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SERIES J: CABLE NETWORKS AND TRANSMISSION OF TELEVISION, SOUND PROGRAMME AND OTHER MULTIMEDIA SIGNALS

Cable modems and home networking

Physical layer specification of second generation HiNoC

Recommendation ITU-T J.196.2

ITU-T

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Physical layer specification of second generation HiNoC

Summary

Recommendation ITU-T J.196.2 specifies the physical (PHY) layer specification of second generation high performance networks over coax (HiNoC) which provides 1 Gbit/s data transmission over coaxial networks in the cable industry. The HiNoC architecture consists of a HiNoC bridge (HB) and HiNoC modems (HMs) and the HiNoC protocol stack includes the media access control (MAC) layer and PHY layer. This Recommendation contains descriptions for the signal transmission mode of the PHY layer, including frame structure, channel coding and modulation techniques.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T J.196.2	2016-10-14	9	11.1002/1000/13049

Keywords

HiNoC, physical layer, second generation HiNoC.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Physical layer specification of second generation HiNoC

1 Scope

This Recommendation specifies the physical (PHY) layer protocol and is part of a series of second generation HiNoC Recommendations for high-speed data transmission over coaxial cable.

This Recommendation applies to bidirectional high-performance wideband access digital systems that use coaxial cable connected between fibre-to-the-building (FTTB) and HiNoC modems (HMs).

Frequency planning, safety and electromagnetic compatibility (EMC) requirements are a national matter and are not covered by this Recommendation. Compliance remains the operators' responsibility.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.972] Recommendation ITU-T G.972 (2016), *Definition of terms relevant to optical fibre submarine cable systems.*

[ITU-T J.112] Recommendation ITU-T J.112 (1998), *Transmission systems for interactive cable television services.*

[ITU-T J.195.1] Recommendation ITU-T J.195.1 (2016), *Functional requirements for high speed transmission over coaxial networks connected with fibre to the building.*

[ITU-T J.195.2] Recommendation ITU-T J.195.2 (2014), *Physical layer specification for high speed transmission over coaxial networks.*

[ITU-T J.195.3] Recommendation ITU-T J.195.3 (2014), *Medium Access Control layer specification for high speed transmission over coaxial networks.*

[ITU-T J.196.1] Recommendation ITU-T J.196.1 (2016), *Functional Requirements for second generation HiNoC.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 available sub-carrier [ITU-T J.195.2]: Sub-carriers of OFDM symbol for data bearing.

3.1.2 constellation mapping [ITU-T J.195.1]: The process of mapping the data bits to the constellation symbol.

3.1.3 control frame [ITU-T J.195.2]: Frame of the MAC layer used for access control and channel allocation.

3.1.4 cyclic prefix [ITU-T J.195.2]: Data located at the front of an OFDM symbol, which is a copy of the data from the end of the OFDM symbol.

3.1.5 cyclic redundancy check [ITU-T J.112]: A method of error detection using cyclic code.

3.1.6 data frame [ITU-T J.195.2]: Frame of the MAC layer used to carry data of the upper layer.

3.1.7 downlink [ITU-T J.195.2]: Link from HiNoC bridge (HB) to HiNoC modem (HM).

3.1.8 forward error correction [ITU-T G.972]: A technique which consists of transmitting the data in an encoded form such that the redundancy added by the coding allows the decoding to detect and correct errors.

3.1.9 frame check sequence [ITU-T J.195.2]: A redundant sequence that is used for verifying the correctness of the received data.

3.1.10 Pd cycle [ITU-T J.195.2]: A time interval between two adjacent downlink probe frames.

3.1.11 probe frame [ITU-T J.195.2]: Frame of the physical layer used for carrying signalling frames of the MAC layer.

3.1.12 scrambler [ITU-T J.195.2]: Process that randomizes data using a pseudo-random binary sequence.

3.1.13 signalling frame [ITU-T J.195.2]: Frame of the MAC layer used for node admission, node quitting/deletion and link maintenance.

3.1.14 unavailable sub-carrier [ITU-T J.195.2]: Sub-carriers of OFDM symbol for adjacent channel protection and zero frequency sub-carrier.

3.1.15 uplink [ITU-T J.195.2]: Link from HiNoC modem (HM) to HiNoC bridge (HB).

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 pilot sub-carrier: Sub-carriers for transmission of specific symbols in an orthogonal frequency division multiplexing (OFDM) symbol.

3.2.2 constellation scrambler: The process that takes phase rotation of the constellation symbols in 4 quadrants by using binary pseudo random sequence.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BCH Bose-Chaudhuri-Hocquenghem (code)

Cd Control down

CP Cyclic Prefix

Dd downlink Data

DQPSK Differential Quadrature Phase-Shift Keying

Du uplink Data

EMC Electromagnetic Compatibility

FEC Forward Error Correction

FTTB Fibre-To-The-Building

GSM Global System for Mobile communications

HB HiNoC Bridge

HiNoC	High performance Network over Coax
HM	HiNoC Modem
IFFT	Inverse Fast Fourier Transform
LDPC	Low Density Parity Check Code
MAC	Media Access Control
MAP	Media Access Plan
MSO	Multiple Systems Operator
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
Pd	downlink Probe
PSD	Power Spectral Density
Pu	uplink Probe
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RF	Radio Frequency
Ru	Report up
SC	Sub-Channel
SCG_Ru	Sub-Carrier Group for Ru frame
SSC	Symbol Sub-Cell
TDMA	Time Division Multiple Access

5 Conventions

The keywords "is/are required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

In the body of this Recommendation and its annexes, the words *shall*, *shall not*, *should* and *may* sometimes appear, in which case they are to be interpreted, respectively, as *is required to*, *is prohibited from*, *is recommended* and *can optionally*. The appearance of such phrases or keywords in an appendix or in material explicitly marked as *informative* are to be interpreted as having no normative intent.

The keywords "HiNoC 1.0" indicate the HiNoC system defined by the ITU-T J.195 series.

The keywords "HiNoC 2.0" indicate the second generation HiNoC.

6 PHY layer structure

6.1 Overview

The functional blocks of the transmitter include scrambler, forward error correction (FEC) coding, constellation mapping, constellation scrambler, orthogonal frequency division multiplexing (OFDM) modulation, cyclic prefix (CP) insertion, framing (into different types of PHY packets) and up conversion to radio frequency (RF) signals. The sequence of the blocks is shown in Figure 1, in which scrambler, FEC coding, constellation scrambler and framing can be optionally closed or opened according to different types of data stream.

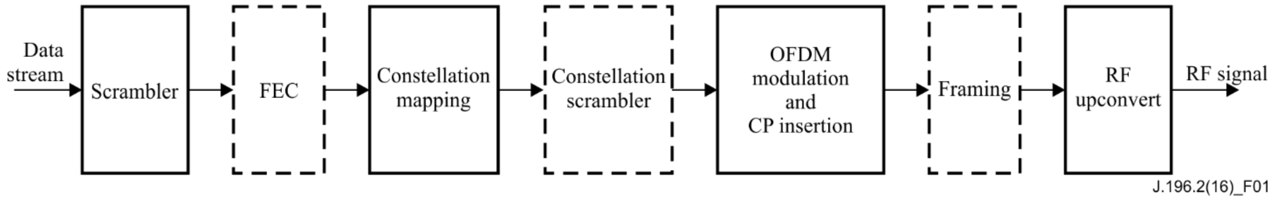

Figure 1 – Functional block diagram of the transmitter

6.2 Scrambler

The procedure of scrambler is required to conform to clause 6.2 of [ITU-T J.195.2].

6.3 FEC coding

6.3.1 Overview

The FEC encoder is required to support Bose-Chaudhuri-Hocquenghem (BCH) codes and can optionally support the low density parity check (LDPC) codes specified in clause 6.3.3.

6.3.2 BCH code

6.3.2.1 Overview

The BCH encoder is required to support three truncated BCH codes with the following code parameters: (392, 248), (1920, 1040) and (1920, 1744).

