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Recommendation

ITU-T J.198.2 (01/2024)

SERIES J: Cable networks and transmission of television, sound programme and other multimedia signals

Cable modems and home networking

Physical layer specification for third-generation HiNoC

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Recommendation ITU-T J.198.2

Physical layer specification for third-generation HiNoC

Summary

Recommendation ITU-T J.198.2 aims to define the physical (PHY) layer specification of a third-generation high performance network over coax (HiNoC 3.0) which provides 10 Gbit/s data transmission over coaxial networks in the cable industry. The HiNoC network consists of a HiNoC bridge (HB) and HiNoC modems (HMs). The HiNoC protocol stack includes a media access control (MAC) layer and a physical (PHY) layer. This Recommendation contains descriptions for the signal transmission mechanism of the HiNoC 3.0 PHY layer, including frame structure, channel coding and modulation techniques. The HiNoC 3.0 protocol supports channel bonding which refers to the scheduling of the MAC layer frames over multiple PHY layer channels.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T J.198.2	2024-01-13	9	11.1002/1000/15800

Keywords

Physical layer, third-generation HiNoC.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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1 Scope

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

The functional requirements of third-generation HiNoC are defined in [ITU-T J.198.1] and the media access control (MAC) layer specification for third-generation HiNoC is defined in [ITU-T J.198.3].

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.

Information on the main differences between the third-generation HiNoC (HiNoC 3.0) and the second-generation HiNoC (HiNoC 2.0) is available in [b-ITU-T J Sup 12].

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 J.195.2] Recommendation ITU-T J.195.2 (2014), *Physical 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*.

[ITU-T J.196.2] Recommendation ITU-T J.196.2 (2016), *Physical layer specification of second generation HiNoC*.

[ITU-T J.196.3] Recommendation ITU-T J.196.3 (2016), *Media access control layer specification of second generation HiNoC*.

[ITU-T J.198.1] Recommendation ITU-T J.198.1 (2022), *Functional requirements for third-generation HiNoC*.

[ITU-T J.198.3] Recommendation ITU-T J.198.3 (2024), *MAC layer specification for third-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 orthogonal frequency division multiplexing (OFDM) symbol for data bearing.

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

3.1.3 constellation scrambler [ITU-T J.196.2]: The process that takes phase rotation of the constellation symbols in four quadrants by using binary pseudo random sequence.

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

3.1.6 forward error correction [b-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.

3.1.7 pilot sub-carrier [ITU-T J.196.2]: Sub-carriers for the transmission of specific symbols in an orthogonal frequency division multiplexing (OFDM) symbol.

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

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

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 HiNoC 2.0: The short form of the second generation HiNoC is defined by [ITU-T J.196.1], [ITU-T J.196.2] and [ITU-T J.196.3].

3.2.2 HiNoC 3.0: The short form of the third-generation HiNoC is defined by [ITU-T J.198.1], [ITU-T J.198.3] and this Recommendation.

3.2.3 HiNoC 2.0+ channel: A channel that supports the access of HiNoC 3.0 and 2.0 modems and has a bandwidth of 128 MHz.

3.2.4 HiNoC 3.0 channel: A channel that only supports the access of HiNoC 3.0 modems and has a bandwidth of 128 MHz.

3.2.5 interleaver: A device that rearranges the bit order of the forward error correction (FEC) codewords.

3.2.6 interleaver depth: The number of FEC codewords rearranged in each interleaving process.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

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
HB	HiNoC Bridge

HiNoC	High performance Network over Coax
HM	HiNoC Modem
MAC	Media Access Control
MAP	Media Access Plan
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
PHY	Physical
RF	Radio Frequency
SC	Sub-Channel
SSC	Symbol Sub-Cell
TDMA	Time Division Multiple Access

5 Conventions

In this Recommendation:

The keywords "**is 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 this Recommendation, 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.

6 PHY layer structure

6.1 Overview

The bandwidth of a single channel in the high performance network over coax (HiNoC) 3.0 physical (PHY) layer is 128 MHz. HiNoC 3.0 PHY layer is required to support the channel bonding mechanism defined in the HiNoC 3.0 MAC layer specification, which means that multiple PHY layer channels can be combined to transmit the MAC layer frames. To ensure compatibility, the bonded channels in the HiNoC 3.0 system are divided into HiNoC 2.0+ channel and HiNoC 3.0 channel, and the channel type can be configured. The HiNoC 2.0+ channel supports the access of HiNoC 2.0 and 3.0 modems, and the HiNoC 3.0 channel only supports the access of HiNoC 3.0 modems. The PHY layer is required to adopt the corresponding signal processing procedure according to the channel type.

