ldpc_b}, K_{ldpc_b} and N_{parity_b} according to code rates are depicted in Table 5.1.3.2-1.

Table 5.1.3.2-1: Parameters of parity check matrix

Coding Type	Code Rate	N_{ldpc_b}	K_{ldpc_b}	N_{parity_b}
Type 1	5/6	24	20	4
	3/4	24	18	6
	2/3	24	16	8
	1/2	24	12	12
Type 2	1/3	60	20	40

For Type 1, the parity check matrix is obtained based on Tables 5.1.3.2-2, 5.1.3.2-3, 5.1.3.2-4 and 5.1.3.2-5 which show the exponents (a_{ij}) of parity check matrix when the code rate equals 5/6, 3/4, 2/3 and 1/2 for each encoded bits, respectively.

For Type 2, the parity check matrix is obtained based on Table 5.1.3.2-6 which shows the exponents (a_{ij}) of parity check matrix when the Z equals 81. The set of exponents (a_{ij}) are used to determine the exponents for all other code length of the same code rate, Z=27 or 54. The exponents $a_{i,j}(Z)$ for code size corresponding to shift size Z, determined above, are derived from a_{ij} by using a modulo function as below:

$$a_{i,j}(Z) = \begin{cases} a_{i,j}, & \text{if } a_{i,j} \le 0 \\ a_{i,j} \bmod Z, & \text{if } a_{i,j} > 0 \end{cases}$$

Table 5.1.3.2-2: Matrix exponents for Code rate R=5/6, Type 1

(a) D = 648 bits, Z=27 bits

17	13	8	21	9	3	18	12	10	0	4	15	19	2	5	10	26	19	13	13	1	0	-1	-1
3	12	11	14	11	25	5	18	0	9	2	26	26	10	24	7	14	20	4	2	-1	0	0	-1
22	16	4	3	10	21	12	5	21	14	19	5	-1	8	5	18	11	5	5	15	0	-1	0	0
7	7	14	14	4	16	16	24	24	10	1	7	15	6	10	26	8	18	21	14	1	-1	-1	0

(b) D = 1296 bits, Z=54 bits

48	29	37	52	2	16	6	14	53	31	34	5	18	42	53	31	45	-1	46	52	1	0	-1	-1
17	4	30	7	43	11	24	6	14	21	6	39	17	40	47	7	15	41	19	-1	-1	0	0	-1
7	2	51	31	46	23	16	11	53	40	10	7	46	53	33	35	-1	25	35	38	0	-1	0	0
19	48	41	1	10	7	36	47	5	29	52	52	31	10	26	6	3	2	-1	51	1	-1	-1	0

(c) D = 1944 bits, Z=81 bits

13	48	80	66	4	74	7	30	76	52	37	60	-1	49	73	31	74	73	23	-1	1	0	-1	-1
69	63	74	56	64	77	57	65	6	16	51	-1	64	-1	68	9	48	62	54	27	-1	0	0	-1
51	15	0	80	24	25	42	54	44	71	71	9	67	35	-1	58	-1	29	-1	53	0	-1	0	0
16	29	36	41	44	56	59	37	50	24	-1	65	4	65	52	-1	4	-1	73	52	1	-1	-1	0

Table 5.1.3.2-3: Matrix exponents for R=3/4, Type 1

(a) D = 648 bits, Z=27 bits

16	17	22	24	9	3	14	-1	4	2	7	-1	26	-1	2	-1	21	-1	1	0	-1	-1	-1	-1
25	12	12	3	3	26	6	21	-1	15	22	-1	15	-1	4	-1	-1	16	-1	0	0	-1	-1	-1
25	18	26	16	22	23	9	-1	0	-1	4	-1	4	-1	8	23	11	-1	-1	-1	0	0	-1	-1
9	7	0	1	17	-1	-1	7	3	-1	3	23	-1	16	-1	-1	21	-1	0	-1	-1	0	0	-1
24	5	26	7	1	-1	-1	15	24	15	-1	8	-1	13	-1	13	-1	11	-1	-1	-1	-1	0	0
2	2	19	14	24	1	15	19	-1	21	-1	2	-1	24	-1	3	-1	2	1	-1	-1	-1	-1	0

(b) D = 1296 bits, Z=54 bits

39	40	51	41	3	29	8	36	-1	14	-1	6	-1	33	-1	11	-1	4	1	0	-1	-1	-1	-1
48	21	47	9	48	35	51	-1	38	-1	28	-1	34	-1	50	-1	50	-1	-1	0	0	-1	-1	-1
30	39	28	42	50	39	5	17	-1	6	-1	18	-1	20	-1	15	-1	40	-1	-1	0	0	-1	-1
29	0	1	43	36	30	47	-1	49	-1	47	-1	3	-1	35	-1	34	-1	0	-1	-1	0	0	-1
1	32	11	23	10	44	12	7	-1	48	-1	4	-1	9	-1	17	-1	16	-1	-1	-1	-1	0	0
13	7	15	47	23	16	47	-1	43	-1	29	-1	52	-1	2	-1	53	-1	1	-1	-1	-1	-1	0

(c) D = 1944 bits, Z=81 bits

48	29	28	39	9	61	-1	-1	-1	63	45	80	-1	-1	-1	37	32	22	1	0	-1	-1	-1	-1
4	49	42	48	11	30	-1	-1	-1	49	17	41	37	15	-1	54	-1	-1	-1	0	0	-1	-1	-1
35	76	78	51	37	35	21	-1	17	64	-1	-1	-1	59	7	-1	-1	32	-1	-1	0	0	-1	-1
9	65	44	9	54	56	73	34	42	-1	-1	-1	35	-1	-1	-1	46	39	0	-1	-1	0	0	-1
3	62	7	80	68	26	-1	80	55	-1	36	-1	26	-1	9	-1	72	-1	-1	-1	-1	-1	0	0
26	75	33	21	69	59	3	38	-1	-1	-1	35	-1	62	36	26	-1	-1	1	-1	-1	-1	-1	0

Table 5.1.3.2-4: Matrix exponents for R=2/3, Type 1

(a) D = 648 bits, Z=27 bits

25	26	14	-1	20	-1	2	-1	4	-1	-1	8	-1	16	-1	18	1	0	-1	-1	-1	-1	-1	-1
10	9	15	11	-1	0	-1	1	-1	-1	18	-1	8	-1	10	-1	-1	0	0	-1	-1	-1	-1	-1
16	2	20	26	21	-1	6	-1	1	26	-1	7	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
10	13	5	0	-1	3	-1	7	-1	-1	26	-1	-1	13	-1	16	-1	-1	-1	0	0	-1	-1	-1
23	14	24	-1	12	-1	19	-1	17	-1	-1	-1	20	-1	21	-1	0	-1	-1	-1	0	0	-1	-1
6	22	9	20	-1	25	-1	17	-1	8	-1	14	-1	18	-1	-1	-1	-1	-1	-1	-1	0	0	-1
14	23	21	11	20	-1	24	-1	18	-1	19	-1	-1	-1	-1	22	-1	-1	-1	-1	-1	-1	0	0
17	11	11	20	-1	21	-1	26	-1	3	-1	-1	18	-1	26	-1	1	-1	-1	-1	-1	-1	-1	0

(b) D = 1296 bits, Z=54 bits

39	31	22	43	-1	40	4	-1	11	-1	-1	50	-1	-1	-1	6	1	0	-1	-1	-1	-1	-1	-1
25	52	41	2	6	-1	14	-1	34	-1	-1	-1	24	-1	37	-1	-1	0	0	-1	-1	-1	-1	-1
43	31	29	0	21	-1	28	-1	-1	2	-1	-1	7	-1	17	-1	-1	-1	0	0	-1	-1	-1	-1
20	33	48	-1	4	13	-1	26	-1	-1	22	-1	-1	46	42	-1	-1	-1	-1	0	0	-1	-1	-1
45	7	18	51	12	25	-1	-1	-1	50	-1	-1	5	-1	-1	-1	0	-1	-1	-1	0	0	-1	-1
35	40	32	16	5	-1	-1	18	-1	-1	43	51	-1	32	-1	-1	-1	-1	-1	-1	-1	0	0	-1
9	24	13	22	28	-1	-1	37	-1	-1	25	-1	-1	52	-1	13	-1	-1	-1	-1	-1	-1	0	0
32	22	4	21	16	-1	-1	-1	27	28	-1	38	-1	-1	-1	8	1	-1	-1	-1	-1	-1	-1	0

(c) D = 1944 bits, Z=81 bits

61	75	4	63	56	-1	-1	-1	-1	-1	-1	8	-1	2	17	25	1	0	-1	-1	-1	-1	-1	-1
56	74	77	20	-1	-1	-1	64	24	4	67	-1	7	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
28	21	68	10	7	14	65	-1	-1	-1	23	-1	-1	-1	75	-1	-1	-1	0	0	-1	-1	-1	-1
48	38	43	78	76	-1	-1	-1	-1	5	36	-1	15	72	-1	-1	-1	-1	-1	0	0	-1	-1	-1
40	2	53	25	-1	52	62	-1	20	-1	-1	44	-1	-1	-1	-1	0	-1	-1	-1	0	0	-1	-1
69	23	64	10	22	-1	21	-1	-1	-1	-1	-1	68	23	29	-1	-1	-1	-1	-1	-1	0	0	-1
12	0	68	20	55	61	-1	40	-1	-1	-1	52	-1	-1	-1	44	-1	-1	-1	-1	-1	-1	0	0
58	8	34	64	78	-1	-1	11	78	24	-1	-1	-1	-1	-1	58	1	-1	-1	-1	-1	-1	-1	0

Table 5.1.3.2-5: Matrix exponents for R=1/2 , Type 1

(a) D = 648 bits, Z=27 bits

0	-1	-1	-1	0	0	-1	-1	0	-1	-1	0	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
22	0	-1	-1	17	-1	0	0	12	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
6	-1	0	-1	10	-1	-1	-1	24	-1	0	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
2	-1	-1	0	20	-1	-1	-1	25	0	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
23	-1	-1	-1	3	-1	-1	-1	0	-1	9	11	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
24	-1	23	1	17	-1	3	-1	10	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
25	-1	-1	-1	8	-1	-1	-1	7	18	-1	-1	0	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
13	24	-1	-1	0	-1	8	-1	6	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1
7	20	-1	16	22	10	-1	-1	23	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
11	-1	-1	-1	19	-1	-1	-1	13	-1	3	17	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
25	-1	8	-1	23	18	-1	14	9	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
3	-1	-1	-1	16	-1	-1	2	25	5	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

(b) D = 1296 bits, Z=54 bits

40	-1	-1	-1	22	-1	49	23	43	-1	-1	-1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
50	1	-1	-1	48	35	-1	-1	13	-1	30	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
39	50	-1	-1	4	-1	2	-1	-1	-1	-1	49	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
33	-1	-1	38	37	-1	-1	4	1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
45	-1	-1	-1	0	22	-1	-1	20	42	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
51	-1	-1	48	35	-1	-1	-1	44	-1	18	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
47	11	-1	-1	-1	17	-1	-1	51	-1	-1	-1	0	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
5	-1	25	-1	6	-1	45	-1	13	40	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1
33	-1	-1	34	24	-1	-1	-1	23	-1	-1	46	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
1	-1	27	-1	1	-1	-1	-1	38	-1	44	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
-1	18	-1	-1	23	-1	-1	8	0	35	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
49	-1	17	-1	30	-1	-1	-1	34	-1	-1	19	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