6.3.2.2 (392, 248) truncated BCH code

The (392, 248) BCH code is truncated from (511, 367) BCH code, a systematic code with the octal representation for the generator polynomial shown as follows:

$(1126657202505666323017001652245562614435511600655)_8$.

6.3.2.3 (1920, 1040) truncated BCH code

The (1920, 1040) BCH code is truncated from (2047, 1167) BCH code, a systematic code with the octal representation for the generator polynomial shown as follows:

(2607213617224645406577025220731152106357217602413642657023052056326613650555607
46124155122706374565474720414262325513114121607751671240010170277341021754016552
31230342573577525607211634376436714210307434573616501027347554213212451363043514
3515626347123264462606121045647652066606334120024047475)$_8$.

6.3.2.4 (1920, 1744) truncated BCH code

The (1920, 1744) BCH code is truncated from (2047, 1871) BCH code, a systematic code with the octal representation for the generator polynomial shown as follows:

$(64372013435571223560747633451755373433074714007120505460007)_8$.

6.3.2.5 Encoding procedure

The truncated BCH encoding procedure is required to conform to clause 6.3.5 of [ITU-T J.195.2].

6.3.3 LDPC code

6.3.3.1 Overview

The LDPC encoder is required to support two LDPC codes with the following code parameters: (1920, 1728) and (3840, 3456).

6.3.3.2 (1920, 1728) LDPC code

The parity check matrix of (1920, 1728) LDPC code is composed of the information bits part and the parity bits part, which correspond to information bits and parity bits respectively and is restricted to the form that the information part is located in the first half of the matrix and the parity part is located in the second half of the matrix.

The information part of (1920, 1728) LDPC parity matrix can be divided into 8*72 sub-matrices with a size of 24*24. Each sub-matrix is a null matrix or cyclic shift of unit matrix. The code table of the information part is shown in Table 1, where I represents the abscissa of the non-zero sub-matrix in mother matrix, J represents the ordinate of the non-zeros sub-matrix in mother matrix, R represents the cyclic right shift amount of the non-zero sub-matrix with respect to the unit matrix. For example, (I,J,R)=(2,1,23), represents that there is a non-zero sub-matrix in the first column and the second row of the mother matrix and it is obtained from cyclic right shifting a unit matrix by 23 bits.

Table 1 – Information part code table of (1920, 1728) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
2	1	23	1	17	4	7	33	3	2	52	19
1	1	5	3	17	10	6	33	7	8	53	4
8	1	8	8	17	16	1	33	17	3	53	10
4	1	19	6	17	20	5	33	19	5	53	18
5	2	0	6	18	3	4	34	9	6	54	6
3	2	5	3	18	5	7	34	11	4	54	11
6	2	18	2	18	19	8	34	18	1	54	20
4	2	21	4	18	22	2	34	20	1	55	2
4	3	2	8	19	23	1	35	3	3	55	19
6	3	4	7	19	3	6	35	6	2	55	22
8	3	10	2	19	13	5	35	11	6	56	3
7	3	22	3	19	15	8	35	17	3	56	9
5	4	3	4	20	3	8	36	8	1	56	14
3	4	6	3	20	5	2	36	9	7	57	6
2	4	17	6	20	7	4	36	11	5	57	10
7	4	21	8	20	21	3	36	12	6	57	11
3	5	0	4	21	3	7	37	8	6	58	2

Table 1 – Information part code table of (1920, 1728) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
2	5	1	5	21	8	6	37	10	7	58	5
4	5	15	1	21	10	2	37	16	4	58	18
1	5	19	6	21	14	4	37	17	5	59	0
1	6	23	2	22	2	7	38	23	2	59	7
8	6	1	6	22	3	2	38	3	7	59	19
5	6	2	8	22	5	1	38	4	4	60	3
3	6	15	7	22	12	8	39	3	7	60	7
4	7	3	8	23	23	7	39	14	5	60	22
8	7	5	7	23	2	6	39	22	1	61	4
3	7	6	6	23	14	7	40	3	5	61	5
2	7	21	2	23	18	8	40	7	3	61	11
6	8	23	8	24	0	5	40	12	4	62	4
5	8	1	3	24	3	8	41	7	3	62	14
2	8	4	5	24	7	1	41	14	1	62	17
4	8	14	2	24	8	7	41	22	4	63	23
5	9	11	6	25	2	5	42	23	5	63	19
8	9	14	4	25	3	7	42	0	1	63	22
1	9	17	3	25	19	2	42	3	5	64	5
4	9	19	8	25	20	8	43	5	7	64	10
5	10	23	2	26	23	6	43	10	1	64	13
1	10	4	7	26	5	2	43	11	5	65	11
6	10	12	8	26	6	3	44	10	1	65	18
4	10	22	5	26	15	5	44	15	3	65	21
6	11	0	6	27	23	7	44	18	7	66	2
1	11	12	5	27	9	2	45	13	3	66	4
2	11	14	8	27	14	1	45	16	1	66	20
5	11	19	7	27	16	4	45	22	7	67	0
1	12	23	1	28	2	1	46	23	3	67	19
4	12	4	3	28	4	8	46	5	1	67	21
6	12	14	4	28	6	5	46	11	7	68	5
7	12	22	6	28	19	1	47	8	1	68	12
8	13	23	3	29	9	3	47	9	3	68	22

Table 1 – Information part code table of (1920, 1728) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
6	13	1	4	29	12	2	47	15	3	69	14
4	13	19	2	29	13	7	48	15	7	69	18
5	13	21	5	29	22	2	48	16	1	69	20
4	14	2	2	30	6	3	48	20	3	70	1
2	14	4	7	30	7	6	49	12	4	70	2
8	14	18	6	30	8	3	49	19	2	70	14
1	14	19	5	30	9	8	49	22	6	71	15
8	15	0	5	31	23	8	50	0	5	71	18
2	15	11	6	31	7	4	50	4	3	71	20
7	15	14	2	31	9	2	50	7	3	72	2
4	15	19	8	31	10	7	51	23	8	72	14
6	16	3	4	32	0	5	51	2	7	72	22
2	16	13	1	32	11	1	51	11			
8	16	19	6	32	12	4	52	23			
4	16	20	3	32	15	5	52	7			

The parity part of (1920, 1728) LDPC parity matrix is transformed from a dual diagonal matrix. The dual diagonal matrix is shown in Figure 2, in which m is the number of parity bits of LDPC code.

$$\begin{bmatrix} 1 & & & & & \\ 1 & 1 & & & & \\ & 1 & 1 & & & \\ & & & \cdots & & \\ & & & & 1 & 1 & \\ & & & & & 1 & 1 \end{bmatrix}_{m\times n}$$

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Figure 2 – Dual diagonal matrix

The transformation rule for the dual diagonal matrix moves the ith row to the i'th row, which is shown in Equation (1) in detail, where "/" is the quotient operation, "%" is the remainder operation.

$$i' = \lfloor (i-1)/8 \rfloor + 1 + ((i-1)\%8) \times q \tag{1}$$

Where,

q is the size of code block, which equals 24 for (1920, 1728) code.

For (1920, 1728) code, the transformation rule is transforming the 1st, 9th, 17th, 25th, …, 185th, 2nd, 10th, 18th, 26th, …, 186th, …, 8th, 16th, 24th, 32nd, …, 192nd rows of the dual diagonal matrix into the 1st, 2nd, 3rd, 4th, 5th, 6th, …, 190th, 191st, 192nd rows of the parity bits.

6.3.3.3 (3840, 3456) LDPC code

The parity check matrix of (3840, 3456) LDPC code is composed of the information part and the parity part and is restricted to the form that the information part is located in the first half of the matrix and the parity part is located in the second half of the matrix.

The information part of (3840, 3456) LDPC parity matrix can be divided into 8*72 sub-matrices with size of 48*48. Each sub-matrix is a null matrix or cyclic shift of unit matrix. The code table of the information part is shown in Table 2, in which the meanings of I, J and R are as in clause 6.3.3.2.

