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Recommendation

ITU-T J.195.2 (03/2024)

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

Cable modems and home networking

Physical layer specification for first-generation HiNoC

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Recommendation ITU-T J.195.2

Physical layer specification for first-generation HiNoC

Summary

Recommendation ITU-T J.195.2 specifies the physical (PHY) layer specification for high-speed data transmission over coaxial cable as part of the high-performance network over coax (HiNoC). The HiNoC architecture consists of a HiNoC bridge (HB) and HiNoC modems (HMs), and the HiNoC protocol stack includes the medium access control (MAC) layer and PHY layer. HiNoC utilizes the unassigned spectrum of the "last 100-meter" coaxial network to provide more bandwidth and improve spectral efficiency. This document contains descriptions for the signal transmission mode of the PHY layer, including frame structure, channel coding and modulation techniques.

Edition 2.0 only updates the title of this and other HiNOC Recommendations without introducing any technical changes.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T J.195.2	2014-10-29	9	11.1002/1000/12311
2.0	ITU-T J.195.2	2024-03-26	9	11.1002/1000/15880

Keywords

HiNoC, PHY layer

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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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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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Recommendation ITU-T J.195.2

Physical layer specification for first-generation HiNoC

1 Scope

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

This Recommendation applies to bi-directional 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 (2011), *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 (2024), *Functional requirements for first-generation HiNOC.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

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

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

3.1.3 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.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 available sub-carrier: Sub-carriers of OFDM symbol for data bearing.

3.2.2 control frame: Frame of the MAC layer used for access control and channel allocation.

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3.2.3 cyclic prefix: Data located at the front of an OFDM symbol, which is a copy of the data from the end of the OFDM symbol.

3.2.4 data frame: Frame of the MAC layer used to carry data of the upper layer.

3.2.5 downlink: Link from HiNoC bridge (HB) to HiNoC modem (HM).

3.2.6 frame check sequence: A redundant sequence that is used for verifying the correctness of the received data.

3.2.7 Pd cycle: A time interval between two adjacent downlink probe frames.

3.2.8 probe frame: Frame of the physical layer used for carrying signalling frames of the MAC layer.

3.2.9 scrambler: Process that randomizes data using a pseudo-random binary sequence.

3.2.10 signalling frame: Frame of the MAC layer used for node admission, node quitting/deletion and link maintenance.

3.2.11 unavailable sub-carrier: Sub-carriers of OFDM symbol for adjacent channel protection and zero frequency sub-carrier.

3.2.12 uplink: Link from HiNoC modem (HM) to HiNoC bridge (HB).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BCH	Bose-Chaudhuri-Hocquenghem
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
Dd	downlink Data
DQPSK	Differential Quadrature Phase-Shift Keying
Du	uplink Data
FCS	Frame Check Sequence
FEC	Forward Error Correction
FTTB	Fibre-To-The-Building
HB	HiNoC Bridge
HiNoC	High performance Network over Coax
HM	HiNoC Modem
IFFT	Inverse Fast Fourier Transform
MAC	Medium Access Control
OFDM	Orthogonal Frequency Division Multiplexing
Pd	downlink Probe
PSD	Power Spectral Density
Pu	uplink Probe
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying

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RF Radio Frequency

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.

6 PHY layer structure

6.1 Overview

A functional block diagram of the transmitter is shown in Figure 1.

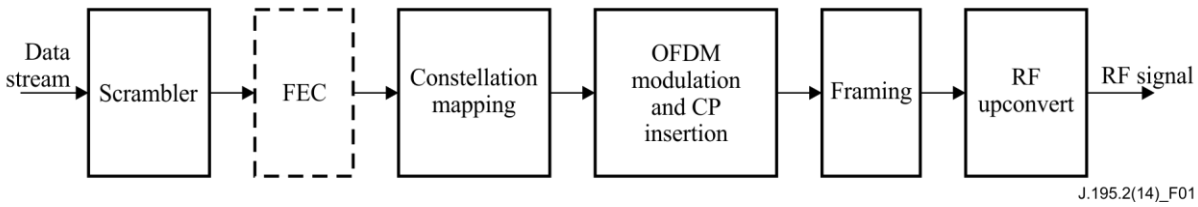

Figure 1 – Functional Block Diagram of the Transmitter

The data streams (service data and signalling data from the medium access control (MAC) layer) are transmitted in the following process: scrambler, optional forward error correction (FEC) coding, constellation mapping, 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.