(c) D = 1944 bits, Z=81 bits

57	-1	-1	-1	50	-1	11	-1	50	-1	79	-1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
3	-1	28	-1	0	-1	-1	-1	55	7	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
30	-1	-1	-1	24	37	-1	-1	56	14	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
62	53	-1	-1	53	-1	-1	3	35	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
40	-1	-1	20	66	-1	-1	22	28	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
0	-1	-1	-1	8	-1	42	-1	50	-1	-1	8	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
69	79	79	-1	-1	-1	56	-1	52	-1	-1	-1	0	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1

65 -1 -1 -1 38 57 -1 -1 72 -1 27 -1 -1 -1 -1 -1 -1 -1 -1 0 0 -1 -1 -1

64 -1 -1 -1 14 52 -1 -1 30 -1 -1 32 -1 -1 -1 -1 -1 -1 -1 -1 0 0 -1 -1

-1 45 -1 70 0 -1 -1 -1 77 9 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 -1

2 56 -1 57 35 -1 -1 -1 -1 -1 12 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 0

24 -1 61 -1 60 -1 -1 27 51 -1 -1 16 1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0

Table 5.1.3.2-6: Matrix exponents for R=1/3, *Z* = 81 bits, Type 2

54 19 24 68 12 2 18 16 13 46 66 52 21 9 -1 80 24 -1 3 11 1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

10 76 29 30 8 28 16 35 62 53 57 53 15 38 72 73 -1 45 38 71 -1 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

70 71 31 35 20 21 6 56 36 52 22 37 50 27 58 16 56 41 -1 -1 0 -1 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

41 24 25 49 28 6 28 60 22 70 11 27 1 -1 67 -1 22 78 76 5 1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

27 70 45 45 28 9 29 30 39 29 56 80 29 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 77 8 69 49 68 78 -1 66 8 6 79 40 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

74 37 -1 41 6 -1 -1 -1 -1 57 63 -1 -1 -1 -1 -1 56 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 24 -1 -1 16 74 27 44 -1 -1 42 12 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 9 20 -1 25 -1 -1 -1 -1 18 3 59 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 79 -1 5 78 -1 1 -1 -1 -1 22 -1 -1 -1 -1 -1 -1 -1 -1 -1 27 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 24 47 -1 -1 67 30 -1 -1 -1 -1 43 -1 -1 18 -1 -1 42 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 78 -1 -1 -1 58 51 70 -1 35 -1 -1 -1 -1 -1 -1 -1 -1 -1 64 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 0 -1 -1 78 -1 39 -1 66 38 -1 -1 -1 -1 4 -1 -1 -1 -1 -1 -1 63 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 45 -1 -1 3 -1 -1 -1 -1 12 11 38 -1 -1 -1 -1 80 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 62 -1 57 12 -1 -1 26 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 27 35 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 29 -1 -1 -1 -1 34 -1 -1 23 -1 51 3 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 48 -1 -1 -1 -1 -1 44 -1 -1 -1 54 -1 -1 -1 -1 71 -1 61 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 7 -1 33 -1 -1 28 -1 -1 -1 -1 2 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 48 -1 11 -1 -1 -1 -1 -1 -1 64 42 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 73 -1 -1 -1 -1 -1 -1 -1 73 -1 -1 -1 -1 -1 -1 77 -1 37 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 45 -1 -1 -1 -1 -1 -1 -1 40 -1 56 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 65 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 51 -1 -1 -1 12 -1 -1 -1 40 -1 -1 -1 -1 -1 -1 -1 -1 -1 41 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 53 5 -1 -1 77 -1 -1 -1 -1 -1 -1 -1 -1 -1 39 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 68 -1 52 -1 11 57 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 66 -1 -1 32 -1 -1 -1 -1 -1 60 -1 -1 -1 29 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 22 -1 -1 -1 -1 -1 9 -1 -1 -1 28 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

58 -1 -1 -1 -1 71 -1 -1 -1 -1 -1 -1 42 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 8 75 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 43 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 32 -1 18 -1 -1 -1 -1 -1 -1 -1 1 -1 -1 76 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 53 -1 -1 -1 -1 -1 -1 41 -1 -1 -1 -1 -1 -1 -1 -1 42 -1 -1 15 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 15 -1 10 -1 44 -1 4 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 59 -1 -1 42 18 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1 -1

52 12 -1 -1 -1 -1 49 -1 74 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1 -1

-1 -1 39 -1 -1 -1 -1 -1 -1 38 18 -1 21 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 47 -1 -1 -1 -1 -1 -1 -1 -1 14 -1 -1 -1 -1 -1 -1 -1 18 48 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 31 -1 -1 -1 -1 -1 31 -1 -1 -1 -1 17 -1 49 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1 -1

-1 26 -1 -1 -1 -1 -1 -1 -1 -1 -1 14 -1 -1 -1 -1 1 4 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1 -1

-1 -1 -1 -1 -1 -1 14 -1 -1 65 -1 -1 2 -1 -1 77 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 37 -1 -1 -1 53 -1 -1 -1 -1 -1 74 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0 -1

-1 -1 37 -1 -1 -1 -1 -1 50 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 16 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 0

5.1.4 Rate matching

5.1.4.1 Rate matching for LDPC coded transport channels

The rate matching for LDPC coded transport channels is defined per coded bit stream d_k. The sequence of bits e_k for transmission is generated according to below.

Denoting by E the rate matching output sequence length for the r-th coded block, the rate matching output bit sequence is e_k, $k = 0,1,\ldots, E-1$.

Define by G the total number of bits available for the transmission of one transport block.

Set $G' = G/(N_L \cdot Q_m)$ where Q_m is equal to 2 for QPSK, 4 for 16QAM and 6 for 64QAM, and where N_L is equal to the number of layers a transport block is mapped onto. Note that for the case of transmit diversity transmission mode, N_L = 1.

Set $\gamma = G' \bmod C$, where C is the number of code blocks computed in section 5.1.2.

if $r < \gamma$

set $E = N_L \cdot Q_m \cdot \lceil G'/C \rceil$

else

set $E = N_L \cdot Q_m \cdot \lfloor G'/C \rfloor$

end if

For Coding Type 1, set $k_0 = 0$.

For Coding Type 2, set $k_0 = \left(\left\lceil \frac{D}{4} \right\rceil \cdot rv_{idx}\right)$, where rv_{idx} =0, 1, 2, or 3.

Set $k = 0$ and $j = 0$

while { $k < E$ }

if $d_{(k_0+j) \bmod D} \neq <NULL>$

$e_k = d_{(k_0+j) \bmod D}$

$k = k + 1$

end if

$j = j + 1$

end while

5.1.4.2 Rate matching for convolutionally coded transport channels and control information

The rate matching for convolutionally coded transport channels and control information consists of interleaving the three bit streams, $d_k^{(0)}$, $d_k^{(1)}$ and $d_k^{(2)}$, followed by the collection of bits and the generation of a circular buffer as depicted in Figure 5.1.4.2-1. The output bits are transmitted as described in section 5.1.4.2.2.

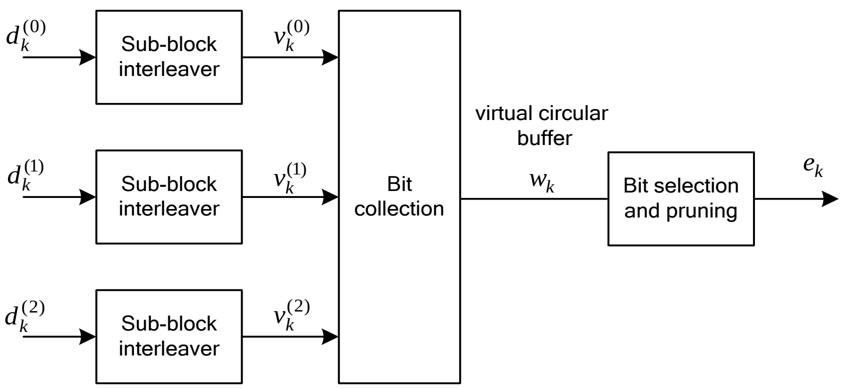

Figure 5.1.4.2-1. Rate matching for convolutionally coded transport channels and control information.

The bit stream $d_k^{(0)}$ is interleaved according to the sub-block interleaver defined in section 5.1.4.2.1 with an output sequence defined as $v_0^{(0)}, v_1^{(0)}, v_2^{(0)}, \ldots, v_{K_\Pi - 1}^{(0)}$ and where K_Π is defined in section 5.1.4.2.1.

The bit stream $d_k^{(1)}$ is interleaved according to the sub-block interleaver defined in section 5.1.4.2.1 with an output sequence defined as $v_0^{(1)}, v_1^{(1)}, v_2^{(1)}, \ldots, v_{K_\Pi - 1}^{(1)}$.

The bit stream $d_k^{(2)}$ is interleaved according to the sub-block interleaver defined in section 5.1.4.2.1 with an output sequence defined as $v_0^{(2)}, v_1^{(2)}, v_2^{(2)}, \ldots, v_{K_\Pi - 1}^{(2)}$.

The sequence of bits e_k for transmission is generated according to section 5.1.4.2.2.

5.1.4.2.1 Sub-block interleaver

The bits input to the block interleaver are denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, \ldots, d_{D-1}^{(i)}$, where D is the number of bits. The output bit sequence from the block interleaver is derived as follows:

(1) Assign $C_{subblock}^{CC} = 32$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2,…, $C_{subblock}^{CC} - 1$ from left to right.

(2) Determine the number of rows of the matrix $R_{subblock}^{CC}$, by finding minimum integer $R_{subblock}^{CC}$ such that:

$$D \le \left(R_{subblock}^{CC} \times C_{subblock}^{CC}\right)$$

The rows of rectangular matrix are numbered 0, 1, 2,…, $R_{subblock}^{CC} - 1$ from top to bottom.