Table 2 – Information part code table of (3840, 3456) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
1	1	37	1	17	46	1	33	37	7	52	16
2	1	1	2	17	31	6	33	19	4	53	27
5	1	43	5	17	8	7	33	0	5	53	20
6	1	4	8	17	18	8	33	1	8	53	33
1	2	23	1	18	12	3	34	40	6	54	0
2	2	29	2	18	47	4	34	33	7	54	40
4	2	37	5	18	26	6	34	10	8	54	16
6	2	2	7	18	24	8	34	37	4	55	41
3	3	27	1	19	39	3	35	19	6	55	31
6	3	28	3	19	33	5	35	47	8	55	40
7	3	30	7	19	0	6	35	13	2	56	17
8	3	9	8	19	21	7	35	39	3	56	23
1	4	45	1	20	33	3	36	7	5	56	47
3	4	11	3	20	31	5	36	18	5	57	34
5	4	20	6	20	21	6	36	39	6	57	36
6	4	32	8	20	39	7	36	4	7	57	23
1	5	17	1	21	21	2	37	7	1	58	29
2	5	34	4	21	15	3	37	19	7	58	12
4	5	12	5	21	4	4	37	38	8	58	10
5	5	30	8	21	12	7	37	8	1	59	21
1	6	29	1	22	28	1	38	6	4	59	13
2	6	27	2	22	14	4	38	16	8	59	20
5	6	46	4	22	11	6	38	30	2	60	41
6	6	36	7	22	6	4	39	9	3	60	14
1	7	35	2	23	22	5	39	37	7	60	22
5	7	37	3	23	32	6	39	5	1	61	31

Table 2 – Information part code table of (3840, 3456) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
7	7	24	4	23	15	2	40	8	4	61	42
8	7	43	7	23	9	4	40	41	8	61	5
2	8	14	2	24	8	5	40	3	2	62	36
5	8	36	3	24	13	4	41	37	3	62	10
6	8	18	4	24	4	6	41	11	5	62	27
7	8	37	7	24	36	8	41	9	4	63	38
1	9	25	1	25	10	4	42	3	5	63	39
2	9	39	4	25	46	5	42	8	7	63	2
3	9	10	6	25	3	8	42	47	1	64	18
8	9	41	8	25	35	2	43	35	3	64	41
2	10	31	1	26	45	5	43	4	5	64	26
3	10	30	2	26	22	6	43	3	2	65	39
6	10	17	3	26	38	3	44	16	3	65	0
7	10	22	5	26	29	4	44	27	4	65	29
1	11	24	2	27	28	5	44	41	1	66	39
2	11	34	3	27	21	3	45	44	3	66	0
5	11	33	6	27	3	7	45	5	7	66	31
6	11	8	8	27	36	8	45	36	4	67	2
1	12	6	1	28	36	3	46	42	5	67	1
2	12	9	6	28	35	4	46	30	8	67	3
3	12	35	7	28	38	8	46	0	1	68	21
6	12	0	8	28	2	2	47	32	4	68	3
1	13	6	3	29	40	5	47	42	7	68	18
2	13	26	4	29	30	6	47	30	5	69	44
4	13	7	6	29	0	3	48	2	7	69	24
7	13	33	8	29	12	4	48	20	8	69	42
1	14	46	2	30	22	7	48	43	1	70	10
5	14	44	3	30	18	5	49	43	2	70	0
6	14	11	4	30	43	6	49	0	8	70	38
8	14	33	6	30	10	8	49	2	3	71	33
1	15	18	1	31	27	2	50	14	6	71	14
4	15	36	2	31	24	4	50	3	7	71	12

Table 2 – Information part code table of (3840, 3456) LDPC code

I	J	R	I	J	R	I	J	R	I	J	R
7	15	34	3	31	26	7	50	12	4	72	25
8	15	11	4	31	35	2	51	27	5	72	0
2	16	27	1	32	20	3	51	8	8	72	20
5	16	45	3	32	4	5	51	39			
6	16	8	7	32	34	2	52	40			
7	16	47	8	32	47	3	52	15			

The parity part of the (3840, 3456) LDPC parity matrix is transformed from a dual diagonal matrix. The dual diagonal matrix is shown in Figure 2.

The transformation rule moves the *i*th row to the i'th row, which is shown in Equation (1) in detail. For (3840, 3456) codes, the size of code block q in Equation (1) equals 48.

6.4 Constellation mapping

6.4.1 Overview

The constellation mapping unit is required to support differential quadrature reference phase-shift keying (DQPSK), quadrature phase-shift keying (QPSK), 8 quadrature amplitude modulation (8QAM), 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, 1024QAM, 2048QAM and 4096QAM constellations. The input bit order of constellation mapping is shown in Figure 3.

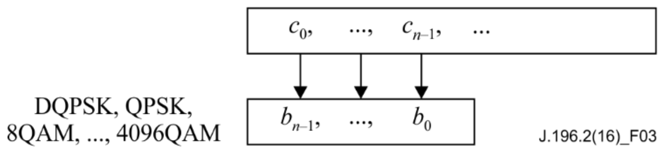

Figure 3 – Input bit order of constellation mapping

The input bit stream is in the order of $c_0, \cdots, c_{n-1}, \cdots$. According to different constellation modes, n bits $\{b_{n-1}, \cdots, b_0\}$ are taken from the bit stream and mapped into a constellation symbol, where b_{n-1} is the first bit sent to the constellation mapping unit.

6.4.2 DQPSK

The method of DQPSK mapping and the value of the initial reference symbol s_0 are required to conform to clause 6.4.2 of [ITU-T J.195.2], but whether or not to output s_0 depends on the PHY layer frame type specified in this Recommendation.

6.4.3 QPSK

The QPSK mapping is required to conform to clause 6.4.3 of [ITU-T J.195.2].

6.4.4 8QAM

The 8QAM mapping is required to conform to clause 6.4.4 of [ITU-T J.195.2].

6.4.5 2^nQAM

When $n = 4,5,6,\dots,12$, 2^nQAM is required to be obtained by rotating or translating QPSK or 8QAM. If the input bit stream of 2^nQAM is $\{b_{n-1},\cdots,b_0\}$, it follows that the real part (*I*) and imaginary part (*Q*) of the output symbol of 2^nQAM are shown in Equation (2) and Equation (3) respectively.

$$I_{2^n} = \begin{cases} (1-2b_{n-1})\left(I_{2^{n-2}} + 3\times 2^{(n-5)/2}\right) & \text{for } n = 5,7,9,11 \\ (1-2b_{n-1})\left(I_{2^{n-2}} + 2^{(n-2)/2}\right) & \text{for } n = 4,6,8,10,12 \end{cases} \tag{2}$$

$$Q_{2^n} = \begin{cases} (1-2b_{n-2})\left(Q_{2^{n-2}} + 3\times 2^{(n-5)/2}\right) & \text{for } n = 5,7,9,11 \\ (1-2b_{n-2})\left(Q_{2^{n-2}} + 2^{(n-2)/2}\right) & \text{for } n = 4,6,8,10,12 \end{cases} \tag{3}$$

6.4.6 Power normalization factor

After constellation mapping, the modulated symbols are required to be normalized by a corresponding power normalization factor according to the constellation mode. The power normalization factors of DQPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, 1024QAM, 2048QAM and 4096QAM constellations are shown in Table 3.

