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Information technology — Telecommunications and information exchange between systems — Powerline communication (PLC) — High speed PLC medium access control (MAC) and physical layer (PHY) —

Part 1: General requirements

Technologies de l'information — Télécommunications et échange d'information entre systèmes — Courants porteurs en ligne (PLC) — Contrôle d'accès au support (MAC) et couche physique (PHY) par PLC à grande vitesse —

Partie 1: Exigences générales

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

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ISO/IEC 12139-1 was prepared by Korean Agency for Technology and Standards (as KS X 4600-1) and was adopted, under a special "fast-track procedure", by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, in parallel with its approval by the national bodies of ISO and IEC.

ISO/IEC 12139 consists of the following parts, under the general title *Information technology — Telecommunications and information exchange between systems — Powerline communication (PLC) — High speed PLC medium access control (MAC) and physical layer (PHY)*:

— *Part 1: General requirements*

Advanced MAC and PHY requirements will form the subject of a future Part 2.

Part 1 covers MAC and PHY technology for In-home/Access data networks via powerline communications (PLC), the system of which is operating below 30MHz. The coexistence schemes will be considered in developing Part 2, which will apply to data and high quality multimedia networks requiring advanced MAC and PHY technology. The used or forbidden band of this standard will be subject to national regulations.

Information technology — Telecommunications and information exchange between systems — Powerline communication (PLC) — High speed PLC medium access control (MAC) and physical layer (PHY) —

Part 1: General requirements

1 Scope

The scope of this standard is a physical and medium access control layer specification with respect to the connectivity for 'In-home' and 'Access' network high speed powerline communication stations.

This standard provides functional requirements and specification of the physical and medium access control layer for high speed powerline communication devices, and does not include specific implementation methods.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 8802-11:2005, Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications

ITU-T G.992.1: Asymmetric Digital Subscriber Line (ADSL) Transceivers

ITU-T G.994.1: Handshake Procedure for Digital Subscriber Line (DSL) Transceivers

IEEE Std 802.3:2000, Information technology — Local and metropolitan area networks — Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications

FCC Rules, 47 CFR (10-1-98 Edition), Part 15: Radio Frequency Devices

Federal Information Processing Standards: Publication 46-3 Data Encryption Standard (DES)

T1E1.4 Trial-Use Standard: Very-High-Bit-Rate Digital Subscriber Lines (VDSL) Metallic Interface Part 1: Functional Requirements and Common Specification

T1E1.4 Trial-Use Standard: Very-High-Bit-Rate Digital Subscriber Lines (VDSL) Metallic Interface Part 3: Technical Specification for a Multi-Carrier Modulation (MCM) Transceiver

3 Terms and Definitions

3.1 Ad-hoc network
A network consisting of only stations within the boundary of communication through powerlines
The ad-hoc network is typically generated in a voluntary manner.

3.2 Backbone
A facility or a collection of facilities for connecting LAN to WAN

3.3 Backoff Period
A period during which stations contend for the medium access

3.4 Backoff Procedure
A procedure to disperse the times at which stations with queued frames attempt transmission

3.5 Backoff Value
The number of time slots that a station shall wait for initiating a transaction

3.6 Bit
The basic unit of the binary system
In binary system, every number is expressed in '0' or '1', each of which is a bit.

3.7 Byte
A unit comprised of a set of bits, the basic unit of data representing '0' or '1'
8 bits constitute 1 byte.

3.8 Carrier Sense
A station's standard for determining whether the medium is currently occupied

3.9 Cell
A synonym for logical network

3.10 Cell Bridge (CB)
A station connecting two different cells
Cell Bridge provides the repeater functionality.

3.11 Ciphertext
Encrypted data

3.12 Cleartext
Unencrypted data

3.13 Collision
An event of two or more frames colliding in the medium, caused by simultaneous transmission of the frames

3.14 Contention Window
A slotted range in which each station can select a time slot to initiate a transaction

3.15 Delimiter
A combination of preamble and control frame

3.16 Differential Modulation
A modulation that encodes information by the 'phase difference' between two consecutive symbols

3.17 Discrete Multi-Tone (DMT)
A modulation technique in which a channel with a certain bandwidth is divided into subchannels (or tones) of narrower bandwidths
Each subchannel is modulated by a different subcarrier.