(3) If $\left(R_{subblock}^{CC} \times C_{subblock}^{CC}\right) > D$, then $N_D = \left(R_{subblock}^{CC} \times C_{subblock}^{CC} - D\right)$ dummy bits are padded such that y_k = <*NULL*> for k = 0, 1,…, N_D - 1. Then, $y_{N_D + k} = d_k^{(i)}$, k = 0, 1,…, D-1, and the bit sequence y_k is written into the $\left(R_{subblock}^{CC} \times C_{subblock}^{CC}\right)$ matrix row by row starting with bit y_0 in column 0 of row 0:

$$\begin{bmatrix} y_0 & y_1 & y_2 & \cdots & y_{C_{subblock}^{CC}-1} \\ y_{C_{subblock}^{CC}} & y_{C_{subblock}^{CC}+1} & y_{C_{subblock}^{CC}+2} & \cdots & y_{2C_{subblock}^{CC}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}} & y_{(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}+1} & y_{(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}+2} & \cdots & y_{(R_{subblock}^{CC}\times C_{subblock}^{CC}-1)} \end{bmatrix}$$

(4) Perform the inter-column permutation for the matrix based on the pattern $\left\langle P(j) \right\rangle_{j \in \{0,1,\ldots,C_{subblock}^{CC}-1\}}$ that is shown in table 5.1.4.2.1-1, where P(j) is the original column position of the j-th permuted column. After permutation of the columns, the inter-column permuted $\left(R_{subblock}^{CC} \times C_{subblock}^{CC}\right)$ matrix is equal to

$$\begin{bmatrix} y_{P(0)} & y_{P(1)} & y_{P(2)} & \cdots & y_{P(C_{subblock}^{CC}-1)} \\ y_{P(0)+C_{subblock}^{CC}} & y_{P(1)+C_{subblock}^{CC}} & y_{P(2)+C_{subblock}^{CC}} & \cdots & y_{P(C_{subblock}^{CC}-1)+C_{subblock}^{CC}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{P(0)+(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}} & y_{P(1)+(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}} & y_{P(2)+(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}} & \cdots & y_{P(C_{subblock}^{CC}-1)+(R_{subblock}^{CC}-1)\times C_{subblock}^{CC}} \end{bmatrix}$$

(5) The output of the block interleaver is the bit sequence read out column by column from the inter-column permuted $\left(R_{subblock}^{CC}\times C_{subblock}^{CC}\right)$ matrix. The bits after sub-block interleaving are denoted by $v_0^{(i)}, v_1^{(i)}, v_2^{(i)}, \ldots, v_{K_\Pi-1}^{(i)}$, where $v_0^{(i)}$ corresponds to $y_{P(0)}$, $v_1^{(i)}$ to $y_{P(0)+C_{subblock}^{CC}}$ … and $K_\Pi = \left(R_{subblock}^{CC}\times C_{subblock}^{CC}\right)$

Table 5.1.4.2.1-1 Inter-column permutation pattern for sub-block interleaver.

Number of columns $C_{subblock}^{CC}$	**Inter-column permutation pattern** $< P(0), P(1), \ldots, P(C_{subblock}^{CC}-1) >$
32	< 1, 17, 9, 25, 5, 21, 13, 29, 3, 19, 11, 27, 7, 23, 15, 31, 0, 16, 8, 24, 4, 20, 12, 28, 2, 18, 10, 26, 6, 22, 14, 30 >

5.1.4.2.2 Bit collection, selection and transmission

The circular buffer of length $K_w = 3K_\Pi$ is generated as follows:

$w_k = v_k^{(0)}$ for $k = 0,\ldots, K_\Pi - 1$

$w_{K_\Pi+k} = v_k^{(1)}$ for $k = 0,\ldots, K_\Pi - 1$

$w_{2K_\Pi+k} = v_k^{(2)}$ for $k = 0,\ldots, K_\Pi - 1$

Denoting by E the rate matching output sequence length, the rate matching output bit sequence is e_k, $k = 0,1,\ldots, E-1$.

Set $k = 0$ and $j = 0$

while { $k < E$ }

if $w_{j \bmod K_w} \neq < NULL >$

$e_k = w_{j \bmod K_w}$

$k = k + 1$

end if

$j = j + 1$

end while

5.1.5 Code block concatenation

The input bit sequence for the code block concatenation block are the sequences e_{rk}, for $r = 0,\ldots,C-1$ and $k = 0,\ldots,E_r-1$. The output bit sequence from the code block concatenation block is the sequence f_k for $k = 0,\ldots,G-1$.

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 $j < E_r$

$f_k = e_{rj}$

$k = k + 1$

$j = j + 1$

end while

$r = r + 1$

end while

5.2 Uplink transport channels and control information

5.2.1 Random access channel

The sequence index for the random access channel is received from higher layers and is processed according to [2].

5.2.2 Uplink shared channel

The processing structure for the UL-SCH transport channel on one UL cell.

- Add CRC to the transport block
- Code block segmentation
- Channel coding of data and control information
- Rate matching
- Code block concatenation
- Multiplexing of data and control information
- Channel interleaver

The coding steps for one UL-SCH transport block are shown in the figure below. The same general processing applies for each UL-SCH transport block.

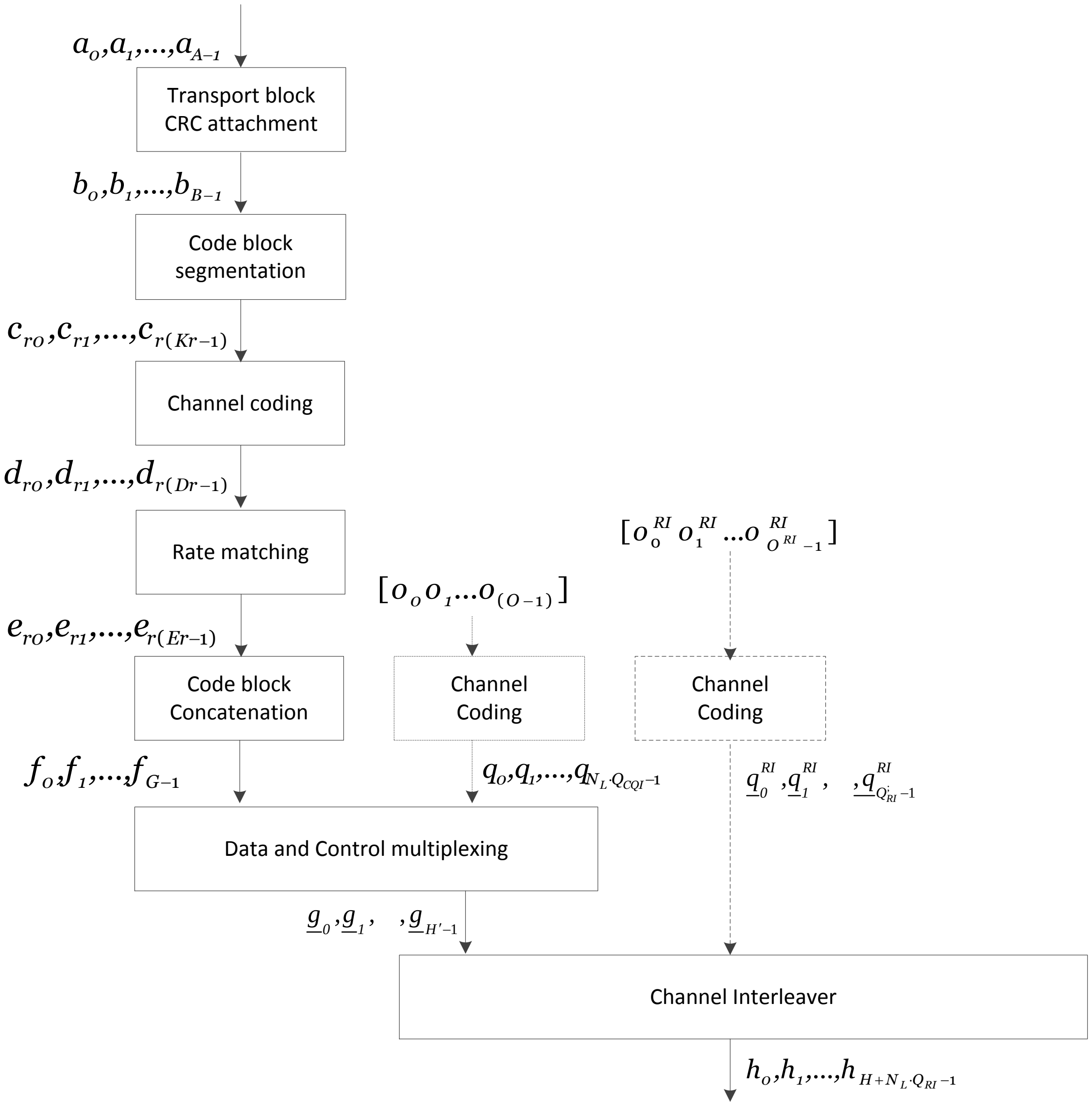

Figure 5.2.2-1: Transport block processing for UL-SCH.

5.2.2.1 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 $a_0, a_1, a_2, a_3, ..., a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, ..., p_{L-1}$. A is the size of the transport block 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 section 6.1.1 of [4].

The parity bits are computed and attached to the UL-SCH transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.2.2.2 Code block segmentation

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

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

5.2.2.3 Channel coding of UL-SCH

Code blocks are delivered to the channel coding block. The bits in a code block are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(K_r-1)}$, 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 section 5.1.3.2.

After encoding the bits are denoted by d_{r0}, d_{r1}, d_{r2}, … , $d_{r(Dr-1)}$ with $D_r = N_{ldpc}$ is the number of bits on the *i*-th coded stream for code block number *r*.

5.2.2.4 Rate matching

LDPC coded blocks are delivered to the rate matching block. They are denoted by d_{r0}, d_{r1}, d_{r2}, … , $d_{r(Dr-1)}$ where *r* is the code block number, *i* is the coded stream index, and $D_r = N_{ldpc}$ is the number of bits in each coded stream of code block number *r*. The total number of code blocks is denoted by *C* and each coded block is individually rate matched according to section 5.1.4.1. After rate matching, the bits are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$, where *r* is the coded block number, and where E_r is the number of rate matched bits for code block number *r*.

5.2.2.5 Code block concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$ for $r = 0, \ldots, C-1$ and where E_r is the number of rate matched bits for the *r*-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$, where *G* is the total number of coded bits for transmission of the given transport block over N_L transmission layers excluding the bits used for control transmission, when control information is multiplexed with the UL-SCH transmission. Note that for the case of transmit diversity transmission mode, $N_L = 1$.

5.2.2.6 Channel coding of control information

Control data arrives at the coding unit in the form of channel quality information (CQI and/or PMI and/or beam state information (BSI) and/or beam refinement information (BRI)), and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When control data are transmitted in the xPUSCH, the channel coding for rank indication, and channel quality and beam related information $o_0, o_1, o_2, \ldots, o_{O-1}$ is done independently.

When the UE transmits rank indicator bits, it shall determine the number of coded modulation symbols per layer Q' for rank indicator bits as follows.

Only one transport block is transmitted in the xPUSCH conveying rank indicator bits:

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{xPUSCH-initial} \cdot N_{symb}^{xPUSCH-initial} \cdot \beta_{offset}^{xPUSCH}}{\sum_{r=0}^{C-1} K_r} \right\rceil, M_{sc}^{xPUSCH} \cdot N_{symb}^{xPUSCH} \right)$$

where

- O is the number of rank indicator bits, and

- $M_{\rm sc}^{\rm xPUSCH}$ is the scheduled bandwidth for xPUSCH transmission in the current sub-frame for the transport block, expressed as a number of subcarriers in [2], where a number of subcarriers used for PCRS transmission are not counted, and

- $N_{\rm symb}^{\rm xPUSCH}$ is the number of OFDM symbols per subframe for xPUSCH in the current sub-frame for the transport block, respectively, where symbol(s) that DMRS is mapped on is not counted.