Table 3 – Constellation mapping normalization factor

Modulation mode	Power normalization factor
DQPSK	1
QPSK	$\sqrt{2}$
8QAM	$\sqrt{6}$
16QAM	$\sqrt{10}$
32QAM	$\sqrt{24}$
64QAM	$\sqrt{42}$
128QAM	$\sqrt{96}$
256QAM	$\sqrt{170}$
512QAM	$\sqrt{384}$
1024QAM	$\sqrt{682}$
2048QAM	$\sqrt{1536}$
4096QAM	$\sqrt{2730}$

6.5 Constellation scrambler

The constellation scrambler takes phase rotation of each constellation symbol carried by the sub-carrier according to the binary pseudo random sequence which is generated by the scrambler specified in [ITU-T J.195.2]. Prior to the first bit of each OFDM symbol, the scrambler is required to be initialized to initial phase "10010001 0110101" (from Bit15 to Bit1). The value of the phase rotation angle is calculated by the two low bits {Bit2, Bit1} of the scrambler as shown in Table 4. The scrambler shifting register shifts 2 bits after processing each constellation symbol.

Table 4 – Calculation of rotation angle

{Bit2，Bit1}	Rotation angle (rad)
00	0
01	$\pi/2$
10	π
11	$3\pi/2$

6.6 OFDM modulation

6.6.1 Overview

An OFDM symbol consists of 2048 sub-carriers in one 128 MHz channel with sub-carrier spacing of 62.5 kHz. The sub-carrier numbering is shown in Figure 4. A set of sub-carriers at the zero frequency and frequencies on both sides of the zero frequency and on both channel sides are defined as unavailable sub-carriers, giving a total number of 66, while the others are defined as available sub-carriers, adding up to 1982. Available sub-carriers can be divided into data sub-carriers and pilot sub-carriers, for transferring constellation symbols and pilot symbols respectively.

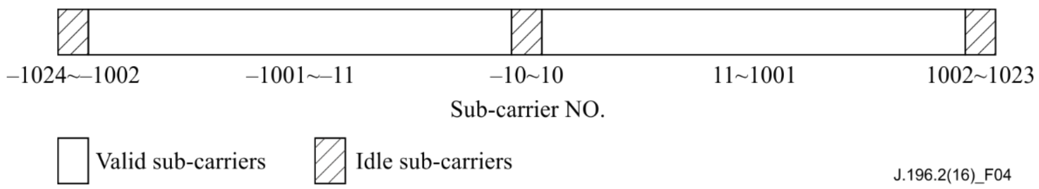

Figure 4 – OFDM sub-carrier numbering

The whole 128MHz bandwidth is divided to 8 sub-channels (SCs) according to the sub-carrier numbering of an OFDM symbol. Each SC has a bandwidth of 16 MHz, consisting of 256 sub-carriers. The sub-carrier distribution for each SC is shown in Table 5, in which SC0 is the basic SC and SC1~SC7 are extended SCs. The functions of basic SC are PHY layer synchronization, signalling interaction and data information transmission. Extended SCs are mainly used to transfer data information and can be configured as closed or open. In addition, each extended SC can optionally be configured as basic SC by the system.

Table 5 – SC sub-carrier numbering

SC numbering	Sequence number of sub-carrier
0	–1024～–769
1	–768～–513
2	–512～–257
3	–256～–1
4	0～255
5	256～511
6	512～767
7	768～1023

6.6.2 OFDM modulation

The frequency-domain symbols are modulated to every sub-carrier from left to right according to Figure 4. The sub-carriers in closed SC and the unavailable sub-carriers in open SCs are modulated with "0". The available sub-carriers in open SCs are modulated with the constellation symbols or pilot symbols. The modulated frequency-domain symbol $X(k),\ -N_s/2 \le k \le N_s/2-1$ is converted to time-domain signal by computing an inverse fast Fourier transform (IFFT), which is mathematically defined by Equation (4).

$$x_s(t) = \sum_{k=-N_s/2}^{N_s/2-1} X(k) e^{j2\pi k \Delta f_0 (t - T_{CP})},\ \ 0 \le t \le T_{OFDM} \tag{4}$$

Where,

- N_s the total number of OFDM sub-carriers, which equals 2048
- Δf_0 OFDM sub-carrier spacing, which equals 62.5 kHz
- T_{CP} the time duration of the cyclic prefix of OFDM, whose value is described in clause 6.6.3
- T_{OFDM} the time duration of OFDM symbol, which equals $T_{CP}+T_U$, where T_U is the OFDM symbol body duration, which equals 16 µs

6.6.3 Cyclic prefix insertion

In the time domain, an OFDM symbol consists of a CP and OFDM symbol body. The CP duration is defined as $T_{CP} = \alpha T_u$, where the factor α can be 1/8, 1/16 or 1/32 according to the channel quality and the CP duration can be 2 µs, 1 µs or 0.5 µs accordingly. The cyclic prefix insertion is shown in Figure 5. For each OFDM symbol, the last samples with appointed time duration are required to be copied to the head of the OFDM symbol, which forms the CP.

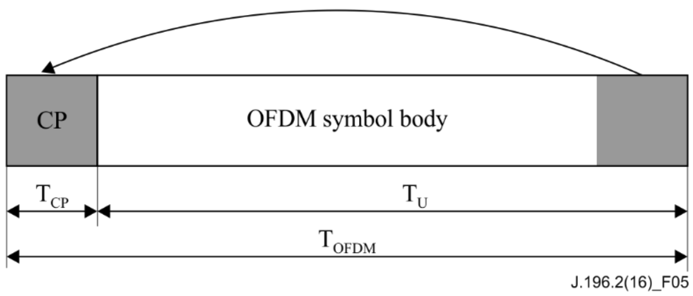

Figure 5 – Cyclic prefix insertion

7 PHY frame format

7.1 Overview

Six types of frames are defined in the HiNoC 2.0 PHY layer: downlink Probe (Pd) frame, downlink Data (Dd) frame, downlink Control (Cd) frame, uplink Probe (Pu) frame, uplink Data (Du) frame and uplink Report (Ru) frame. Pd and Pu frames are used to carry MAC signalling frames. Dd and Du frames are used to carry MAC data frames. Cd frame is used to carry MAC media access plan (MAP) frames. The Ru frame is used to carry MAC report (R) frames.

The time-domain format of these PHY frames is shown in Figure 6 and the six PHY frame formats are shown separately in Table 6. The preambles are used for frame synchronization and frequency synchronization.

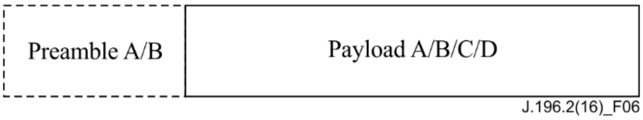

Figure 6 – PHY frame format

Table 6 – PHY frame format

Frame type	Preamble	Payload
Pd frame	Preamble A	Payload A
Dd frame	[None]	Payload B
Cd frame	[None]	Payload C
Pu frame	Preamble B	Payload A
Du frame	[None]	Payload B
Ru frame	[None]	Payload D

7.2 Preamble A

Preamble A consists of a synchronizing signal $S_A(t)$ followed by a reserved signal $R_A(t)$ as shown in Figure 7.

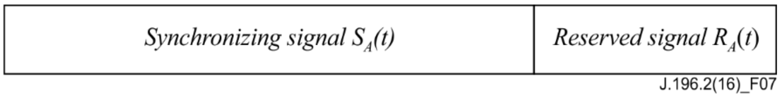

Figure 7 – Preamble A format

The duration of the reserved signal $R_A(t)$ is 0.125 µs. The reserved signal $R_A(t)$ includes two time-domain signal samples R_{A1} and R_{A2} with a sampling rate of 16MHz, the default values of which are $(1+j)/\sqrt{2}$.

The synchronizing signal $S_A(t)$ is composed of two same pseudo-random signals $S_{A,0}(t)$. The duration T_A of $S_A(t)$ is 3.875 µs and it is generated according to Equation (5).

$$S_A(t)=\begin{cases} S_{A,0}(t) & 0\le t\le \frac{T_A}{2} \\ S_{A,0}(t-\frac{T_A}{2}) & \frac{T_A}{2}<t\le T_A \end{cases} \tag{5}$$

$S_{A,0}(t)$ is defined by Equation (6).

$$S_{A,0}(t)=\frac{e^{j\pi(\Delta f)_A t}}{\sqrt{N_A}}\sum_{k=-N_A/2}^{N_A/2-1} X_A(k)e^{j2\pi k(\Delta f)_A t} \qquad 0\le t\le \frac{T_A}{2} \tag{6}$$

Where,

- N_A the number of sub-carriers of synchronizing signal in preamble A, which equals 248
- $X_A(k)$ frequency-domain synchronizing signal on the *k*th sub-carrier
- $(\Delta f)_A$ sub-carrier spacing of synchronizing signal in preamble A, which equals 516.1290 kHz.