The functional blocks of the transmitter of a single channel include a scrambler, forward error correction (FEC) encoder, interleaver, constellation mapper, constellation scrambler, orthogonal frequency division multiplexing (OFDM) modulator, cyclic prefix (CP) inserter, framer (into different types of PHY packets) and radio frequency (RF) upconverter. The sequence of the blocks is shown in Figure 1, in which the scrambler, FEC encoder, interleaver, constellation scrambler and the framer can be optionally closed or opened according to the different types of data streams.

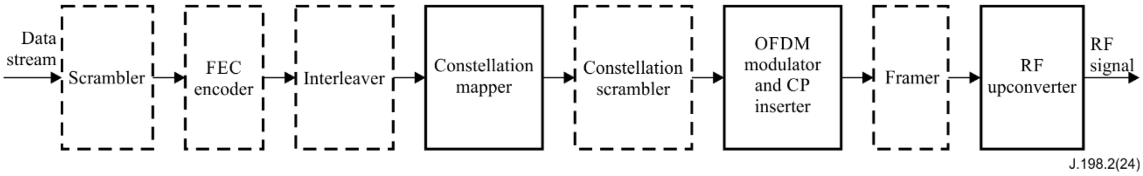

Figure 1 – Functional blocks sequence of the transmitter

6.2 Scrambler

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

6.3 FEC encoding

The FEC encoding is required to conform to clause 6.3 of [ITU-T J.196.2].

6.4 Interleaver

Interleaver rearranges the bit order of the FEC codewords. The FEC codewords are divided into the interleaver blocks each of which consists of M successive codewords. The bit length of each interleaver block is L*M, where M is the interleaver depth, configured by the MAC signalling frame. L is the FEC codeword length in bit. If the number M_{tail} of the FEC codewords in the last interleaver block is less than M, the bit length of the last interleaver block is L*M_{tail}.

Each interleaver block is filled into a table with M rows and L columns. The bits are written in the table row by row (from left to right). Therefore, each row corresponds to an FEC code. The bits are read from the table column by column (from top to bottom) as the output. The interleaving scheme is shown in Figure 2.

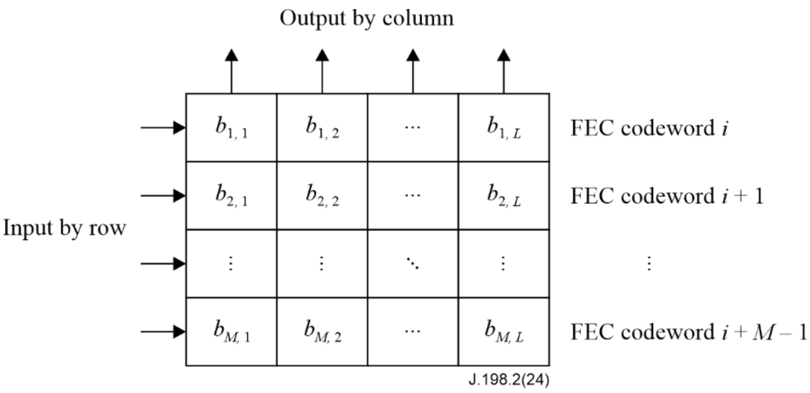

Figure 2 – Interleaving scheme

6.5 Constellation mapping

6.5.1 Overview

The constellation mapping unit is required to support 14 mapping modes: differential quadrature phase-shift keying (DQPSK), quadrature phase-shift keying (QPSK), 8 quadrature amplitude modulation (8 QAM), 16 QAM, 32 QAM, 64 QAM, 128 QAM, 256 QAM, 512 QAM, 1 024 QAM, 2 048 QAM, 4 096 QAM, 8 192 QAM and 16 384 QAM constellations. The input bit order of the constellation mapping is shown in Figure 3.

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

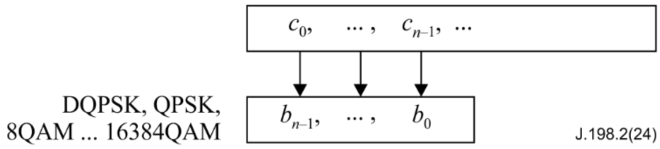

Figure 3 – Input bit order of constellation mapping

6.5.2 DQPSK

The DQPSK mapping is required to conform to clause 6.4.2 of [ITU-T J.195.2].