- $N_{\rm symb}^{\rm xPUSCH\text{-}initial} = N_{\rm symb}^{\rm xPUSCH}$, $M_{sc}^{xPUSCH-initial} = M_{sc}^{xPUSCH}$, C, and K_r are obtained from the initial xPDCCH for the same transport block. If there is no initial xPDCCH for the same transport block, C, and K_r shall be determined from:

  - the random access response grant for the same transport block, when the xPUSCH is initiated by the random access response grant.

For rank indication, $Q_{RI} = Q_m \cdot Q'$, and $\beta_{offset}^{xPUSCH} = \beta_{offset}^{RI}$, where Q_m is the modulation order of a given transport block, and β_{offset}^{RI} shall be determined according to [3]

For rank indication (RI)

-If RI feedback consists of 1-bit of information, i.e., $[o_0^{RI}]$, it is first encoded according to Table 5.2.2.6-1. The $[o_0^{RI}]$ to RI mapping is given by Table 5.2.2.6-2.

Table 5.2.2.6-1: Encoding of 1-bit RI.

Q_m	Encoded RI
2	$[o_0^{RI}\ y]$
4	$[o_0^{RI}\ y\ x\ x]$
6	$[o_0^{RI}\ y\ x\ x\ x\ x\ ]$

Table 5.2.2.6-2: o_0^{RI} to RI mapping.

o_0^{RI}	RI
0	1
1	2

The “x” and “y” in Table 5.2.2.6-1 is placeholders for [2] to scramble the RI bits in a way that maximizes the Euclidean distance of the modulation symbols carrying rank information.

For the case where RI feedback consists of one or two bits of information the bit sequence $q_0^{RI}, q_1^{RI}, q_2^{RI}, \ldots, q_{Q_{RI}-1}^{RI}$ is obtained by concatenation of multiple encoded RI blocks where Q_{RI} is the total number of coded bits for all the encoded RI blocks. The last concatenation of the encoded RI block may be partial so that the total bit sequence length is equal to Q_{RI}.

When rank information is to be multiplexed with UL-SCH at a given xPUSCH, the rank information is multiplexed in all layers of all transport blocks of that xPUSCH. For a given transport block, the vector sequence output of the channel coding for rank information is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$, where $\underline{q}_i^{RI}$, $i = 0, \ldots, Q'_{RI} - 1$ are column vectors of length $(Q_m \cdot N_L)$ and where $Q'_{RI} = Q_{RI} / Q_m$. The vector sequence is obtained as follows:

Set *i*, *j*, *k* to 0

while $i < Q_{RI}$

$\underline{\hat{q}}_k^{RI} = [q_i^{RI} \ldots q_{i+Q_m-1}^{RI}]$ -- temporary row vector

$\underline{q}_k^{RI} = [\overbrace{\underline{\hat{q}}_k^{RI} \ldots \underline{\hat{q}}_k^{RI}}^{N_L}]^T$ -- replicating the row vector $\underline{\hat{q}}_k^{RI}$ N_L times and transposing into a column vector

$i = i + Q_m$

$k = k + 1$

end while

where N_L is the number of layers onto which the UL-SCH transport block is mapped. Note that for the case of transmit diversity transmission mode, N_L = 1.

For channel quality control information (CQI and/or PMI and/or BSI and/or BRI denoted as CQI/PMI/BSI/BRI)

When the UE transmits channel quality control information bits, it shall determine the number of modulation coded symbols per layer Q' for channel quality and beam related information as

$$Q' = \min\left(\left\lceil \frac{(O+L)\cdot M_{sc}^{xPUSCH-initial}\cdot N_{symb}^{xPUSCH-initial}\cdot \beta_{offset}^{xPUSCH}}{\sum_{r=0}^{C-1} K_r} \right\rceil, M_{sc}^{xPUSCH}\cdot N_{symb}^{xPUSCH} - \frac{Q_{RI}}{Q_m}\right)$$

where

- O is the number of CQI/PMI/BSI/BRI bits, and
- L is the number of CRC bits given by $L = \begin{cases} 0 & O \le 11 \\ 8 & \text{otherwise} \end{cases}$, and
- $Q_{CQI} = Q_m \cdot Q'$ and $\beta_{offset}^{xPUSCH} = \beta_{offset}^{CQI}$, where β_{offset}^{CQI} shall be determined according to [3] depending on the number of transmission codewords for the corresponding xPUSCH.
- If RI is not transmitted, then $Q_{RI} = 0$.

$N_{symb}^{xPUSCH-initial}$, $M_{sc}^{xPUSCH-initial}$, C, and K_r are obtained from the xPDCCH for the same transport block. If there is no xPDCCH for the same transport block, $M_{sc}^{xPUSCH-initial}$, C, and K_r shall be determined from:

- the random access response grant for the same transport block, when the xPUSCH is initiated by the random access response grant.

For UL-SCH data information $G = N_L \cdot \left(N_{\text{symb}}^{\text{xPUSCH}} \cdot M_{\text{sc}}^{\text{xPUSCH}} \cdot Q_m - Q_{CQI} - Q_{RI}\right)$, where

- N_L is the number of layers the corresponding UL-SCH transport block is mapped onto, note that for the case of transmit diversity transmission mode, N_L = 1, and
- $M_{\text{sc}}^{\text{xPUSCH}}$ is the scheduled bandwidth for xPUSCH transmission in the current sub-frame for the transport block, where the subcarriers used for PCRS transmission are not counted, and
- $N_{\text{symb}}^{\text{xPUSCH}}$ is the number of OFDM symbols in the current xPUSCH transmission sub-frame block obtained from the xPDCCH for the same transport block, where symbol(s) that DMRS is mapped on are not counted.

If the CQI/PMI/BSI/BRI payload size is less than or equal to 11 bits, the channel coding of the channel quality and beam related information is performed according to section 5.2.2.6.3 with input sequence $o_0, o_1, o_2, \ldots, o_{O-1}$, where any CQI/PMI bits occur at the beginning of the input sequence, followed by any BSI bits, followed by any BRI bits.

For CQI/PMI/BSI/BRI payload sizes greater than 11 bits, the CRC attachment, channel coding and rate matching of the channel quality and beam related information is performed according to sections 5.1.1, 5.1.3.1 and 5.1.4.2, respectively. The input bit sequence to the CRC attachment operation is $o_0, o_1, o_2, ..., o_{O-1}$, where any CQI/PMI bits occur at the beginning of the input sequence, followed by any BSI bits, followed by any BRI bits. The output bit sequence of the CRC attachment operation is the input bit sequence to the channel coding operation. The output bit sequence of the channel coding operation is the input bit sequence to the rate matching operation.

The output sequence for the channel coding of channel quality and beam related information is denoted by $q_0, q_1, q_2, q_3, ..., q_{N_L \cdot Q_{CQI} - 1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto. Note that for the case of transmit diversity transmission mode, $N_L = 1$.

5.2.2.6.1 Channel quality information formats for wideband CQI reports

Table 5.2.2.6.1-1 shows the fields and the corresponding bit widths for the channel quality information feedback for wideband reports for xPDSCH transmissions.

Table 5.2.2.6.1-1: Fields for channel quality information feedback for one wideband CQI report

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Field	Bit width		
	Rank = 1	Rank = 2	No PMI
Wideband CQI	4	4	4
Precoding matrix indicator (PMI)	{2,4,8}	{2,4,8}	0
Rank indication (RI)	1	1	0

The bit width of PMI depends on the number of the corresponding CSI-RS port, for 2/4/8 Tx ports, the bit width of PMI is equal to 2 bits, 4bits, and 8bits respectively.

5.2.2.6.2 Beam related information formats for wideband reports

Table 5.2.2.6.2-1 shows the fields and the corresponding bit widths for the beam state information feedback for wideband report for xPDSCH transmissions.

Table 5.2.2.6.2-1: Fields for BSI feedback for wideband report.

Field	Bit width
BRS index	9*N
Wide-band BRSRP	7*N

Table 5.2.2.6.2-2 shows the fields and the corresponding bit widths for the beam refinement information feedback for wideband report for xPDSCH transmissions.

Table 5.2.2.6.2-2: Fields for BRI feedback for one wideband report.

Field	Bit width
BRRS index	3*N
Wide-band BRRS-RP	7*N

The beam related information in Table 5.2.2.6.2-1 and Table 5.2.2.6.2-2 form the bit sequence $o_0, o_1, o_2, ..., o_{O-1}$ with o_0 corresponding to the first bit of the first field in the table, o_1 corresponding to the second bit of the first field in the table, and o_{O-1} corresponding to the last bit in the last field in the table. The first bit of each field corresponds to MSB and the last bit LSB.

5.2.2.6.3 Channel coding for CQI/PMI/BSI/BRI information in xPUSCH

The channel quality and/or beam related information bits input to the channel coding block are denoted by $o_0, o_1, o_2, o_3, \ldots, o_{O-1}$ where O is the number of bits. The number of channel quality and beam related information bits depend on the transmission format. When xPUCCH-based reporting format is used, the number of CQI/PMI/BSI/BRI bits is defined in section 5.2.3.3.1 for wideband reports. When xPUSCH-based reporting format is used, the number of CQI/PMI/BSI/BRI bits is defined in section 5.2.2.6.1 for wideband reports.

The channel quality and/or beam related information is first coded using a (32, O) block code. The code words of the (32, O) block code are a linear combination of the 11 basis sequences denoted $M_{i,n}$ and defined in Table 5.2.2.6.3-1.

Table 5.2.2.6.3-1: Basis sequences for (32, *O*) 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

The encoded CQI/PMI/BSI/BRI block is denoted by $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$ where $B = 32$ and

$$b_i = \sum_{n=0}^{O-1} \left(o_n \cdot M_{i,n}\right) \bmod 2 \text{ where } i = 0, 1, 2, \ldots, B\text{-}1.$$

The output bit sequence $q_0, q_1, q_2, q_3, \ldots, q_{N_L \cdot Q_{CQI}-1}$ is obtained by circular repetition of the encoded CQI/PMI/BSI/BRI block as follows

$q_i = b_{(i \bmod B)}$ where $i = 0, 1, 2, \ldots, N_L \cdot Q_{CQI}$-1, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto. Note that for the case of transmit diversity transmission mode, $N_L = 1$.

5.2.2.7 Data and control multiplexing

The control and data multiplexing is performed such that the multiplexing ensures control and data information are mapped to different modulation symbols.

The inputs to the data and control multiplexing are the coded bits of the control information denoted by $q_0, q_1, q_2, q_3, ..., q_{N_L \cdot Q_{CQI}-1}$, where $Q'_{CQI} = Q_{CQI} / Q_m$, and the coded bits of the UL-SCH denoted by $f_0, f_1, f_2, f_3, ..., f_{G-1}$. The output of the data and control multiplexing operation is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, ..., \underline{g}_{H'-1}$, where $H = (G + N_L \cdot Q_{CQI})$ and $H' = H / (N_L \cdot Q_m)$, and where $\underline{g}_i$, $i = 0, ..., H'-1$ are column vectors of length $(Q_m \cdot N_L)$. H is the total number of coded bits allocated for UL-SCH data and CQI/PMI/BSI/BRI information across the N_L transmission layers of the transport block. Note that for the case of transmit diversity transmission mode, $N_L = 1$.