6.2 Scrambler

The data entering into the transmitter is scrambled using the pseudo-random binary sequence that is defined by the generator polynomial $p(x) = 1 + x^{14} + x^{15}$. The structure of scrambler is shown in Figure 2. Prior to the first bit of each frame, the scrambler shifting register is required to be initialized to initial phase '010010011011000' (from bit 15 to bit 1) as shown in Figure 2. For each input bit, the scrambler is shifted 1 position. The input bits are combined with the scrambling sequence through an exclusive-or operator (XOR), resulting in the randomized output bits.

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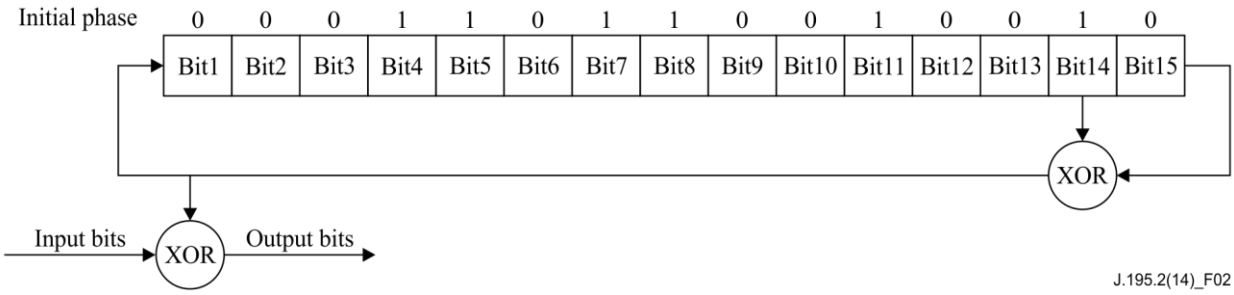

Figure 2 – Structure of the Scrambler

6.3 FEC code

6.3.1 Overview

The FEC encoder is required to support three truncated Bose-Chaudhuri-Hocquenghem (BCH) codes with the following code parameters: (508.472), (504.432), and (392.248).

6.3.2 (508.472) truncated BCH code

The (508.472) BCH code is truncated from (511.475) BCH code, a systematic code with the generator polynomial as shown in Equation (1).

$$g_1(x) = x^{36} + x^{35} + x^{34} + x^{31} + x^{30} + x^{25} + x^{23} + x^{21} + x^{20} + x^{19} + x^{16} + x^{15} + x^{11} + x^{8} + x^{7} + x^{5} + 1 \qquad (1)$$

The octal representation for the generator polynomial is $(1630256304641)_8$.

6.3.3 (504.432) truncated BCH code

The (504.432) BCH code is truncated from (511.439) BCH code, a systematic code with the generator polynomial as shown in Equation (2).

$$\begin{aligned} g_2(x) = {} & x^{72} + x^{71} + x^{69} + x^{68} + x^{67} + x^{63} + x^{61} + x^{60} + x^{59} + x^{57} + x^{50} + x^{49} + x^{47} + x^{44} + \\ & x^{43} + x^{41} + x^{40} + x^{39} + x^{35} + x^{33} + x^{32} + x^{28} + x^{27} + x^{26} + x^{25} + x^{24} + x^{23} + x^{22} + \\ & x^{21} + x^{20} + x^{19} + x^{18} + x^{17} + x^{13} + x^{10} + x^{9} + x^{7} + x^{6} + x^{5} + x^{2} + 1 \end{aligned} \qquad (2)$$

The octal representation for the generator polynomial is $(1561350064670543777423345)_8$.