6.5.3 QPSK

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

6.5.4 8 QAM

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

6.5.5 2^n QAM constellation

For n = 4, 5, 6, …, 14, 2^n QAM is obtained by rotating or translating low-order QPSK or 8 QAM. When mapping the input bit stream $\{b_{n-1}, \cdots, b_0\}$ to 2^n QAM, the real part (I) and the imaginary part (Q) of the output symbol 2^n QAM are required to be as defined in equation (1) and equation (2) respectively.

$$I_{2^n} = \begin{cases} (1-2b_{n-1})\left(I_{2^{n-2}} + 3\times 2^{(n-5)/2}\right) & n = 5, 7, 9, 11, 13 \\ (1-2b_{n-1})\left(I_{2^{n-2}} + 2^{(n-2)/2}\right) & n = 4, 6, 8, 10, 12, 14 \end{cases} \tag{1}$$

$$Q_{2^n} = \begin{cases} (1-2b_{n-2})\left(Q_{2^{n-2}} + 3\times 2^{(n-5)/2}\right) & n = 5, 7, 9, 11, 13 \\ (1-2b_{n-2})\left(Q_{2^{n-2}} + 2^{(n-2)/2}\right) & n = 4, 6, 8, 10, 12, 14 \end{cases} \tag{2}$$

6.5.6 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 the 14 constellation modulation modes are shown in Table 1.

Table 1 – Constellation mapping normalization factor

Modulation mode	Power normalization factor
DQPSK	1
QPSK	$\sqrt{2}$
8QAM	$\sqrt{6}$
16QAM	$\sqrt{10}$
32QAM	$\sqrt{24}$

Table 1 – Constellation mapping normalization factor

Modulation mode	Power normalization factor
64QAM	$\sqrt{42}$
128QAM	$\sqrt{96}$
256QAM	$\sqrt{170}$
512QAM	$\sqrt{384}$
1024QAM	$\sqrt{682}$
2048QAM	$\sqrt{1536}$
4096QAM	$\sqrt{2730}$
8192QAM	$\sqrt{6144}$
16384QAM	$\sqrt{10922}$

6.6 Constellation scrambler

The constellation scrambler is required to conform to clause 6.5 of [ITU-T J.196.2].

6.7 OFDM modulation

The orthogonal frequency division multiplexing (OFDM) modulation is required to conform to clause 6.6 of [ITU-T J.196.2], where all seven extended sub-channels (SCs) on each HiNoC 3.0 channel are required to be opened.

7 PHY frame format

7.1 Overview

The frames are required to conform to clause 7.1 of [ITU-T J.196.2].

7.2 Preamble A

Preamble A is required to conform to clause 7.2 of [ITU-T J.196.2].

7.3 Preamble B

Preamble B is required to conform to clause 7.3 of [ITU-T J.196.2].

7.4 Payload A

7.4.1 Overview

Payload A is used as the payload part of Pd and Pu frames for information transmission. Payload A consists of two OFDM symbols and each OFDM symbol is divided into a basic SC and seven extended SCs as defined in clause 6.6.1 of [ITU-T J.196.2].

The generation process of payload A on the HiNoC 2.0+ channel is required to conform to clause 7.4 of [ITU-T J.196.2].

For payload A on HiNoC 3.0 channel, it is required to use all the basic SC and extended SCs of payload A to carry the MAC signalling frames or custom random bit sequences, where the length of each MAC signalling frame or random bit sequence equals 3 968 bits. The generation process of payload A is shown in Figure 4. Each MAC signalling frame or random bit sequence is transmitted in the following process: scrambler, FEC encoding, protected field insertion, DQPSK mapping and OFDM modulation.