In the case of single transport block transmission, and assuming that N_L is the number of layers onto which the UL-SCH transport block is mapped ($N_L = 1$ for transmit diversity transmission), the control information and the data shall be multiplexed as follows:

Set *i*, *j*, *k* to 0

while $j < N_L . Q_{CQI}$ -- first place the control information

$$\underline{g}_k = [q_j \,..\, q_{j+N_L \cdot Q_m - 1}]^T$$

$$j = j + N_L \cdot Q_m$$

$$k = k + 1$$

end while

while $i < G$ -- then place the data

$$\underline{g}_k = [f_i \ldots f_{i+Q_m \cdot N_L - 1}]^T$$

$$i = i + Q_m \cdot N_L$$

$$k = k + 1$$

end while

5.2.2.8 Channel interleaver

The channel interleaver described in this section in conjunction with the resource element mapping for xPUSCH in [2] implements a time-first mapping of control modulation symbols and frequency-first mapping of data modulation symbols onto the transmit waveform.

The inputs to the channel interleaver are denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, ..., \underline{g}_{H'-1}$, and $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, ..., \underline{q}_{Q'_{RI}-1}^{RI}$.

The number of modulation symbols per layer in the subframe is given by $H'_{total} = H' + Q'_{RI}$. The output bit sequence from the channel interleaver is derived as follows:

(1) Assign $C_{mux} = N_{\text{symb}}^{\text{PUSCH}}$ to be the number of columns of the matrix. The columns of the matrix are numbered 0, 1, 2,…, $C_{mux} - 1$ from left to right. $N_{\text{symb}}^{\text{PUSCH}}$ is determined according to section 5.2.2.6.

(2) The number of rows of the matrix is $R_{mux} = \left(H'_{total} \cdot Q_m \cdot N_L\right) / C_{mux}$ and define $R'_{mux} = R_{mux} / \left(Q_m \cdot N_L\right)$.

The rows of the rectangular matrix are numbered 0, 1, 2,…, $R_{mux} - 1$ from top to bottom.

$$\begin{bmatrix} \underline{y}_0 & \underline{y}_1 & \underline{y}_2 & \cdots & \underline{y}_{C_{mux}-1} \\ \underline{y}_{C_{mux}} & \underline{y}_{C_{mux}+1} & \underline{y}_{C_{mux}+2} & \cdots & \underline{y}_{2C_{mux}-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \underline{y}_{(R'_{mux}-1)\times C_{mux}} & \underline{y}_{(R'_{mux}-1)\times C_{mux}+1} & \underline{y}_{(R'_{mux}-1)\times C_{mux}+2} & \cdots & \underline{y}_{(R'_{mux}\times C_{mux}-1)} \end{bmatrix}$$

(3) If rank information is transmitted in this subframe, the vector sequence $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, ..., \underline{q}_{Q'_{RI}-1}^{RI}$ is written into the $\left(R_{mux} \times C_{mux}\right)$ matrix by sets of $\left(Q_m \cdot N_L\right)$ rows starting with the vector $\underline{y}_0$ in column 0 and rows 0 to $\left(Q_m \cdot N_L - 1\right)$ according to the following pseudo-code:

Set i to 0.

while $i < Q'_{RI}$,

$\underline{y}_i = \underline{q}_i^{RI}$

$i = i + 1$

end while

(4) Write the portion of the input vector sequence containing CQI/PMI/BSI/BRI information, $\underline{g}_0, \underline{g}_1, \underline{g}_2, ..., \underline{g}_{Q'_{CQI}-1}$, into the $\left(R_{mux} \times C_{mux}\right)$ matrix according to the following pseudo-code:

Set i to 0.

while $i < Q'_{CQI}$,

$\underline{y}_{i+Q'_{RI}} = \underline{g}_i$

$i = i + 1$

end while

(5) Write the remaining portion of the input vector sequence containing the UL-SCH data, $\underline{g}_{Q'_{CQI}}, \underline{g}_{Q'_{CQI}+1}, \underline{g}_{Q'_{CQI}+2}, ..., \underline{g}_{H'-1}$, into the $\left(R_{mux} \times C_{mux}\right)$ matrix column by column starting with the vector $\underline{y}_0$ and moving downward, skipping the matrix entries that are already occupied.

(6) The output of the block interleaver is the bit sequence read out column by column from the $\left(R_{mux} \times C_{mux}\right)$ matrix. The bits after channel interleaving are denoted by $h_0, h_1, h_2, ..., h_{H'_{total} \cdot Q_m \cdot N_L - 1}$, where N_L is the number of layers the corresponding UL-SCH transport block is mapped onto.

5.2.3 Uplink control information on xPUCCH

Data arrives to the coding unit in the form of indicators for scheduling request, and HARQ acknowledgement, rank indicator, channel quality information (CQI and/or PMI), beam related information (BSI and/or BRI).

One form of channel coding is used, as shown in Figure 5.2.3-1 for at least one or combination of HARQ-ACK, scheduling request, rank indicator, channel quality information (CQI and/or PMI), and beam related information (BSI and/or BRI) transmitted on xPUCCH.

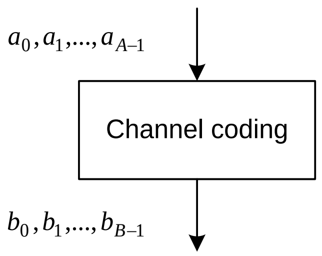

Figure 5.2.3-1: Processing for UCI.

5.2.3.1 Channel coding for UCI HARQ-ACK

The HARQ-ACK bits are received from higher layers for each subframe. HARQ-ACK consists of 1-bit of information, i.e., b_0 corresponding to ACK/NACK bit for codeword 0. Each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'. For the case where xPUCCH format 2 [2] is scheduled [3], the HARQ-ACK feedback consists of the concatenation of HARQ-ACK bits which the UE needs to feedback for downlink subframes. For all cells, single codeword transmission modes, 1 bit of HARQ-ACK information, a_k, is used. The HARQ-ACK bits are processed for transmission according to section 11.1 [3].

Define $N_{A/N}^{\text{xPUCCHformat 2}}$ as the number of HARQ-ACK bits when xPUCCH format 2 is used for transmission of HARQ-ACK feedback (section 11.1 in [3]).

The sequence of bits $a_0, a_1, a_2, ..., a_{N_{A/N}^{\text{xPUCCHformat 2}}-1}$ is obtained from the HARQ-ACK bits for different downlink subframes.

Define B_c^{DL} as the number of downlink subframes for which the UE needs to feedback HARQ-ACK bits in cell c as defined in Section 7.3 of [3].

The number of HARQ-ACK bits for the UE to convey is computed as follows:

Set $k = 0$ – counter of HARQ-ACK bits

set $l = 0$ – counter of downlink subframes

while $l < B_c^{DL}$

   $k = k + 1$

   $l = l+1$

end while

For $N_{A/N}^{\text{xPUCCHformat 2}} \leq 10$, the bit sequence $a_0, a_1, a_2, ..., a_{N_{A/N}^{\text{xPUCCHformat 2}}-1}$ is obtained by setting $a_i = o_i^{ACK}$.

The sequence of bits $a_0, a_1, a_2, ..., a_{N_{A/N}^{\text{xPUCCHformat 2}}-1}$ is encoded as follows

$$\tilde{b}_i = \sum_{n=0}^{N_{A/N}^{\text{xPUCCHformat2}}-1} \left(a_n \cdot M_{i,n}\right) \bmod 2$$

where i = 0, 1, 2, …, 31 and the basis sequences $M_{i,n}$ are defined in Table 5.2.2.6.3-1.

The output bit sequence $b_0, b_1, b_2, \ldots, b_{B-1}$ is obtained by circular repetition of the sequence $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, \ldots, \tilde{b}_{31}$

$$b_i = \tilde{b}_{(i \bmod 32)}$$

where i = 0, 1, 2, …, B-1 and where $B = 8 \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$.

5.2.3.2 Channel coding for UCI scheduling request

The scheduling request indication is received from higher layers and is processed according to [2] and [3].

5.2.3.3 Channel coding for UCI channel quality information

The channel quality information bits input to the channel coding block are denoted by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$ where A is the number of bits. The number of channel quality information bits depends on the transmission format as indicated in section 5.2.3.3.1 for wideband reports.

For the channel quality information bits $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, if A ≤ 11, channel coding defined in section 5.2.3.1 shall be applied. The output bit sequence $b_0, b_1, b_2, \ldots, b_{B-1}$ where $B = 8 \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$ is obtained after the channel coding.

For 11 < A ≤ 22, the bit sequence $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$ is obtained by setting $a_{i/2} = o_i$ if i is even and $a_{\lceil A/2 \rceil + (i-1)/2} = o_i$ if i is odd. The sequences of bits $a_0, a_1, a_2, \ldots, a_{\lceil A/2 \rceil - 1}$ and $a_{\lceil A/2 \rceil}, a_{\lceil A/2 \rceil + 1}, a_{\lceil A/2 \rceil + 2}, \ldots, a_{A-1}$ are encoded as follows

$$\tilde{b}_i = \sum_{n=0}^{\lceil A/2 \rceil - 1} \left(a_n \cdot M_{i,n}\right) \bmod 2$$

and

$$\tilde{\tilde{b}}_i = \sum_{n=0}^{A - \lceil A/2 \rceil - 1} \left(a_{\lceil A/2 \rceil + n} \cdot M_{i,n}\right) \bmod 2$$

where i = 0, 1, 2, …, 31 and the basis sequences $M_{i,n}$ are defined in Table 5.2.2.6.3-1.

The output bit sequence $b_0, b_1, b_2, \ldots, b_{B-1}$ where $B = 8 \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$ is obtained by the alternate concatenation of the bit sequences $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, \ldots, \tilde{b}_{31}$ and $\tilde{\tilde{b}}_0, \tilde{\tilde{b}}_1, \tilde{\tilde{b}}_2, \ldots, \tilde{\tilde{b}}_{31}$ as follows

Set $i, j = 0$

while $i < 8 \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$

$b_i = \tilde{b}_{(j \bmod 32)}$, $b_{i+1} = \tilde{b}_{((j+1) \bmod 32)}$

$b_{i+2} = \tilde{\tilde{b}}_{(j \bmod 32)}$, $b_{i+3} = \tilde{\tilde{b}}_{((j+1) \bmod 32)}$

$i = i + 4$

$j = j + 2$

end while

5.2.3.3.1 Channel quality information formats for wideband reports

Table 5.2.3.3.1-1 shows the fields and the corresponding bit widths for the channel quality information feedback for wideband reports for xPDSCH transmissions.

Table 5.2.3.3.1-1: Fields for channel quality information feedback for one wideband CQI report.

Field	Bit width		
	Rank = 1	Rank = 2	No PMI
Wideband CQI	4	4	4
Precoding matrix indicator (PMI)	{2,4,8}	{2,4,8}	0
Rank indication (RI)	1	1	0

The bit width of precoding matrix depends on the number of the corresponding CSI-RS port, for 2/4/8 Tx ports, the bit width of PMI is equal to 2 bits, 4bits, and 8bits, respectively.