6.3.4 (392.248) truncated BCH code

The (392.248) BCH code is truncated from (511.367) BCH code, a systematic code with the generator polynomial as shown in Equation (3).

$$\begin{aligned} g_3(x) = {} & x^{144} + x^{141} + x^{139} + x^{137} + x^{136} + x^{134} + x^{133} + x^{131} + x^{129} + x^{128} + x^{127} + x^{126} + x^{124} + x^{118} + \\ & x^{116} + x^{114} + x^{110} + x^{108} + x^{107} + x^{106} + x^{104} + x^{103} + x^{101} + x^{100} + x^{97} + x^{96} + x^{94} + x^{91} + \\ & x^{90} + x^{84} + x^{83} + x^{82} + x^{81} + x^{72} + x^{71} + x^{70} + x^{68} + x^{66} + x^{64} + x^{61} + x^{59} + x^{56} + x^{54} + \\ & x^{53} + x^{51} + x^{50} + x^{49} + x^{46} + x^{44} + x^{43} + x^{39} + x^{38} + x^{35} + x^{31} + x^{30} + x^{29} + x^{27} + x^{26} + \\ & x^{24} + x^{21} + x^{18} + x^{17} + x^{16} + x^{8} + x^{7} + x^{5} + x^{3} + x^{2} + 1 \end{aligned} \qquad (3)$$

The octal representation for the generator polynomial is $(1126657202505666323017001652245562614435511600655)_8$.

6.3.5 Encoding procedure

The truncated BCH encoding procedure is shown in Figure 3. Suppose that the (n, k) truncated BCH code comes from the (n_s, k_s) systematic BCH code. Input bits enter the BCH encoder in order of $d_0, d_1, \cdots, d_{k-1}$. And $k_s - k$ zeros are added in front of d_0 to form k_s information bits. Then k_s information

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bits are encoded to an n_s bits code as per the original BCH code. Finally, the added $k_s - k$ zeros are deleted to get n bits output sequence $c_0, c_1, \cdots, c_{n-1}$.

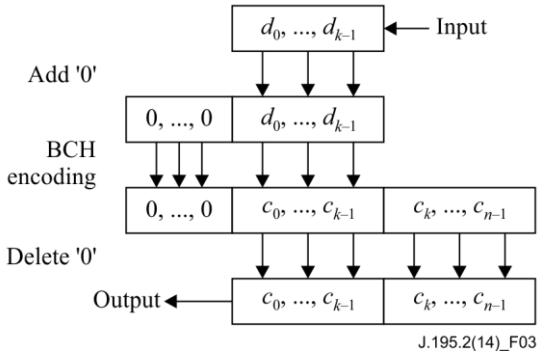

Figure 3 – Encoding procedure of truncated BCH code

6.4 Constellation mapping

6.4.1 Overview

The constellation mapping unit is required to support differential quadrature phase-shift keying (DQPSK), quadrature phase-shift keying (QPSK), 8 quadrature amplitude modulation (8QAM), 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, and 1024QAM constellations. The input bit order of constellation mapping is shown in Figure 4.

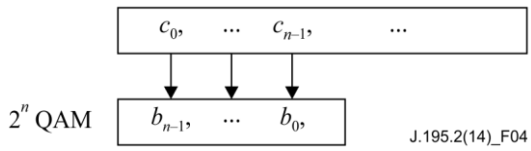

Figure 4 – Input bit order of constellation mapping

The input bit stream is in the order of c_0, ..., c_{n-1}, ... According to different constellation modes, n bits $\{b_{n-1},...,b_0\}$ are taken from the bit stream and mapped into a 2^n QAM symbol, where b_{n-1} is the first bit sent to the constellation mapping unit.

6.4.2 DQPSK

For the DQPSK constellation, the modulated symbol s_n is taken as the reference symbol, and two input bits b_1b_0 are mapped into symbol s_{n+1} according to the mapping table shown in Table 1.

Table 1 – DQPSK mapping

S_n	b_1b_0			
	00	**01**	**10**	**11**
+1	+1	+j	−j	−1
−1	−1	−j	+j	+1
+j	+j	−1	+1	−j
−j	−j	+1	−1	+j

As shown in Figure A.1 of Annex A, the four DQPSK symbols +1, +j, −1, −j correspond to the four points on the axis and the corresponding phases are 0, $\pi/2$, π, $3\pi/2$. The initial reference symbol

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s_0 is set to +1 and s_0 should not be output. The DQPSK mapping is initialized at the beginning of each frame.

6.4.3 QPSK

For the QPSK constellation, each group of bits b_1b_0 is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.2 of Annex A and Table B.1 of Annex B.

6.4.4 8QAM

For 8QAM modulation, each group of bits $b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.3 of Annex A and Table B.2 of Annex B.