Equation (7) expresses the frequency-domain synchronizing signal $X_A(k)$ on each sub-carrier in preamble A.

$$X_A(31i + m\text{-}124) = Z(i)P_A(m), \quad i = 0,1,...,7,\ m = 0,1,...,30 \tag{7}$$

$P_A(m)$ is defined by Equation (8).

$$P_A(m) = \begin{cases} e^{j(\frac{16\pi}{N_A} n_{m,A} + \frac{\pi}{4})} & 2 \le m \le 14 \ \text{ or } \ 16 \le m \le 28 \\ 0 & m = 0,1,15,29,30 \end{cases} \tag{8}$$

Where,

$n_{m,A}$ integers whose values are provided in Table 7

Table 7 – Values of $n_{m,A}$

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

$Z(i)$ is defined in Table 8. The parameter i indicates the SC numbering. When $i = 0$, $Z(i) = 1$; When $i > 0$, $Z(i) = 0$, except that if the ith SC is configured as basic SC, the value of $Z(i)$ is non-zero.

Table 8 – Values of $Z(i)$

i	$Z(i)$
0	1
1	0 or $e^{j\pi/8}$ (optional)
2	0 or $e^{j\pi/2}$ (optional)
3	0 or $e^{-j7\pi/8}$ (optional)
4	0 or 1 (optional)
5	0 or $e^{-j7\pi/8}$ (optional)

Table 8 – Values of $Z(i)$

i	$Z(i)$
6	0 or $e^{j\pi/2}$ (optional)
7	0 or $e^{j\pi/8}$ (optional)

7.3 Preamble B

Preamble B consists of a synchronizing signal S_B (t) followed by a reserved signal $R_B(t)$ as shown in Figure 8.

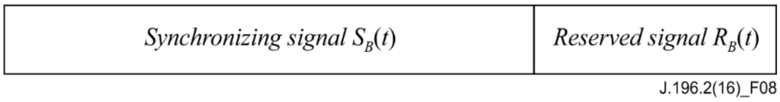

Figure 8 – Preamble B format

The duration of the reserved signal $R_B(t)$ is 0.0625 μs. Reserved signal $R_B(t)$ includes one time-domain signal sample R_B with a sampling rate of 16MHz, the default value of which is $(1+j)/\sqrt{2}$.

The synchronizing signal $S_B(t)$ is a pseudo-random signal with the duration T_B, which is equal to 3.9375μs ,and is generated according to Equation (9).

$$S_B(t) = \frac{e^{j\pi(\Delta f)_B t}}{\sqrt{N_B}} \sum_{k=-N_B/2}^{N_B/2-1} X_B(k) e^{j2\pi k(\Delta f)_B t} \qquad 0 \le t \le T_B \tag{9}$$

Where,

N_B——the number of sub-carriers of synchronizing signal in preamble B, which equals 504.

$X_B(k)$——frequency-domain synchronizing signal on the kth sub-carrier.

$(\Delta f)_B$——sub-carrier spacing of synchronizing signal in preamble B, which equals 253.9683 kHz.

Equation (10) expresses the frequency-domain synchronizing signal $X_B(k)$ on each sub-carrier in preamble B.

$$X_B(k) = \begin{cases} e^{j(\frac{16\pi}{N_B} n_{k,B} + \frac{\pi}{4})} & -247 \le k \le -222 \ \text{or} \ -220 \le k \le -195 \\ 0 & -252 \le k \le -248 \ \text{or} \ k = -221 \ \text{or} \ -194 \le k \le 251 \end{cases} \tag{10}$$

Where,

$n_{k,B}$ ——integers whose values are provided in Table 9.

Table 9 – Values of $n_{k,B}$

k	$n_{k,B}$	k	$n_{k,B}$
–247	60	–220	59
–246	48	–219	5
–245	60	–218	3
–244	35	–217	23
–243	12	–216	35

Table 9 – Values of $n_{k,B}$

–242	0	–215	30
–241	19	–214	0
–240	60	–213	59
–239	20	–212	25
–238	46	–211	17
–237	58	–210	15
–236	30	–209	21
–235	0	–208	12
–234	51	–207	0
–233	42	–206	33
–232	48	–205	5
–231	46	–204	17
–230	38	–203	43
–229	4	–202	3
–228	0	–201	44
–227	33	–200	0
–226	28	–199	51
–225	40	–198	28
–224	60	–197	3
–223	58	–196	15
–222	4	–195	3

7.4 Payload A

7.4.1 Overview

Payload A which consists of two OFDM symbols is used for Pd and Pu frames transmission. The basic SC of payload A is required to carry MAC signalling frames and the length of each MAC signalling frame equals 496 bits. The open extended SCs of payload A are required to transmit empty signalling frames and each empty signalling frame contains 490-bit '0'. The closed SCs of Payload A are prohibited from transmitting any frames. Figure 9 shows the generation process of a SC carrying a MAC signalling frame or an empty signalling frame. MAC signalling frames or empty signalling frames are transmitted in the following process: scrambler, FEC encoding, protected field insertion, DQPSK mapping and OFDM modulation into corresponding SCs.

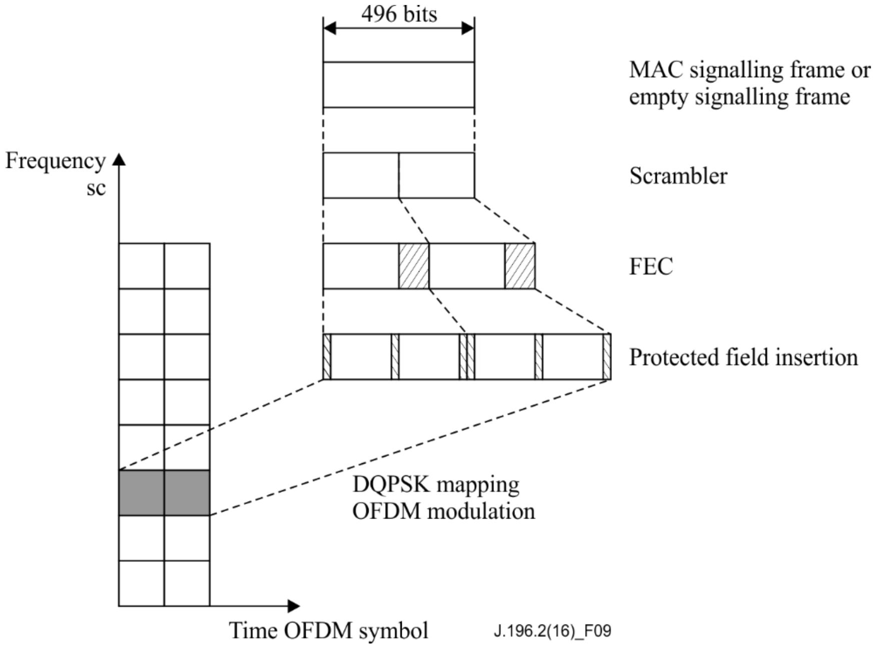

Figure 9 – Generation process of payload A

7.4.2 Scrambler

MAC signalling frames or empty signalling frames are required to be scrambled as described in clause 6.2. The scrambler is required to be reset at the beginning of each frame.

7.4.3 FEC encoding

After being scrambled, the data bits are required to be FEC encoded using the (392, 248) truncated BCH code specified in clause 6.3.2.