The channel quality bits in Table 5.2.3.3.1-1 form the bit sequence $a_0, a_1, a_2, a_3, ..., a_{A-1}$ with a_0 corresponding to the first bit of the first field in each of the tables, a_1 corresponding to the second bit of the first field in each of the tables, and a_{A-1} corresponding to the last bit in the last field in each of the tables. The first bit corresponds to MSB and the last bit LSB.

5.2.3.4 Channel coding for UCI Beam related information feedback

The beam related information bits input to the channel coding block are denoted by $a_0, a_1, a_2, a_3, ..., a_{A-1}$ where A is the number of bits. The number of beam related information bits depends on the transmission format as indicated in section 5.2.3.4.1 for wideband reports.

For the beam related information (BSI or BRI) bits, $a_0, a_1, a_2, a_3, ..., a_{A-1}$, if A ≤11, then channel coding defined in Section 5.2.3.1 shall be applied. The output bit sequence $b_0, b_1, b_2, ...,, b_{B-1}$ where $B = 8 \cdot N_{sc}^{RB}$ is obtained after the channel coding. Otherwise, channel coding defined in section 5.2.3.3 shall be applied and the output bit sequence $b_0, b_1, b_2, ...,, b_{B-1}$ where $B = 8 \cdot N_{sc}^{RB}$ is obtained by the alternate concatenation of the bit sequences defined in section 5.2.3.3.

5.2.3.4.1 BSI format for wideband report

Table 5.2.3.4.1-1 shows the fields and the corresponding bit widths for the BSI feedback for wideband reports.

Table 5.2.3.4.1-1: Fields for BSI feedback for one wideband report.

Field	Bit width
Beam index	9
Wide-band BRSRP	7

The BSI bits in Table 5.2.3.4.1-1 form the bit sequence $a_0, a_1, a_2, a_3, ..., a_{A-1}$ with a_0 corresponding to the first bit of the first field in each of the tables, a_1 corresponding to the second bit of the first field in each of the tables, and a_{A-1} corresponding to the last bit in the last field in each of the tables. The first bit corresponds to MSB and the last bit LSB.

5.2.3.4.2 BRI format for wideband report

Table 5.2.3.4.2-1 shows the fields and the corresponding bit widths for the BRI feedback for wideband report.

Table 5.2.3.4.2-1: Fields for BRI feedback for one wideband report.

Field	Bit width
BRRS-RI	3
Wide-band BRRS-RP	7

The BRI bits in Table 5.2.3.4.2-1 form the bit sequence $a_0, a_1, a_2, a_3, ..., a_{A-1}$ with a_0 corresponding to the first bit of the first field in each of the tables, a_1 corresponding to the second bit of the first field in each of the tables, and a_{A-1} corresponding to the last bit in the last field in each of the tables. The first bit corresponds to MSB and the last bit LSB.

5.2.3.5 Channel coding for multiple UCIs

When the UE has to simultaneously transmit multiple UCIs in a subframe, the UCIs shall be combined into a single stream of bits $a_0, a_1, a_2, a_3, ..., a_{A-1}$ in the order of HARQ-ACK bits, scheduling request bit, RI bit, channel quality information bits, beam state information bits, and beam refinement information bits, starting from a_0. In case transmission of UCI feedback using xPUCCH format 2 [P5G.211] coincides with a subframe configured to the UE by higher layers for transmission of scheduling request, the scheduling request bit (1 = positive SR; 0 = negative SR) is always transmitted on xPUCCH format 2.

For the combined information bits $a_0, a_1, a_2, a_3, ..., a_{A-1}$, if A ≤ 11, then channel coding defined in section 5.2.3.1 shall be applied. The output bit sequence $b_0, b_1, b_2, ..., , b_{B-1}$ where $B = 8 \cdot N_{sc}^{RB}$ is obtained after the channel coding. Otherwise, channel coding defined in section 5.2.3.3 shall be applied and the output bit sequence $b_0, b_1, b_2, ..., , b_{B-1}$ where $B = 8 \cdot N_{sc}^{RB}$ is obtained by the alternate concatenation of the bit sequences defined in section 5.2.3.3.

5.2.4 Uplink control information on xPUSCH without UL-SCH data

When control data are sent via xPUSCH without UL-SCH data, the following coding steps can be identified:

- Channel coding of control information
- Control information mapping
- Channel interleaver

5.2.4.1 Channel coding of control information

Control data arrives at the coding unit in the form of channel quality and beam related information (CQI and/or PMI and/or BSI and/or BRI) and rank indication. Different coding rates for the control information are achieved by allocating different number of coded symbols for its transmission. When the UE transmits rank indicator, or channel quality and beam related information, it shall determine the number of coded symbols Q' for the above information bits as

$$Q' = \min\left(\left\lceil \frac{O \cdot M_{sc}^{xPUSCH} \cdot N_{symb}^{xPUSCH} \cdot \beta_{offset}^{xPUSCH}}{O_{CQI-MIN}} \right\rceil, N_{symb}^{xPUSCH} \cdot M_{sc}^{xPUSCH}\right)$$

where O is the number of rank indicator bits, or beam related information bits as defined section 5.2.2.6, $O_{CQI-MIN}$ is the number of CQI bits including CRC bits assuming rank equals to 1, M_{sc}^{PUSCH} is the scheduled bandwidth for xPUSCH transmission in the current subframe expressed as a number of subcarriers in [2], where a number of subcarriers used for PCRS transmission are not counted, and $N_{\text{symb}}^{\text{PUSCH}}$ is the number of OFDM symbols per subframe for xPUSCH in the current sub-frame, where symbol(s) that DMRS is mapped on is not counted .

For rank indication $Q_{RI} = Q_m \cdot Q'$ and [$\beta_{offset}^{xPUSCH} = \beta_{offset}^{RI} / \beta_{offset}^{CQI}$], where β_{offset}^{RI} shall be determined according to [3].

For CQI and/or PMI and/or BSI and/or BRI information $Q_{CQI} = N_{symb}^{xPUSCH} \cdot M_{sc}^{xPUSCH} \cdot Q_m - Q_{RI}$.

The channel coding and rate matching of the control data is performed according to section 5.2.2.6. The coded output sequence for channel quality and beam related information is denoted by $q_0, q_1, q_2, q_3, ..., q_{Q_{CQI}-1}$, and the coded vector sequence output for rank indication is denoted by $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$.

5.2.4.2 Control information mapping

The input are the coded bits of the channel quality and beam related information denoted by $q_0, q_1, q_2, q_3, ..., q_{Q_{CQI}-1}$. The output is denoted by $\underline{g}_0, \underline{g}_1, \underline{g}_2, \underline{g}_3, \ldots, \underline{g}_{H'-1}$, where $H = Q_{CQI}$ and $H' = H / Q_m$, and where $\underline{g}_i$, $i = 0, \ldots, H'-1$ are column vectors of length Q_m. H is the total number of coded bits allocated for CQI/PMI/BSI/BRI information.

The control information shall be mapped as follows:

Set j, k to 0

while $j < Q_{CQI}$

$\underline{g}_k = [q_j \ldots q_{j+Q_m-1}]^T$

$j = j + Q_m$

$k = k + 1$

end while

5.2.4.3 Channel interleaver

The vector sequences $\underline{g}_0, \underline{g}_1, \underline{g}_2, \ldots, \underline{g}_{H'-1}$ and $\underline{q}_0^{RI}, \underline{q}_1^{RI}, \underline{q}_2^{RI}, \ldots, \underline{q}_{Q'_{RI}-1}^{RI}$ are channel interleaved according section 5.2.2.8. The bits after channel interleaving are denoted by $h_0, h_1, h_2, ..., h_{H+Q_{RI}-1}$.

5.3 Downlink transport channels and control information

5.3.1 Broadcast channel

Figure 5.3.1-1 shows the processing structure for the BCH transport channel. Data arrives to the coding unit in the form of a maximum of one transport block every transmission time interval (TTI) of 40ms. The following coding steps can be identified:

- Add CRC to the transport block
- Channel coding
- Rate matching

The coding steps for BCH transport channel are shown in the figure below.

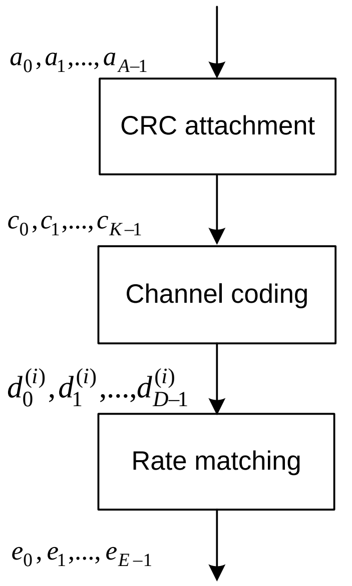

Figure 5.3.1-1: Transport channel processing for BCH.

5.3.1.1 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. Denote the bits in a transport block delivered to layer 1 by $a_0, a_1, a_2, a_3,...,a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3,...,p_{L-1}$. A is the size of the transport block and set to 16 bits 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 [5].

The parity bits are computed and attached to the BCH transport block according to section 5.1.1 setting L to 16 bits. After the attachment, the CRC bits are scrambled according to the 5G Node transmit antenna configuration with the sequence $x_{ant,0}, x_{ant,1},...,x_{ant,15}$ as indicated in Table 5.3.1.1-1 to form the sequence of bits $c_0, c_1, c_2, c_3,...,c_{K-1}$ where

$c_k = a_k$ for k = 0, 1, 2, …, A-1

$c_k = \left(p_{k-A} + x_{ant,k-A}\right) \mathrm{mod}\, 2$ for k = A, A+1, A+2,..., A+15.

Table 5.3.1.1-1: CRC mask for xPBCH.

Number of transmit antenna ports for BRS	PBCH CRC mask $< x_{ant,0}, x_{ant,1},...,x_{ant,15} >$
1	<0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0>
2	<1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1>
4	<0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1>
8	<1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0>

5.3.1.2 Channel coding

Information bits are delivered to the channel coding block. They are denoted by $c_0, c_1, c_2, c_3,...,c_{K-1}$, where K is the number of bits, and they are tail biting convolutionally encoded according to section 5.1.3.1.

After encoding the bits are denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)},...,d_{D-1}^{(i)}$, with $i = 0,1,$ and 2, and where D is the number of bits on the i-th coded stream, i.e., $D = K$.

5.3.1.3 Rate matching

A tail biting convolutionally coded block is delivered to the rate matching block. This block of coded bits is denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)}, \ldots, d_{D-1}^{(i)}$, with $i = 0, 1, \text{and } 2$, and where i is the coded stream index and D is the number of bits in each coded stream. This coded block is rate matched according to section 5.1.4.2.

After rate matching, the bits are denoted by $e_0, e_1, e_2, e_3, \ldots, e_{E-1}$, where E is the number of rate matched bits as defined in section 6.6.1 of [2].

5.3.1A Extended broadcast channel

Figure 5.3.1A-1 shows the processing structure for the BCH transport channel. Data arrives to the coding unit in the form of a maximum of one transport block every ePBCH transmission periodicity, which is given in [2]. The following coding steps can be identified:

- Add CRC to the transport block
- Channel coding
- Rate matching

The coding steps for BCH transport channel are shown in the figure below.