6.4.5 16QAM

For 16QAM modulation, each group of bits $b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.4 of Annex A and Table B.3 of Annex B.

6.4.6 32QAM

For 32QAM modulation, each group of bits $b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.5 of Annex A and Table B.4 of Annex B.

6.4.7 64QAM

For 64QAM modulation, each group of bits $b_5b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.6 of Annex A and Table B.5 of Annex B.

6.4.8 128QAM

For 128QAM modulation, each group of bits $b_6b_5b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.7 of Annex A and Table B.6 of Annex B.

6.4.9 256QAM

For 256QAM modulation, each group of bits $b_7b_6b_5b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.8 of Annex A and Table B.7 of Annex B.

6.4.10 512QAM

For 512QAM modulation, each group of bits $b_8b_7b_6b_5b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.9 of Annex A and Table B.8 of Annex B.

6.4.11 1024QAM

For 1024QAM modulation, each group of bits $b_9b_8b_7b_6b_5b_4b_3b_2b_1b_0$ is mapped into a complex value (I+jQ) according to the constellation mapping shown in Figure A.10 of Annex A and Table B.9 of Annex B.

6.4.12 Power normalization factor

The power normalization factors of QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM and 1024QAM constellations are shown in Table 2.

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Table 2 – Constellation mapping normalization factor

Modulation mode	Power normalization factor
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	$\sqrt{682}$

6.5 OFDM modulation and cyclic prefix insertion

6.5.1 OFDM modulation

An OFDM symbol consists of 256 sub-carriers in one 16 MHz channel with sub-carrier spacing of 62.5 kHz. The sub-carrier numbering is shown in Figure 5. A set of sub-carriers at the zero frequency point and frequencies on both channel sides are defined as unavailable sub-carriers, while the others are defined as available sub-carriers. Constellation symbols are required to be modulated onto available sub-carriers only. With 210 available carriers used, the effective channel bandwidth is 13.125 MHz.

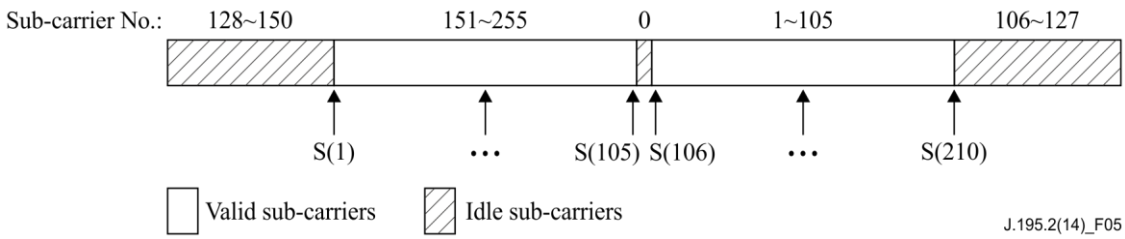

Figure 5 – OFDM sub-carrier numbering

The constellation symbols $s(k)$ are modulated to each available sub-carrier according to Figure 5. The corresponding relationship of frequency-domain signal $X_s(k)$ and constellation symbols $s(k)$ is shown in Equation (4).

$$X_s(k) = \begin{cases} s(k+105) & 1 \le k \le 105 \\ s(k-150) & 151 \le k \le 255 \\ 0 & k = 0 \text{ or } 106 \le k \le 150 \end{cases} \tag{4}$$

Frequency-domain signal $X_s(k)(0 \le k \le N_s - 1)$ is converted to time-domain signal $x_s(t)$ by computing an inverse Fast Fourier Transform (IFFT), which is mathematically defined by Equation (5) as follows.

$$x_s(t) = \frac{1}{\sqrt{N_s}} \sum_{k=0}^{N_s-1} X_s(k) e^{j2\pi k(\Delta f)_s (t - T_{CP})}, 0 \le t \le T_s \tag{5}$$

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Where,

N_s : the total number of OFDM sub-carriers, which equals 256

$(\Delta f)_s$: OFDM sub-carrier spacing, which equals 62.5 kHz

T_{CP} : the time duration of the cyclic prefix of OFDM, which equals 1 µs

T_s : the time duration of OFDM symbol, which equals 17 µs

6.5.2 Cyclic prefix insertion

In the time domain, an OFDM symbol consists of a CP and OFDM symbol body. The CP duration, T_{CP}, is required to be 1 µs. The OFDM symbol body duration, T_U, is 16 µs, hence the OFDM symbol duration T_s is 17 µs.