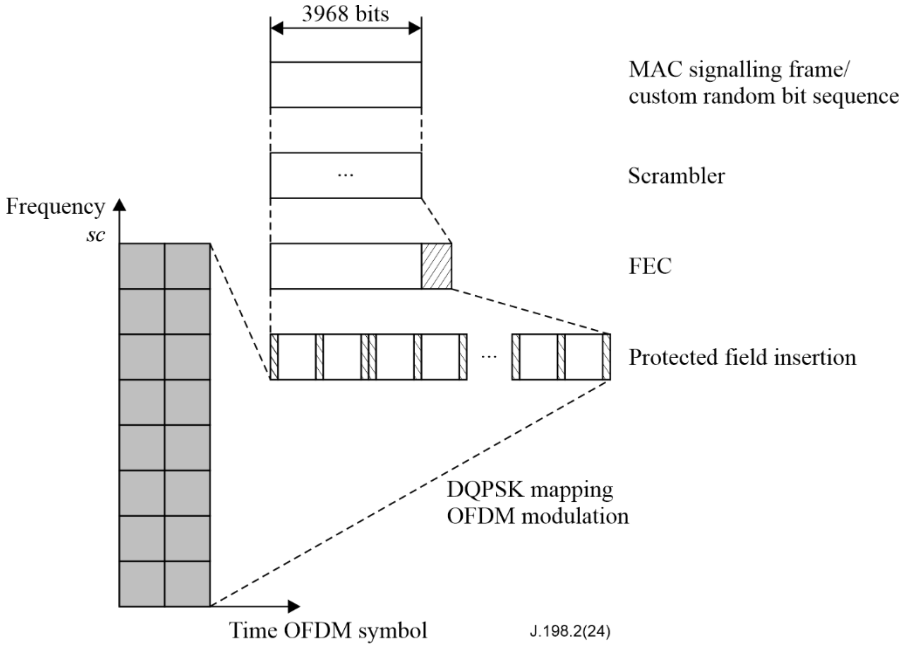

Figure 4 – Generation process of payload A on HiNoC 3.0 channel

7.4.2 Scrambler

The scrambler is required to conform to clause 7.4.2 of [ITU-T J.196.2].

7.4.3 FEC encoding

The FEC encoding is required to conform to clause 7.4.3 of [ITU-T J.196.2].

7.4.4 Protected field insertion

The protected field insertion is required to conform to clause 7.4.4 of [ITU-T J.196.2].

7.4.5 DQPSK mapping

The DQPSK mapping is required to conform to clause 7.4.5 of [ITU-T J.196.2].

7.4.6 OFDM modulation

In payload A, all of the 1 982 available sub-carriers are data sub-carriers. The DQPSK symbols are required to be filled into the corresponding data sub-carriers of each OFDM symbol in order, from low to high in the frequency domain and from front to back in the time domain. Then OFDM modulation which is specified in clause 6.7 is performed and two OFDM symbols are generated as one payload A.

7.5 Payload B

7.5.1 Overview

Payload B consists of several OFDM symbols. It is used as the payload part of the downlink data (Dd) and the uplink data (Du) frames to carry the MAC data frames.

The generation process of payload B on the HiNoC 2.0+ channel is required to conform to clause 7.5 of [ITU-T J.196.2].

For payload B on the HiNoC 3.0 channel, the generation process is shown in Figure 5. MAC data frames are transmitted in the following process: scrambler, FEC encoding, interleaving, adaptive modulation and OFDM modulation.

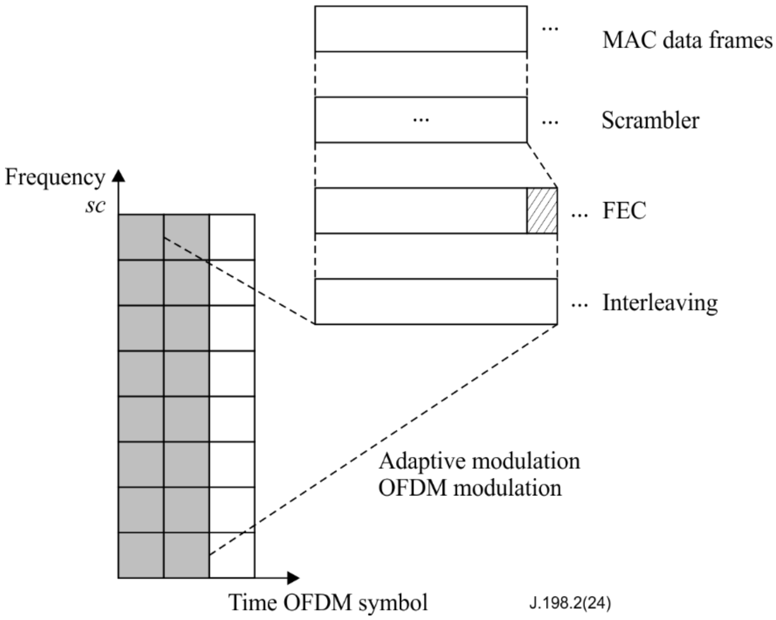

Figure 5 – Generation process of payload B on HiNoC 3.0 channel

7.5.2 Scrambler

The scrambler is required to conform to clause 7.5.2 of [ITU-T J.196.2].