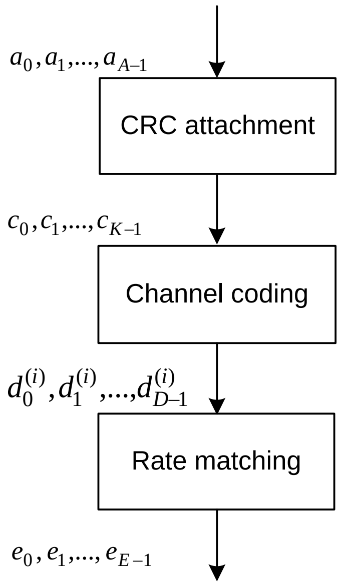

Figure 5.3.1A-1: Transport channel processing for BCH.

5.3.1A.1 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. Denote the bits in a transport block delivered to layer 1 by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$. A is the size of the transport block and set to 152 bits 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 [5].

The parity bits are computed and attached to the BCH transport block according to section 5.1.1 setting L to 16 bits.

5.3.1A.2 Channel coding

Information bits are delivered to the channel coding block. They are denoted by $c_0, c_1, c_2, c_3, \ldots, c_{K-1}$ ($c_k = a_k$), where K is the number of bits, and they are tail biting convolutionally encoded according to section 5.1.3.1.

After encoding the bits are denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)}, \ldots, d_{D-1}^{(i)}$, with $i = 0,1, \text{and } 2$, and where D is the number of bits on the i-th coded stream, i.e., $D = K$.

5.3.1A.3 Rate matching

A tail biting convolutionally coded block is delivered to the rate matching block. This block of coded bits is denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)}, \ldots, d_{D-1}^{(i)}$, with $i = 0,1, \text{and } 2$, and where i is the coded stream index and D is the number of bits in each coded stream. This coded block is rate matched according to section 5.1.4.2.

After rate matching, the bits are denoted by $e_0, e_1, e_2, e_3, \ldots, e_{E-1}$, where E is the number of rate matched bits as defined in section 6.6.1 of [2].

5.3.2 Downlink shared channel

The processing structure for each transport block for the DL-SCH transport channel,

Figure 5.3.2-1 shows the processing structure for each transport block for the DL-SCH, transport channel. Data arrives to the coding unit in the form of a maximum of two transport blocks every transmission time interval (TTI) per DL cell. The following coding steps can be identified for each transport block of a DL cell:

- Add CRC to the transport block
- Code block segmentation
- Channel coding
- Rate matching
- Code block concatenation

The coding steps for one transport block of DL-SCH are shown in the figure below. The same processing applies for each transport block on each DL cell.

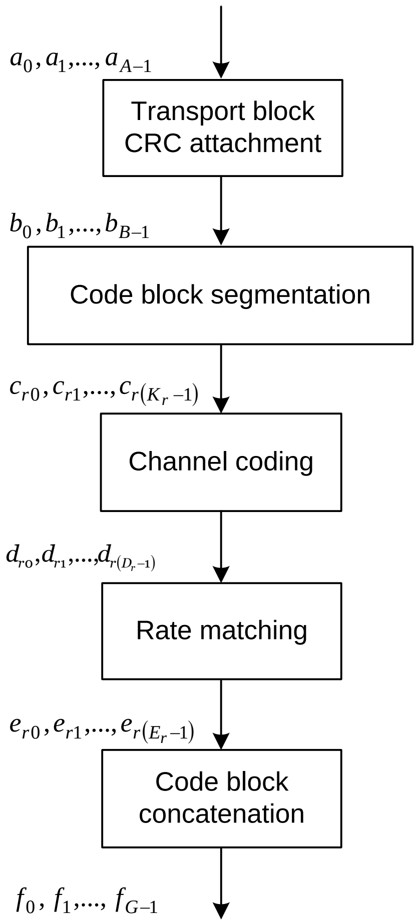

Figure 5.3.2-1: Transport block processing for DL-SCH.

5.3.2.1 Transport block CRC attachment

Error detection is provided on transport blocks 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 $a_0, a_1, a_2, a_3, ..., a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3, ..., p_{L-1}$. A is the size of the transport block 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 section 6.1.1 of [4].

The parity bits are computed and attached to the transport block according to section 5.1.1 setting L to 24 bits and using the generator polynomial $g_{CRC24A}(D)$.

5.3.2.2 Code block segmentation

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

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

5.3.2.3 Channel coding

Code blocks are delivered to the channel coding block. They are denoted by $c_{r0}, c_{r1}, c_{r2}, c_{r3}, ..., c_{r(K_r-1)}$, 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 section 5.1.3.2.

After encoding the bits are denoted by d_{r0}, d_{r1}, d_{r2}, … , $d_{r(Dr-1)}$ with $D_r = N_{ldpc}$ is the number of bits on the i-th coded stream for code block number r.

5.3.2.4 Rate matching

LDPC coded blocks are delivered to the rate matching block. They are denoted by d_{r0}, d_{r1}, d_{r2}, … , $d_{r(Dr-1)}$ where r is the code block number, i is the coded stream index, and $D_r = N_{ldpc}$ is the number of bits in each coded stream of code block number r. The total number of code blocks is denoted by C and each coded block is individually rate matched according to section 5.1.4.1.

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

5.3.2.5 Code block concatenation

The bits input to the code block concatenation block are denoted by $e_{r0}, e_{r1}, e_{r2}, e_{r3}, \ldots, e_{r(E_r-1)}$ for $r = 0, \ldots, C-1$ and where E_r is the number of rate matched bits for the r-th code block.

Code block concatenation is performed according to section 5.1.5.

The bits after code block concatenation are denoted by $f_0, f_1, f_2, f_3, \ldots, f_{G-1}$, where G is the total number of coded bits for transmission. This sequence of coded bits corresponding to one transport block after code block concatenation is referred to as one codeword in section 6.3.1 of [2]. In case of multiple transport blocks per TTI, the transport block to codeword mapping is specified according to section 5.3.3.1.5, 5.3.3.1.5A or 5.3.3.1.5B, depending on the DCI Format.

5.3.3 Downlink control information

Figure 5.3.3-1 shows the processing structure for one DCI. The following coding steps can be identified:

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

The coding steps for DCI are shown in the figure below.

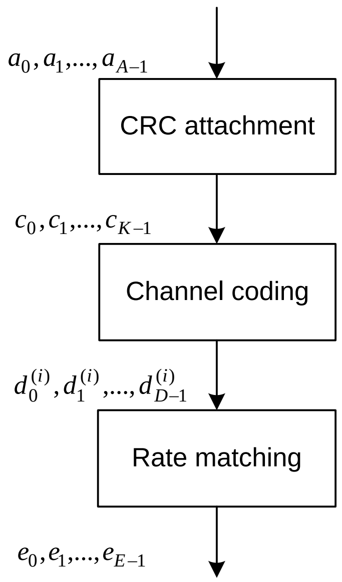

Figure 5.3.3-1: Processing for one DCI.

5.3.3.1 DCI formats

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.

Note: All DCI formats shall have the same payload size of 60 bits.

5.3.3.1.1 Format A1

DCI format A1 is used for the scheduling of xPUSCH.
The following information is transmitted by means of the DCI format A1 at the subframe index n:

- DCI format discriminator – 2 bits, where 00 indicates format A1
- xPUSCH range – 2bits, as defined in Section 9.2 of [3]
- Transmission timing of xPUSCH – 3 bits, where this field indicates transmission time offset value $l \in \{0, 1, \ldots, 7\}$
  - If this DCI format assigns more than zero RB or requests SRS, then the corresponding xPUSCH is scheduled in subframe index $n+4+l+m$
  - Otherwise, this field shall be set to all zeros

  where the value of m is indicated by the “transmission timing of CSI-RS / BRRS” field.

- RB assignment – 9 bits
  - If the indicated value is smaller than or equal to 324, then this field assigns more than zero RB as described in Section 9.2 of [3]
  - Else if the indicated value is equal to 325, then this format does not assign any of RB
  - Else if the indicated value is equal to 326, then this format does not assign any of RB and used for random access procedure initiated by a xPDCCH order
  - Otherwise, then this format is assumed to be misconfigured and UE shall discard the corresponding xPDCCH.

If this DCI format assigns more than zero RB,

- HARQ process number – 4 bits
- MCS – 4 bits
- NDI – 1 bit

Else if this DCI format is used for random access procedure initiated by a xPDCCH order,

- Frequency band index – 3 bits, as defined in 5.7 of [2]
- OCC indicator – 1 bit, as defined in 5.7 of [2]
- Cyclic shift indicator – 2 bits, as defined in 5.7 of [2]
- Reserved – 3 bits, which shall be set to all zeros

Otherwise,

- Reserved – 9 bits, which shall be set to all zeros.

- CSI / BSI / BRI request – 3 bits
  - If the indicated value is 000, then none of CSI/BSI/BRI is requested
  - Else if the indicated value is 001, then this DCI format triggers BSI reporting
  - Else if the indicated value is 010, then this DCI format allocates BRRS and also triggers corresponding BRI reporting
  - Else if the indicated value is 011, then this DCI format allocates BRRS but does not trigger BRI reporting
  - Else if the indicated value is 100, then this DCI format allocates CSI-RS and also triggers corresponding CSI reporting
  - The values 101, 110 and 111 are reserved.
- Transmission timing of CSI-RS / BRRS – 2 bits, where this field indicates transmission time offset value $m \in \{0, 1, 2, 3\}$
  - If this DCI format allocates either of CSI-RS or BRRS, then the corresponding transmission is allocated in subframe $n + m$
  - Otherwise, it shall be set to all zeros.
- Indication of OFDM symbol index for CSI-RS / BRRS allocations – 2 bits
  - If this DCI format allocates CSI-RS, then this field indicates OFDM symbols used for CSI-RS transmission
    - ✓ 00 : {13th}, 01 : {14th}, 10 : {13&14th}, 11 : Reserved
  - Else if this DCI format allocates BRRS and higher-layer gives either of 1 or 2 symbol BRRS configuration, then this field indicates OFDM symbols used for BRRS transmission
    - ✓ 00 : {13th}, 01 : {14th}, 10 : {13&14th}, 11 : Reserved
  - Else if this DCI format allocates BRRS and higher-layer gives either of 5 or 10 symbol BRRS configuration, then this field indicates OFDM symbols used for BRRS transmission
    - ✓ 00 : {5 symbols in slot 0}, 01 : {5 symbols in slot 1}, 10 : {10 symbols}, 11 : Reserved
  - Otherwise, it shall be set to all zeros.

If this DCI format allocates either of CSI-RS or BRRS transmission,

- Process indicator – 2 bits
    - ✓ 00 : {Process #0}, 01 : {Process #1}, 10 : {Process #2}, 11 : {Process #3}

Else if this DCI format triggers BSI request,

- Number of BSI reports – 2 bits
    - ✓ 00 : {1 BSI report}, 01 : {2 BSI reports}, 10 : {4 BSI reports}, 11 : Reserved.

Otherwise,

- Reserved – 2 bits, which shall be set to all zeros.