3.18 Flip-flop
A circuit that has two stable states
It maintains its state until the input decides on one stable state and another input approves of it by deciding on the other state.
It can memorize a bit by corresponding two stable states to '1' and '0'.

3.19 Frame
A synonym for PSDU

3.20 Home Networking
Sharing digital data and constructing an environment with availability of broadband communication by forming a network between information devices at home

3.21 InterFrame Space
A time interval between frames on the medium

3.22 Link Timer
A value that increases at each symbol after the link between two stations is established

3.23 Logical Network
A network classified by Group Identifier (GID)
A single physical network can be divided into more than one logical network.
Logical Network is a synonym for cell.

3.24 MAC Management Information (MMI)
Management information for MAC generated by MAC Management Entity (MME)

3.25 MAC Protocol Data Unit (MPDU)
A frame unit that consists of frame header and frame body
Frame body contains either MSDU(s) or MMI(s), each in FBB format.

3.26 MAC Service Data Unit (MSDU)
A frame unit used in the MAC layer
It contains data from link layer.

3.27 Medium BUSY
A medium state indicating that a station has occupied the medium
To determine this state, Physical Carrier Sense (PCS) and Virtual Carrier Sense (VCS) are used.

3.28 Medium CONTENTION
A medium state indicating that stations are contending for the medium access
It starts after Short Contention InterFrame Space (SCIFS) or Long Contention InterFrame Space (LCIFS) from the end of the last previous transaction.

3.29 Medium IDLE
A medium state indicating that no station has occupied the medium
It starts after SCIFS or LCIFS plus maximum Contention Window Size (CWS) from the end of the last previous transaction.

3.30 MAC Interface (MI)
The logical interface between the upper link layer and the MAC layer of the station

3.31 Network
A collection of interconnected elements that provides connection services to users

3.32 PHY Interface (PI)
The physical interface between the station and powerline

3.33 Privacy
The service to prevent the content of messages from being read by others beside the intended recipients

3.34 Proxy Station
The representative of all stations within a logical network
It renders partial Automatic Repeat reQuest (ARQ) possible.

3.35 PHY Service Data Unit (PSDU)
A frame unit used in physical layer

3.36 Reassembly
The reverse process of segmentation

3.37 Repeater
A station that relays frames from one station to another station for which direct communication is impeded

3.38 Routing Table
A table that maps MAC addresses to Station Identifier (SID) and Tone Map Index (TMI)

3.39 Scrambler
A circuit that converts the input data into random signal series in order to repress the single frequency component by repeating regular data patterns among the successive input data

3.40 Segmentation
A process of partitioning a service block into multiple segments

3.41 Serial Interface
The interface in which all the data are transmitted through the same communication line, bit after bit

3.42 Service Block
A synonym for Frame Body Block (FBB)

3.43 Station
A synonym for PLC Transceiver Unit (PTU)

3.44 Sub-frame
A group of symbols existing in a frame
Sub-frame includes the control frame and the data frame.

3.45 Symbol
A bit or a defined sequence of bits

3.46 Symbol Block
A group of symbols processed as one unit in physical layer
Its length is always 16 symbols.

3.47 Time Slot
A time unit used in backoff procedure

3.48 Transaction
A minimal set of interactively transmitted/received frames between two stations

3.49 Transaction Combo
A combination of consecutive transactions
Except for the first transaction, all transactions in a transaction combo do not contend for the medium. The interframe space between two contiguous transactions in a transaction combo is always Short Response InterFrame Space (SRIFS).

3.50 Transmission Mode
Frame-based transmission scheme
Transmission mode is classified into Diversity (DV), Extended DV (EDV), and NORMAL modes.

3.51 VLAN Tag
The field within the layer-2 frame header defined in 802.1Q

4 Acronyms and Abbreviations

ACK	ACKnowledgement
AES	Advanced Encryption Standard
AG	AGC Gain
AGC	Automatic Gain Control
ARQ	Automatic Repeat reQuest
A/V	Audio/Video
BF	Broadcast Flag
BPS	Bits Per Symbol
BPSK	Binary Phase Shift Keying
CB	Cell Bridge
CE	Channel Estimation
CF	Control Frame
CFCS	Control Frame Check Sequence
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
CRD	Collision Recovery Duration
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CTS	Clear To Send
CWS	Contention Window Size
D8PSK	Differential 8-ary Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
DES	Data Encryption Standard
DF	Data Frame
DFCS	Data Frame Check Sequence