7.5.3 FEC encoding

The FEC encoding is required to conform to clause 7.5.3 of [ITU-T J.196.2].

7.5.4 Interleaving

The interleaving is performed as specified in clause 6.4. The interleaver is required to be reset before each payload B is interleaved.

7.5.5 Adaptive constellation mapping

Sub-carrier grouping adaptive constellation mapping is adopted and is required to conform to clause 7.5.4 of [ITU-T J.196.2] with the difference that two more constellations 8 192QAM and 16 384QAM specified in clause 6.5.5 are required to be supported in this Recommendation.

7.5.6 OFDM modulation

In payload B, 1 982 OFDM available sub-carriers are divided into 1 920 data sub-carriers and 62 pilot sub-carriers. The distribution of the data sub-carriers and pilot sub-carriers in payload B is required to conform to clause 7.5.5 of [ITU-T J.196.2].

Each pilot sub-carrier is filled with a fixed pilot symbol. The pilot symbols corresponding to the pilot sub-carriers are required to conform to clause 7.5.5 of [ITU-T J.196.2].

After the sub-carrier grouping adaptive constellation mapping, constellation symbols are filled into the data sub-carriers. According to the multiple access mode, the way of filling the constellation symbols into the sub-carriers can be based on the time division multiple access (TDMA) mode or orthogonal frequency division multiple access (OFDMA) mode, where the TDMA mode is the required basic mode and the 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 the constellation symbols is called a symbol sub-cell (SSC). An SSC consists of N_{ssc} successive sub-carriers in an OFDM symbol and the sub-carriers of different SSCs are non-overlapping, where N_{ssc} is configured by the MAC signalling frame. Constellation symbols of payload B are filled into an arbitrary number of successive SSCs in sequence and the last SSC is prohibited from being 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 6 is an example of the SSC distribution and sub-carrier filling in the OFDMA mode. In Figure 6, each block represents an SSC and one OFDM symbol is divided into several SSCs. For the payload B of HM2, constellation symbols are firstly filled into the available SSCs from the one following the last SSC of HM1's payload B and from low frequency to high frequency within the same OFDM symbol. When one OFDM symbol is filled up and there are still constellation symbols left, the rest continue to be filled into the SSCs of the following OFDM symbol, until all the constellation symbols are filled into the OFDM symbols.

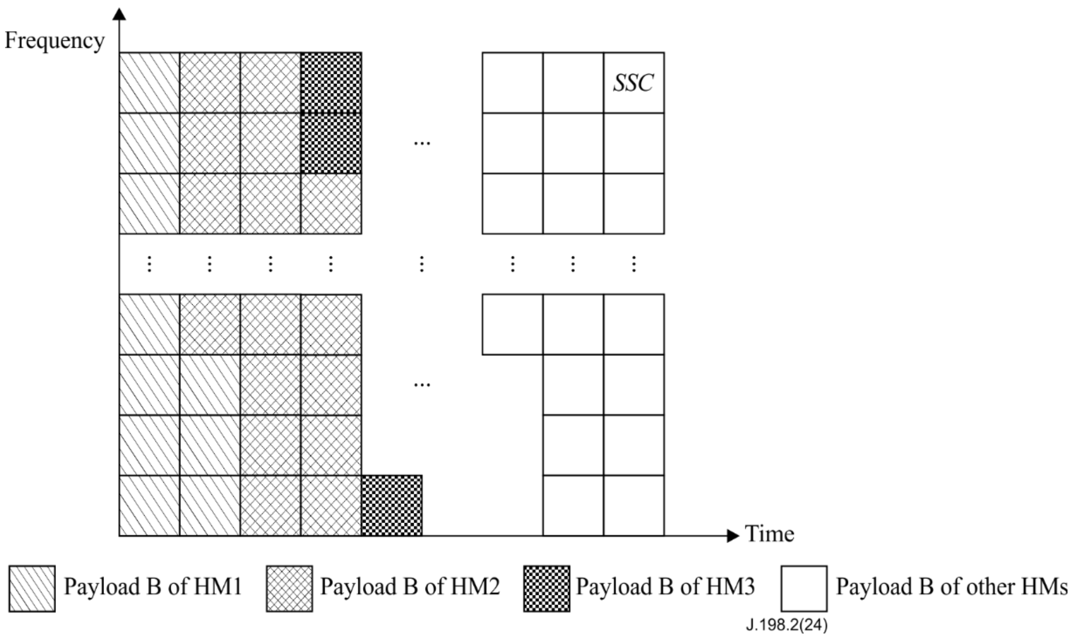

Figure 6 – Example of SSC distribution and sub-carrier filling in OFDMA mode

OFDM modulation is performed as specified in clause 6.7 after the data sub-carriers and pilot sub-carriers are filled.