The cyclic prefix insertion is shown in Figure 6. For each OFDM symbol, the last 16 samples (the time duration of which is 1 µs) of the IFFT output are required to be copied to the head of the OFDM symbol, which forms the CP.

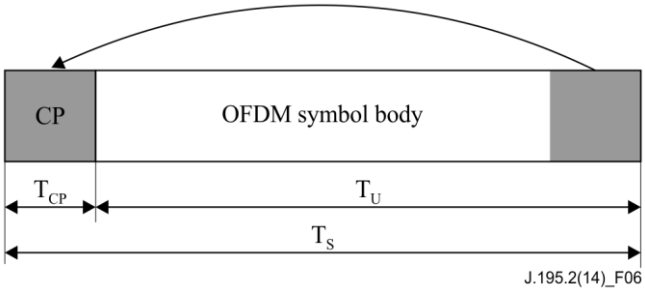

Figure 6 – Cyclic prefix insertion

7 Physical layer frame format

7.1 Overview

Four types of frames are defined in the HiNoC PHY layer: downlink probe (Pd) frame, uplink probe (Pu) frame, downlink data (Dd) frame, and uplink data (Du) frame. All of these PHY frames consist of a preamble and payload as shown in Figure 7.

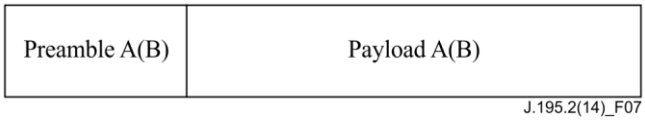

Figure 7 – PHY frame format

The four PHY frame formats are shown separately in Table 3.

Table 3 – PHY Frame Format

Frame type	Preamble	Payload
Pd frame	Preamble A	Payload A
Pu frame	Preamble B	Payload A
Dd frame	Preamble B	Payload B
Du frame	Preamble B	Payload B

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The transmission of the four PHY frames is required to follow the timing relationship as shown in Figure 8. Pd frames are required to be transmitted periodically, and the Pd cycle, which is the time interval between the start time of two adjacent Pd frames, is equal to 65536 µs. The time slot for a Pu frame is in the middle of a Pd cycle, and the time interval between the start time of an adjacent Pd frame and a Pu frame is 32768 µs. The time slots for Pu frames are required to be reserved, and the MAC protocol decides whether Pu frames are transmitted or not. Dd frames and Du frames are required to be transmitted in the other time slots according to the time slot allocation by the MAC protocol.

The HiNoC system is required to utilize periodically transmitted Pd frames to synchronize the network.

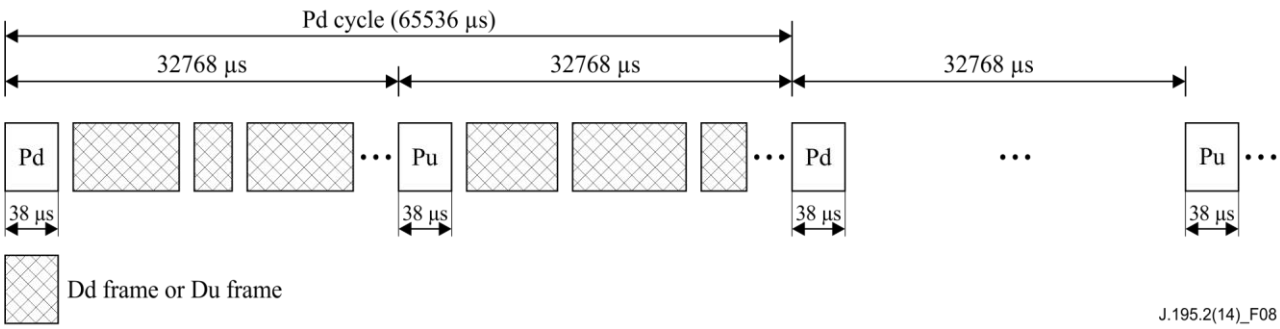

Figure 8 – Timing relationship of PHY frames

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 9.