DMT	Discrete Multi-Tone
DQPSK	Differential Quadrature Phase Shift Keying
DSID	Destination Station ID
DT	Delimiter Type
DV	DiVersity
DVF	DiVersity Flag
EDV	Extended DiVersity
FBB	Frame Body Block
FBBL	Frame Body Block Length
FBBP	Frame Body Block Payload
FBBPAD	Frame Body Block PADding
FBBSSID	Frame Body Block Source Station ID
FBBT	Frame Body Block Type
FBBTTL	Frame Body Block Time To Live
FBBV	Frame Body Block Version
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FPV	Frame Protocol Version
GF	Galois Field
GID	Group ID
ID	IDentifier
IFFT	Inverse Fast Fourier Transform
IFS	InterFrame Space
ITR	Inverse TRaining
LCIFS	Long Contention InterFrame Space
LRIFS	Long Response InterFrame Space
LSB	Least Significant Bit
LSF	Last Segment Flag
MAC	Medium Access Control
MII	Media Independent Interface
MME	MAC Management Entity
MMI	MAC Management Information
MPDU	MAC Protocol Data Unit
MSB	Most Significant Bit
MSDU	MAC Service Data Unit
MTMI	My Tone Map Index

N/A	Not Applicable
NFBB	Number of Frame Body Block
NSB	Number of Symbol Block
NMS	Network Management System
PCS	Physical Carrier Sense
PHY	PHYsical (layer)
PLC	PowerLine Communication
PRS	Pseudo-Random Sequence
PSDU	PHY Service Data Unit
PSK	Phase Shift Keying
PTMI	Partner's Tone Map Index
PUNCI	PUNCturing Indicator
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RET	REsponse Type
RF	Response Flag
RS	Reed-Solomon
RT	Routing Table
RTS	Request To Send
SB	Service Block
SC	Segment Count
SCIFS	Short Contention InterFrame Space
SEG	SEGmentation
SID	Station ID
SN	Sequence Number
SNR	Signal-to-Noise Ratio
SRB	Slot Reservation Bit
SRIFS	Short Response InterFrame Space
SSID	Source Station ID
STA	STAtion
TM	Tone Map
TMI	Tone Map Index
TR	TRaining
TS	Training Sequence
TSD	Time Slot Duration
TSF	Training Sequence Flag

TSR	Training Sequence Request
UART	Universal Asynchronous Receiver Transmitter
VC	Version Control
VCS	Virtual Carrier Sense
VF	Variant Field
VLAN	Virtual Local Area Network

5 Reference Models

High speed PLC refers to interactive communication between more than two PLC devices in in-home or access network by using low and medium voltage powerline. Each PLC device can communicate with other PLC devices with the same group identifier as itself, and can communicate in various manners by forming a single logical network with them.

5.1 PLC Reference Model

Reference model of a high speed PLC system is constituted as in Fig. 1.

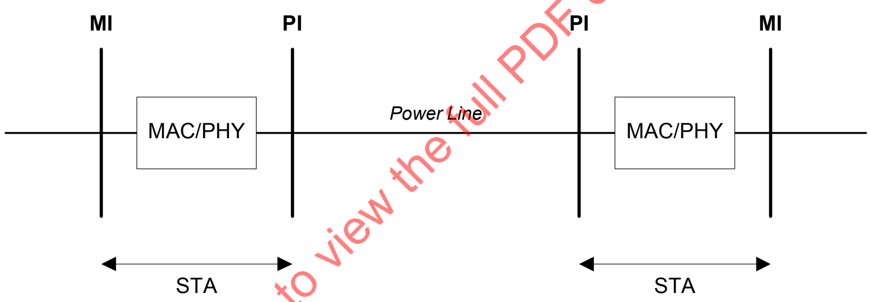

Fig. 1 - PLC Reference Model

PHY Interface (PI) is the physical interface between STA and the powerline. MAC Interface (MI) is the logical interface defining the relationship between the upper link layer and MAC layer of STA. The device including MAC and PHY, which are defined in this standard, is referred to as STA.