7.6 Payload C

7.6.1 Overview

Payload C consists of several OFDM symbols and is used for control down (Cd) frame transmission.

The generation process of payload C on the HiNoC 2.0+ channel is required to conform to clause 7.6 of [ITU-T J.196.2].

For payload C on the HiNoC 3.0 channel, both the basic SC and the extended SCs are required to be used together to carry the MAC media access plan (MAP) frames. Figure 7 shows the generation process of a payload C carrying a MAC MAP frame. The MAC MAP frame is transmitted in the following process: scrambler, FEC encoding, protected field insertion, DQPSK mapping, constellation scrambler and OFDM modulation.

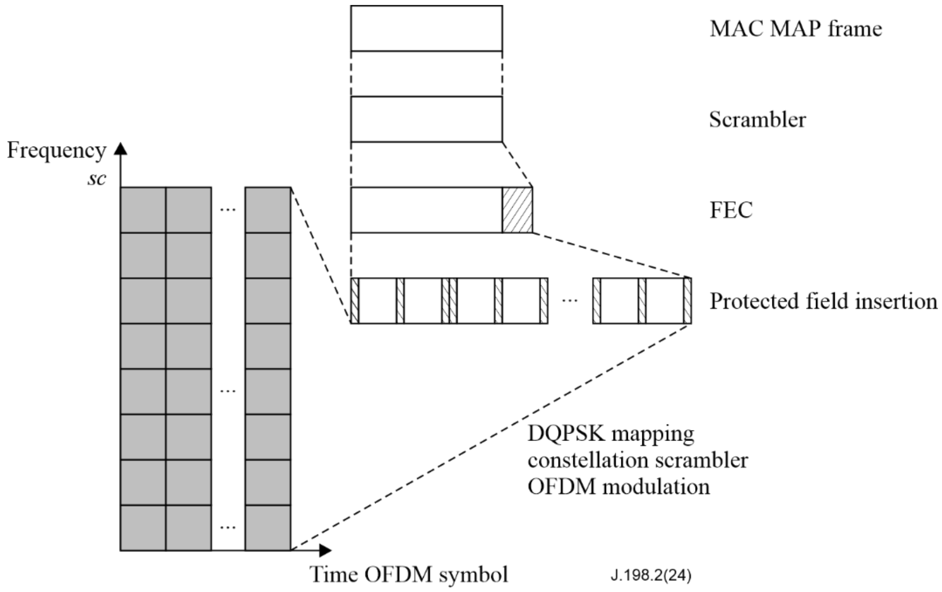

Figure 7 – Generation process of payload C on HiNoC 3.0 channel

7.6.2 Scrambler

The scrambler is required to conform to clause 7.6.2 of [ITU-T J.196.2].

7.6.3 FEC encoding

The FEC encoding is required to conform to clause 7.6.3 of [ITU-T J.196.2].

7.6.4 Protected field insertion

The protected field insertion is required to conform to clause 7.6.4 of [ITU-T J.196.2].

7.6.5 DQPSK mapping

The DQPSK mapping is required to conform to clause 7.6.5 of [ITU-T J.196.2].

7.6.6 Constellation scrambler

The constellation scrambler is required to conform to clause 7.6.6 of [ITU-T J.196.2].

7.6.7 OFDM modulation

In payload C, all of the 1 982 available sub-carriers are data sub-carriers. The data sub-carriers of the OFDM symbols are filled with scrambled DQPSK symbols of the MAC MAP frame and it is required to be filled successively in order, from low to high in the frequency domain and from front to back in the time domain. Then the OFDM modulation is performed as specified in clause 6.7.

7.7 Payload D

The payload D is required to conform to clause 7.7 of [ITU-T J.196.2].

8 Spectrum mask

The spectrum mask is required to conform to clause 8 of [ITU-T J.196.2].

Bibliography

[b-ITU-T G.972] Recommendation ITU-T G.972 (2020), *Definition of terms relevant to optical fibre submarine cable systems*.

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