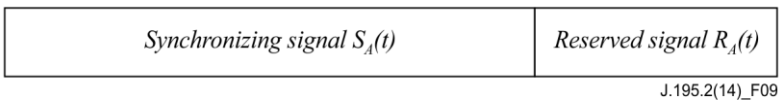

Figure 9 – Preamble A format

The synchronizing signal $S_A(t)$ is composed of two identical bandwidth limited pseudo-random signals. The duration T_A of $S_A(t)$ is 3.875 µs, and it is generated according to Equation (6). The duration of reserved signal $R_A(t)$ is 0.125 µs.

$$S_A(t) = \begin{cases} \dfrac{1}{\sqrt{N_A}} \sum_{k=0}^{N_A-1} X_A(k) e^{j2\pi k(\Delta f)_A t} & 0 \le t \le \dfrac{T_A}{2} \\ \dfrac{1}{\sqrt{N_A}} \sum_{k=0}^{N_A-1} X_A(k) e^{j2\pi k(\Delta f)_A (t-\frac{T_A}{2})} & \dfrac{T_A}{2} < t \le T_A \end{cases} \quad (6)$$

Where,

N_A: the number of sub-carriers of synchronizing signal in preamble A, which is equal to 31

$X_A(k)$: frequency domain synchronizing signal on the kth sub-carrier

$(\Delta f)_A$: sub-carrier spacing of synchronizing signal in preamble A, which is equal to 516.1290 kHz

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

$$X_A(k) = \begin{cases} e^{j(\frac{2\pi}{N_A} n_{k,A} + \frac{\pi}{4})} & 1 \le k \le 13 \text{ or } 18 \le k \le 30 \\ 0 & 0, \quad 14 \le k \le 17 \end{cases} \tag{7}$$

Where,

$n_{k,A}$: integers whose values are provided in Table 4.

Table 4 – Values of $n_{k,A}$

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

Reserved signal $R_A(t)$ includes two time-domain signal samples, R_{A1} and R_{A2}. The default values of R_{A1} and R_{A2} are $(1+j)/\sqrt{2}$.

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 10.

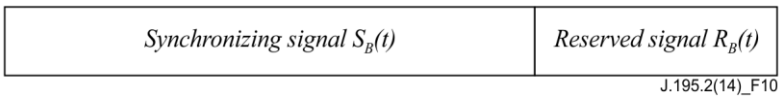

Figure 10 – Preamble B format

The synchronizing signal $S_B(t)$ is a bandwidth-limited pseudo-random signal with the duration T_B, which is equal to 3.9375 µs, and is generated according to Equation (8). The duration of reserved signal $R_B(t)$ is 0.0625 µs.

$$S_B(t) = \frac{1}{\sqrt{N_B}} \sum_{k=0}^{N_B-1} X_B(k) e^{j2\pi k(\Delta f)_B t}, 0 \le t \le T \tag{8}$$

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Where,

N_B: the number of sub-carriers of synchronizing signal in preamble B, which is equal to 63

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

$(\Delta f)_B$: sub-carrier spacing of synchronizing signal in preamble B, which is equal to 253.9683 kHz

Equation (9) expresses the frequency domain-synchronizing signal $X_B(k)$ on each sub-carrier in preamble B.

$$X_B(k) = \begin{cases} e^{j(\frac{2\pi}{N_B} n_{k,B} + \frac{\pi}{4})} & 1 \le k \le 26 \text{ or } 37 \le k \le 62 \\ 0 & 0, \quad 27 \le k \le 36 \end{cases} \tag{9}$$

Where,

$n_{k,B}$: are integers whose values are provided in Table 5.

Table 5 – Values of $n_{k,B}$

k	$n_{K,B}$	k	$n_{K,B}$
1	59	37	60
2	5	38	48
3	3	39	60
4	23	40	35
5	35	41	12
6	30	42	0
7	0	43	19
8	59	44	60
9	25	45	20
10	17	46	46
11	15	47	58
12	21	48	30
13	12	49	0
14	0	50	51
15	33	51	42
16	5	52	48
17	17	53	46
18	43	54	38
19	3	55	4
20	44	56	0
21	0	57	33
22	51	58	28
23	28	59	40
24	3	60	60

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