- "UCI on xPUSCH w/o xUL-SCH data" indicator – 1 bit,
  - If no UCI report is triggered, then this field is invalid and shall be set to zero
  - Otherwise, the indicated value of 0 allows multiplexing of xUL-SCH data and UCI and the indicated value of 1 allows only UCI transmission on xPUSCH.
- Beam switch indication – 1 bit, as described in Section 5.1.1 and Section 5.2.1 of [3].
- SRS request – 3 bits,
  - MSB 2 bits are used for the indication of SRS configurations
    - ✓ 00 : {No SRS request}, 01 : {Config. #0}, 10 : {Config. #1}, 11 : {Config. #2}
  - LSB 1 bit
    - ✓ If SRS is not requested, this field is invalid and shall be set to zero
    - ✓ If SRS is requested, 0 indicates SRS transmission on the 13th OFDM symbol and 1 indicates SRS transmission on the 14th OFDM symbol in subframe $n + 4 + l + m+1$.

- DMRS, RI, and SCID indication – 4 bits, as specified in Table 5.3.3.1.1-1
- Precoding matrix indicator – 3 bits, as specified in Table 5.3.3A.2-1 of [2]
- TPC command for xPUSCH – 2 bits, as defined in Section 6.1.1.1 of [3]
- UL PCRS – 2 bits
  - 00: {No PCRS}, 01: {PCRS on AP 50}, 10: {PCRS on AP 51}, 11: {PCRS on AP 50 and 51}

  Note: If no PCRS is transmitted, both PCRS Res are used for xPUSCH. If PCRS is transmitted, both PCRS Res are not used for xPUSCH.

If the number of information bits in format A1 is less than 60 bits, zeros shall be appended to format A1 until the payload size equals to 60 bits.

Table 5.3.3.1.1-1: Antenna port(s), scrambling identity, and number of layers indication by UL DCI formats

Value	Message
0	1 Layer, port 40, $n_{SCID} = 0$
1	1 Layer, port 40, $n_{SCID} = 1$
2	1 Layer, port 41, $n_{SCID} = 0$
3	1 Layer, port 41, $n_{SCID} = 1$
4	1 Layer, port 42, $n_{SCID} = 0$
5	1 Layer, port 42, $n_{SCID} = 1$
6	1 Layer, port 43, $n_{SCID} = 0$
7	1 Layer, port 43, $n_{SCID} = 1$

8	2 Layers, ports {40, 41}, n_{SCID} = 0
9	2 Layers, ports {40, 41}, n_{SCID} = 1
10	2 Layers, ports {42, 43}, n_{SCID} = 0
11	2 Layers, ports {42, 43}, n_{SCID} = 1
12 - 15	Reserved

5.3.3.1.2 Format A2

DCI format A2 is used for the scheduling of xPUSCH

All of the information fields in the DCI format A1 are also used for DCI format A2 except the following field

- DCI format discriminator – 2 bits, where 01 indicates format A2

If the number of information bits in format A2 is less than 60 bits, zeros shall be appended to format A2 until the payload size equals to 60 bits.

5.3.3.1.3 Format B1

DCI format B1 is used for the scheduling of xPDSCH.
The following information is transmitted by means of the DCI format B1 at the subframe index *n*:

- DCI format discriminator – 2 bits, where 10 indicates format B1
- xPDSCH range – 2bits, as defined in Section 8.1.4 of [3]
- RB assignment – 9 bits
  - If the indicated value is smaller than or equal to 324, then this field assigns more than zero RB as described in Section 8.1.4 of [3]
  - Else if the indicated value is equal to 325, then this format does not assign any of RB
  - Else if the indicated value is equal to 326, then this format does not assign any of RB and used for random access procedure initiated by a xPDCCH order
  - Otherwise, then this format is assumed to be misconfigured and UE shall discard the corresponding xPDCCH.

If this DCI format assigns more than zero RB,

- HARQ process number – 4 bits
- MCS – 4 bits
- NDI – 1 bit
- Redundancy version – 2 bits
- Bit-mapping index for HARQ-ACK multiplexing (BMI) – 3bits, as described in Section 8.5 of [3]

Else if this DCI format is used for random access procedure initiated by a xPDCCH order,

- Frequency band index – 3 bits

- OCC indicator – 1 bit
- Cyclic shift indicator – 2 bits
- Reserved – 8 bits, which shall be set to all zeros

Otherwise,

- Reserved – 14 bits, which shall be set to all zeros.

- CSI / BSI / BRI request – 3 bits
  - If the indicated value is 000, then none of CSI/BSI/BRI is requested
  - Else if the indicated value is 001, then this DCI format triggers BSI reporting
  - Else if the indicated value is 010, then this DCI format allocates BRRS and also triggers corresponding BRI reporting
  - Else if the indicated value is 011, then this DCI format allocates BRRS but does not trigger BRI reporting
  - Else if the indicated value is 100, then this DCI format allocates CSI-RS and also triggers corresponding CSI reporting
  - The indicated values, 101, 110, and 111 are reserved.
- Transmission timing of CSI-RS / BRRS – 2 bits, where this field indicates transmission time offset value $m \in \{0, 1, 2, 3\}$
  - If this DCI format allocates either of CSI-RS or BRRS, then the corresponding transmission is allocated in subframe $n + m$
  - Otherwise, it shall be set to all zeros
- Indication of OFDM symbol index for CSI-RS / BRRS allocations – 2 bits
  - If this DCI format allocates CSI-RS, then this field indicates OFDM symbols used for CSI-RS transmission
    - ✓ 00 : {13th}, 01 : {14th}, 10 : {13&14th}, 11 : Reserved
  - Else if this DCI format allocates BRRS and higher-layer gives either of 1 or 2 symbol BRRS configuration, then this field indicates OFDM symbols used for BRRS transmission
    - ✓ 00 : {13th}, 01 : {14th}, 10 : {13&14th}, 11 : Reserved
  - Else if this DCI format allocates BRRS and higher-layer gives either of 5 or 10 symbol BRRS configuration, then this field indicates OFDM symbols used for BRRS transmission
    - ✓ 00 : {5 symbols in slot 0}, 01 : {5 symbols in slot 1}, 10 : {10 symbols}, 11 : Reserved
  - Otherwise, it shall be set to all zeros.

If this DCI format allocates either of CSI-RS or BRRS transmission,

- Process indicator – 2 bits
  - ✓ 00 : {Process #0}, 01 : {Process #1}, 10 : {Process #2}, 11 : {Process #3}

Otherwise,

- Reserved – 2 bits, which shall be set to all zeros.

- Transmission timing of xPUCCH for UCI report – 3 bits, where this field indicates transmission time offset value $k \in \{0, 1, 2, \ldots, 7\}$
  - xPUCCH transmission is allocated in subframe index $n + 4 + k + m$
- Frequency resource index of xPUCCH for UCI report – 4 bits

- Beam switch indication – 1 bit, as described in Section 5.1.1 and Section 5.2.1 of [3].
- SRS request – 3 bits,
  - MSB 2 bits are used for the indication of SRS configurations
    - ✓ 00 : {No SRS request}, 01 : {Config. #0}, 10 : {Config. #1}, 11 : {Config. #2}
  - LSB 1 bit
    - ✓ If SRS is not requested, this field is invalid and shall be set to zero
    - ✓ If SRS is requested, 0 indicates SRS transmission on the 13th OFDM symbol and 1 indicates SRS transmission on the 14th OFDM symbol in subframe $n + 4 + m + k + 1$.

- Antenna port(s) and number of layers indication–4 bits, as specified in Table 5.3.3.1.3-1.
- Scrambling identity – 1bit
  - ✓ If the indicated value is 0, then $n_{SCID} = 0$
  - ✓ If the indicated value is 1, then $n_{SCID} = 1$
- TPC command for xPUCCH – 2 bits, as defined in Section 6.1.2 of [3].
- DL PCRS – 2 bits
  - ✓ 00 : {No PCRS }, 01 : {PCRS on AP 60}, 10 : {PCRS on AP 61}, 11 : {PCRS on AP 60 and 61}

If the number of information bits in format B1 is less than 60 bits, zeros shall be appended to format B1 until the payload size equals to 60 bits.

Table 5.3.3.1.3-1: Antenna port(s), and number of layers indication by DL DCI formats

Value	Message
0	1 Layer, port 8 (Ch. estimation w/o OCC)
1	1 Layer, port 9 (Ch. estimation w/o OCC)
2	1 Layer, port 10 (Ch. estimation w/o OCC)
3	1 Layer, port 11 (Ch. estimation w/o OCC)
4	2 Layers, ports {8, 9} (Ch. estimation w/o OCC)
5	2 Layers, ports {10, 11} (Ch. estimation w/o OCC)
6	2 Layers, ports {8, 12} (OCC=2)
7	2 Layers, ports {9, 13} (OCC=2)
8	2 Layers, ports {10, 14} (OCC=2)
9	2 Layers, ports {11, 15} (OCC=2)
10-15	Reserved

5.3.3.1.4 Format B2

DCI format B2 is used for the scheduling of xPDSCH.

All of the information fields in the DCI format B1 are also used for DCI format B2 except the following field

- DCI format discriminator – 2 bits, where 11 indicates format B2

If the number of information bits in format B2 is less than 60 bits, zeros shall be appended to format B2 until the payload size equals to 60 bits.

5.3.3.2 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 $a_0, a_1, a_2, a_3,...,a_{A-1}$, and the parity bits by $p_0, p_1, p_2, p_3,...,p_{L-1}$. A is the payload size and L is the number of parity bits.

The parity bits are computed and attached according to section 5.1.1 setting L to 16 bits, resulting in $b_0, b_1, b_2, b_3,...,b_{B-1}$, where $B = A + L$.

After attachment, the CRC parity bits are scrambled with the corresponding RNTI $x_{rnti,0}, x_{rnti,1},...,x_{rnti,15}$, where $x_{rnti,0}$ corresponds to the MSB of the RNTI, to form the sequence of bits $c_0, c_1, c_2, c_3,...,c_{B-1}$. The relation between c_k and b_k is:

$c_k = b_k$ for k = 0, 1, 2, …, A-1

$c_k = (b_k + x_{rnti,k-A}) \mod 2$ for k = A, A+1, A+2,..., A+15.

5.3.3.3 Channel coding

Information bits are delivered to the channel coding block. They are denoted by $c_0, c_1, c_2, c_3,...,c_{K-1}$, where K is the number of bits, and they are tail biting convolutionally encoded according to section 5.1.3.1.

After encoding the bits are denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)},...,d_{D-1}^{(i)}$, with $i = 0,1, \text{and } 2$, and where D is the number of bits on the i-th coded stream, i.e., $D = K$.

5.3.3.4 Rate matching

A tail biting convolutionally coded block is delivered to the rate matching block. This block of coded bits is denoted by $d_0^{(i)}, d_1^{(i)}, d_2^{(i)}, d_3^{(i)},...,d_{D-1}^{(i)}$, with $i = 0,1, \text{and } 2$, and where i is the coded stream index and D is the number of bits in each coded stream. This coded block is rate matched according to section 5.1.4.2.

After rate matching, the bits are denoted by $e_0, e_1, e_2, e_3,...,e_{E-1}$, where E is the number of rate matched bits.