7.4.4 Protected field insertion

After the above process, two 392-bit FEC code blocks are get. The process of protected field insertion is shown in Figure 10. Each FEC code block is required to be equally divided into two segments. Each segment is filled into the signalling data unit in a left-first order, being inserted with protected fields.

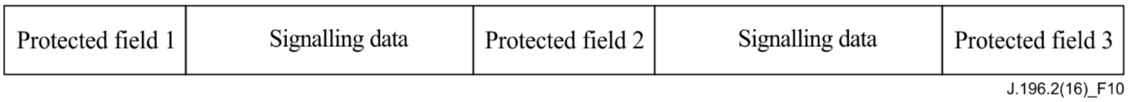

Figure 10 – Protected field insertion

The protection field definition is different according to different SCs. The protection fields are defined in Table 10.

Table 10 – Protected field definition

SC number	Protected field 1	Protected field 2	Protected field 3
0	9-bit '1' and 1-bit '0'	12-bit '1'	52-bit '1'
1,2,5,6	55-bit '1' and 1-bit '0'	12-bit '1'	52-bit '1'
3	55-bit '1' and 1-bit '0'	12-bit '1'	32-bit '1'
4	33-bit '1' and 1-bit '0'	12-bit '1'	52-bit '1'
7	55-bit '1' and 1-bit '0'	12-bit '1'	8-bit '1'

7.4.5 DQPSK mapping

After protected field insertion, the data bits are required to be mapped using DQPSK constellation specified in clause 6.4.2. However, the initial reference value s_0 is prohibited from being output.

7.4.6 OFDM modulation

In payload A, all of the 1982 available sub-carriers are data sub-carriers. The DQPSK symbols of one MAC signalling frame or empty signalling frame are required to be filled into a corresponding SC and then be OFDM modulated, generating two OFDM symbols. The process of OFDM modulation is specified in clause 6.6, where the CP duration T_{CP} is fixed to 1 μs.

7.5 Payload B

7.5.1 Overview

Payload B which consists of several OFDM symbols is used for Dd and Du frames transmission, carrying MAC data frames. Figure 11 shows the generation process of a payload B. MAC data frames are transmitted in the following process: scrambler, FEC encoding, adaptive constellation mapping and OFDM modulation.

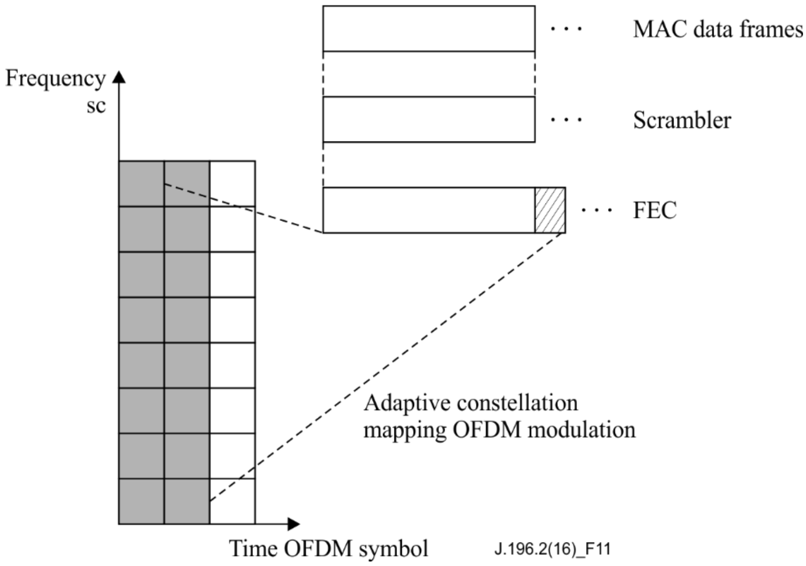

Figure 11 – Generation process of payload B

7.5.2 Scrambler

MAC Data frames are required to be scrambled as described in clause 6.2. The scrambler is required to be reset at the beginning of each Data frame.

7.5.3 FEC encoding

After being scrambled, the data bits are required to be FEC encoded using BCH or LDPC (option) codes as specified in clause 6.3.

7.5.4 Adaptive constellation mapping

In payload B, 1982 OFDM available sub-carriers is divided into 1920 data sub-carriers and 62 pilot sub-carriers. The sub-carrier distribution is described in clause 7.5.5.

Sub-carrier grouping adaptive constellation mapping is adopted in payload B. 2048 OFDM sub-carriers are divided into 128 sub-carrier groups, where each group consists of 16 successive sub-carriers started from the left side. It is required to select a proper constellation for each sub-carrier group dynamically to adapt to the channel characteristics and form a constellation scheme for 128 sub-carrier groups. The constellation can vary from 2 to 12 bits per symbol (QPSK, 8QAM,

16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, 1024QAM, 2048QAM and 4096QAM) as specified in clause 6.4. According to the constellation scheme, the data bits are mapped into constellation symbols and then modulated onto the corresponding data sub-carriers.

7.5.5 OFDM modulation

The distribution of data sub-carriers and pilot sub-carriers is shown in Figure 12. The numbers of pilot sub-carriers are $\{32k_P + 16,\ -31 \le k_P \le 30\}$ and the others are data sub-carriers.

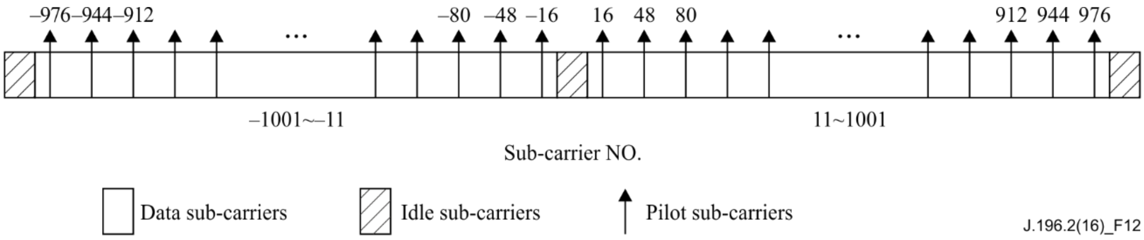

Figure 12 – Distribution of OFDM sub-carriers

Each pilot sub-carrier is filled with a fixed pilot symbol. The pilot symbols corresponding to the pilot sub-carriers from the left side are as follows:

$$\begin{aligned}\{&+1,\ -1,\ -1,\ +1,\ +1,\ +1,\ -1,\ +1,\ -1,\ +1,\ +1,\ -1,\ -1,\ -1,\ -1,\ +1,\\ &-1,\ +1,\ +1,\ +1,\ -1,\ -1,\ -1,\ +1,\ +1,\ -1,\ +1,\ +1,\ -1,\ +1,\ -1,\ -1,\\ &+1,\ -1,\ -1,\ -1,\ +1,\ -1,\ -1,\ +1,\ +1,\ -1,\ -1,\ +1,\ -1,\ +1,\ -1,\ +1,\\ &-1,\ -1,\ -1,\ -1,\ -1,\ +1,\ +1,\ +1,\ +1,\ +1,\ -1,\ +1,\ +1,\ +1\}.\end{aligned}$$

After sub-carrier grouping adaptive constellation mapping, constellation symbols are filled into data sub-carriers. According to the multiple access mode, the way of filling constellation symbols into sub-carriers can be based on time division multiple access (TDMA) mode or orthogonal frequency division multiple access (OFDMA) mode, where TDMA mode is the required basic mode and OFDMA mode is optional.

a) In TDMA mode, the constellation symbols of payload B can be filled into an arbitrary number of successive OFDM symbols and these OFDM symbols cannot be occupied by any other payload B.

b) In OFDMA mode, the minimum unit for filling constellation symbols is called a symbol sub-cell (SSC). A SSC consists of 256 successive sub-carriers in an OFDM symbol and sub-carriers of different SSCs are non-overlapping. Each OFDM symbol contains 8 SSCs and the sub-carrier distribution for each SSC is the same with SC as specified in clause 6.6.1. Constellation symbols of payload B are filled into an arbitrary number of successive SSCs in sequence and the SSC cannot be occupied by any other payload B in case of not being filled up. SSCs are required to be filled from low to high in the frequency domain and from front to back in the time domain.

Figure 13 is an example of SSC distribution in OFDMA mode. In Figure 13, each block represents a SSC. Constellation symbols of HM2’s payload B are filled into the available SSCs of the same OFDM symbol from the one following the last SSC of HM1’s payload B and from low to high in the frequency domain. When the constellation symbols cannot be filled into one OFDM symbol, the rest continue to be filled into the SSCs of the next OFDM symbol, until all the constellation symbols are filled into the OFDM symbols.

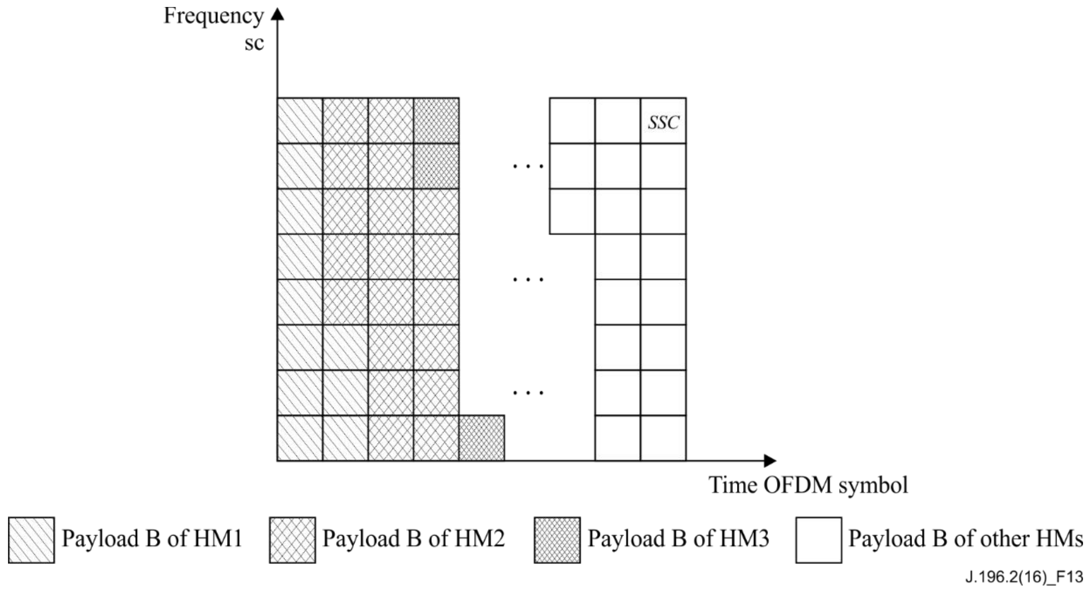

Figure 13 – Example of sub-carrier filling

OFDM modulation is performed after data sub-carriers and pilot sub-carriers are filled as specified in clause 6.6.

7.6 Payload C

7.6.1 Overview

Payload C which consists of several OFDM symbols is used for Cd frames transmission. The basic SC and extended SCs of payload C are required to carry independent MAC MAP frames separately. Figure 14 shows the generation process of a SC carrying a MAC MAP frame. MAC MAP frames are transmitted in the following process: scrambler, FEC encoding, DQPSK mapping, constellation scrambler and OFDM modulation.

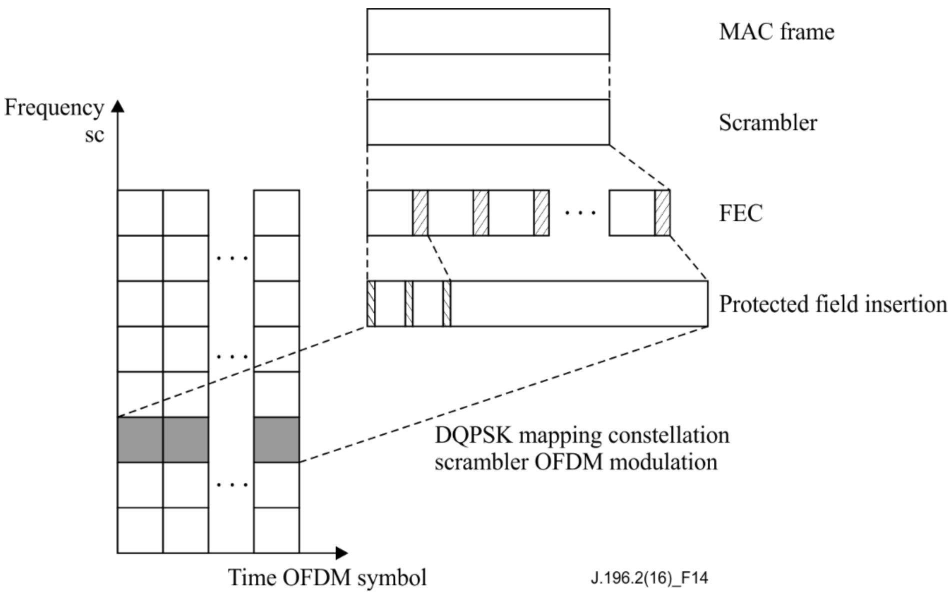

Figure 14 – Generation process of payload C

7.6.2 Scrambler

MAC MAP frames are required to be scrambled as described in clause 6.2. The scrambler is required to be reset at the beginning of each MAP frame.

7.6.3 FEC encoding

After being scrambled, the data bits are required to be FEC encoded using the (392, 248) truncated BCH code as specified in clause 6.3.2.

7.6.4 Protected field insertion

After being FEC encoded, the data bits are required to be inserted with protected fields as specified in clause 7.4.4.

7.6.5 DQPSK mapping

After protected field insertion, the data bits are required to be mapped using DQPSK constellation specified in clause 6.4.2. However, the initial reference value s_0 is prohibited from being output.

7.6.6 Constellation scrambler

After DQPSK mapping, the constellation symbols are required to be constellation scrambled as specified in clause 6.5.

7.6.7 OFDM modulation

In payload C, all of the 1982 available sub-carriers are data sub-carriers. The DQPSK symbols of one MAC MAP frame are required to be filled into a corresponding SC and then be OFDM modulated. The process of OFDM modulation is specified in clause 6.6.

7.7 Payload D

7.7.1 Overview

Payload D which consists of several OFDM symbols is used for Ru frames transmission, carrying 18-bit-length MAC report frames. Figure 15 shows the generation process of a payload D. MAC report frames are transmitted in the following process: DQPSK mapping, repetition encoding, constellation scrambler and OFDM modulation.

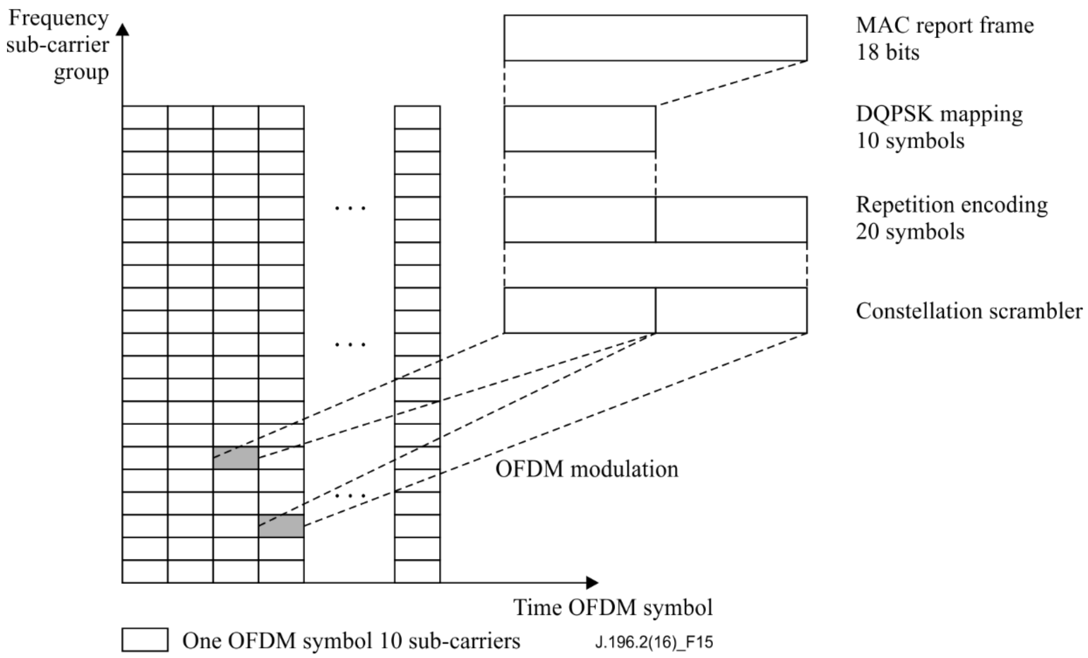

Figure 15 – Generation process of payload D

7.7.2 DQPSK mapping

The 18-bit MAC report frame is required to be mapped using DQPSK constellation specified in clause 6.4.2, generating 10 constellation symbols, where the initial reference value s_0 is required to be output.

7.7.3 Repetition encoding

10 DQPSK symbols are required to be repeated once as a group, forming 2 groups of DQPSK symbols.

7.7.4 Constellation scrambler

After repetition encoding, the 20 DQPSK symbols are required to be constellation scrambled as specified in clause 6.5.

7.7.5 OFDM modulation

In payload D, every 10 successive sub-carriers form a sub-carrier group for Ru frame (SCG_Ru). Each OFDM symbol contains 160 SCG_Rus, each one of which is numbered as SCG_Ru(m, n), m=0,1,2,…,M, n=0,1,2, …,159, where m indicates the mth OFDM symbol in payload D and M indicates the length (the number of OFDM symbols) of payload D and is configured by MAC layer. The OFDM sub-carrier numbering k for the first sub-carrier of SCG_Ru(m, n) is calculated by Equation (11).

$$k=10n+56\left\lfloor \frac{n}{20} \right\rfloor-\Delta,\quad \text{Where } \Delta=\begin{cases} 1001,\ n-20\left\lfloor \frac{n}{20} \right\rfloor<10 \\ 990,\ n-20\left\lfloor \frac{n}{20} \right\rfloor\geq 10 \end{cases} \tag{11}$$

SCG_Rus in the basic SC are required to be available while that in extended SCs are alternative. Two groups of DQPSK symbols are modulated onto two SCG_Rus appointed by MAC layer. After that, OFDM modulation is performed as specified in clause 6.6.

8 Spectrum mask

The spectrum mask of the transmitted signal is shown in Figure 16 and the spectrum mask parameters are shown in Table 11.

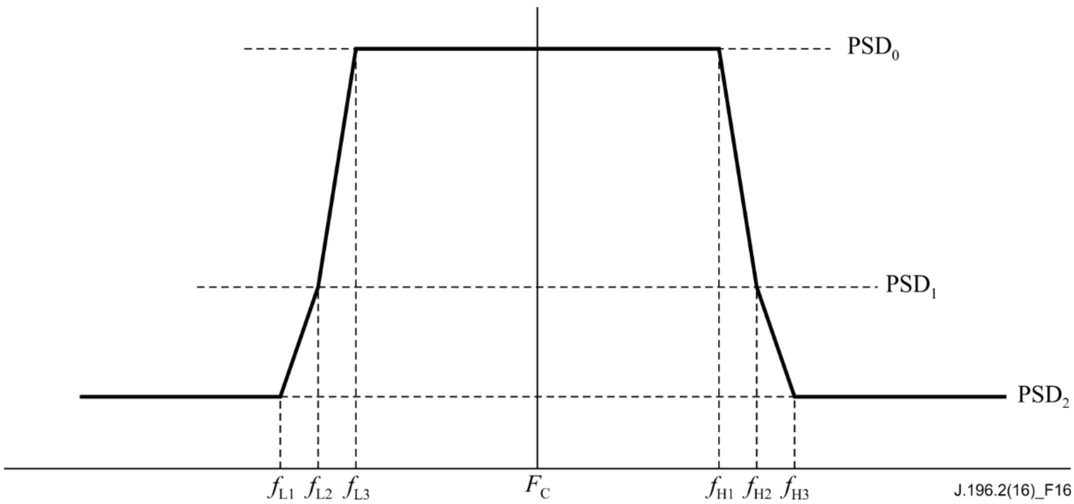

Figure 16 – Spectrum mask

Table 11 – Spectrum mask parameters

Parameters	**Frequency** **MHz**	**PSD** **dBm/Hz**
$F_C - f_{L1}$	65.40625	$PSD_2 = PSD_0$-60
$F_C - f_{L2}$	64	$PSD_1 = PSD_0$-50
$F_C - f_{L3}$	62.59375	PSD_0
F_C	–	PSD_0
$f_{H1} - F_C$	62.59375	PSD_0
$f_{H2} - F_C$	64	$PSD_1 = PSD_0$-50
$f_{H3} - F_C$	65.40625	$PSD_2 = PSD_0$-60
NOTE 1 – $PSD_0 \leq$-71dBm/Hz. NOTE 2 – F_C is carrier frequency.		

Appendix I

HiNoC 2.0 and 1.0 PHY layer brief comparison

(This appendix does not form an integral part of this Recommendation.)

HiNoC 2.0 is the second generation HiNoC. HiNoC 1.0 refers to the HiNoC system defined in [ITU-T J.195.1], [ITU-T J.195.2] and [ITU-T J.195.3].

A brief comparison of HiNoC 2.0 and 1.0 PHY layer is shown in Table I.1.

Table I.1 – HiNoC 2.0 and 1.0 PHY layer brief comparison

Key parameters/Mechanism	HiNoC 2.0	HiNoC 1.0
Channel Bandwidth	128 MHz/channel (supporting channel bundle)	16 MHz/channel (supporting channel bundle)
Modulation	OFDM, Sub-carrier grouping adaptive modulation	OFDM, Sub-carrier adaptive modulation
Constellation	DQPSK, QPSK, 2^nQAM(n=3,4,…,11,12)	DQPSK, QPSK, 2^nQAM(n=3,4,…,10)
FEC	BCH, LDPC(option)	BCH
Frame Type	Pd frame, Dd frame, Cd frame, Pu frame, Du frame, Ru frame	Pd frame, Dd frame Pu frame, Du frame
Duplex/Multiple access mode	TDD/TDMA, OFDMA	TDD/TDMA

Appendix II

Operational notes

(This appendix does not form an integral part of this Recommendation.)

Possible interference from or to the wireless signal or radiocommunication services, such as terrestrial broadcast, global system for mobile communications (GSM), 3G/4G, Wi-Fi and aeronautical navigation, might degrade the signal or service quality both in coaxial cable and in air and can even be risky to flight safety in the worst-case scenario. Therefore, any multiple systems operator (MSO) which plans to deploy HiNoC 2.0/1.0 should be cautious about the spectrum allocation, coaxial cable mounting and maintenance and equipment screening to minimize the risk from and to any other possible signal outside the coaxial cable. Specifically, any deployment of HiNoC 2.0 should not be within 1 km range of any airport.

Frequency planning, safety and EMC requirements are a national matter and are not covered by this Recommendation. Compliance remains the operators' responsibility and any operator who needs to mitigate, calculate or estimate the EMC conditions of their network should refer to [b-ITU-T K.106], [b-ITU-T K.60], [b-ITU-R P.525], [b-ITU-R P.528] and [b-ITU-R P.1238-8].

Bibliography

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[b-ITU-T K.106] Recommendation ITU-T K.106 (2015), *Techniques to mitigate interference between radio devices and cable or equipment connected to wired broadband networks and cable television networks.*

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