5.2 Interface Protocol Reference Model

Interface protocol reference model, illustrated in Fig. 2, is another expression of reference model and emphasizing the layer structure. The "upper layer" in this standard refers to the link layer above MI.

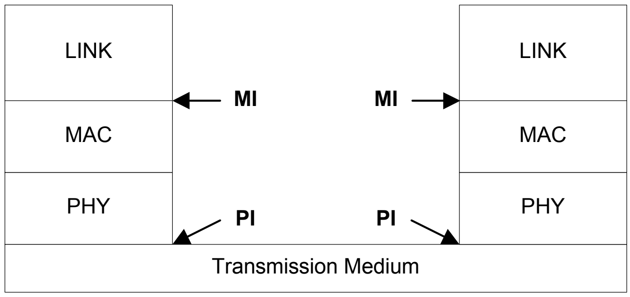

Fig. 2 - PLC Protocol Reference Model

5.3 PLC Network Topology

5.3.1 Home Networking

Fig. 3 illustrates the network topology in case of STA being applied to in-home for home networking only. STAs of each home shall form a cell (logical network) through GID. Each cell co-exists on the same physical network, but they shall be logically separated. Privacy shall be guaranteed by encoding data using different encryption keys. STAs of each cell render ad-hoc network and access network services possible through one-to-many communication.

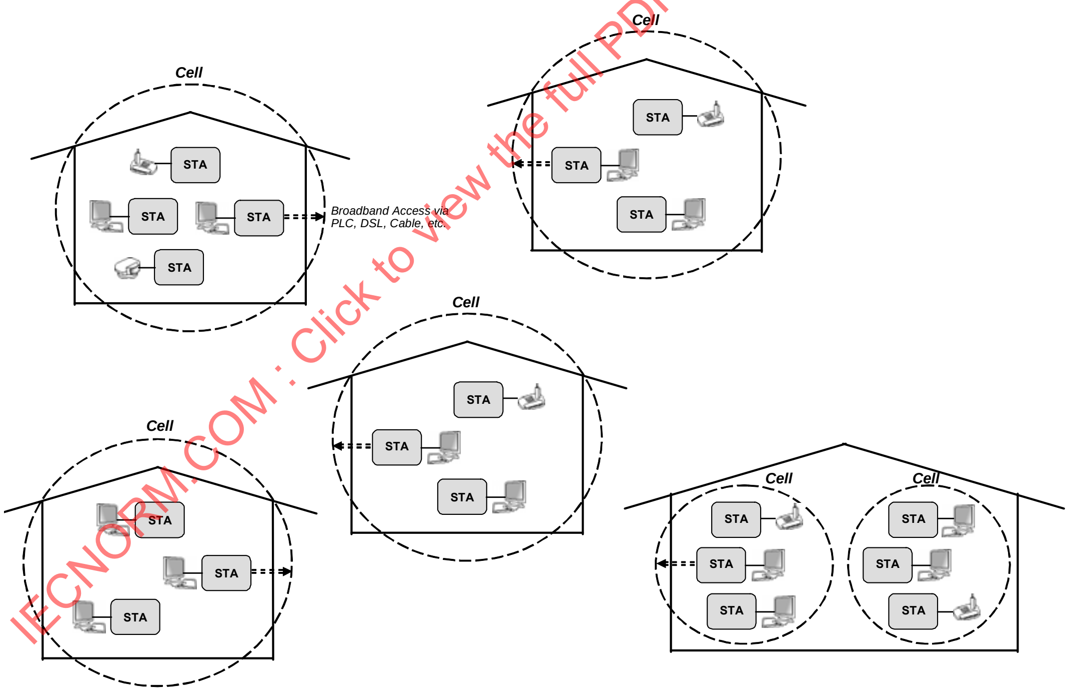

Fig. 3 - PLC Network Topology for Home Networking

5.3.2 Access Network

Fig. 4 illustrates the network topology in case of STA being applied to the access network. The entire PLC network is roughly divided into in-home network and access network.

STA functioning as the connection point with the backbone network in the access network is located on neighborhood transformer and thereby renders it possible for STAs existing in the same physical network to form a high speed access network.

Cell Bridge (CB), which is STA connecting two separate cells (two logical networks), makes it possible for the STAs at home to access a high speed access network. CB also functions as the repeater extending the communication coverage.

STAs composing in-home network can access a high speed access network through home networking and CB.

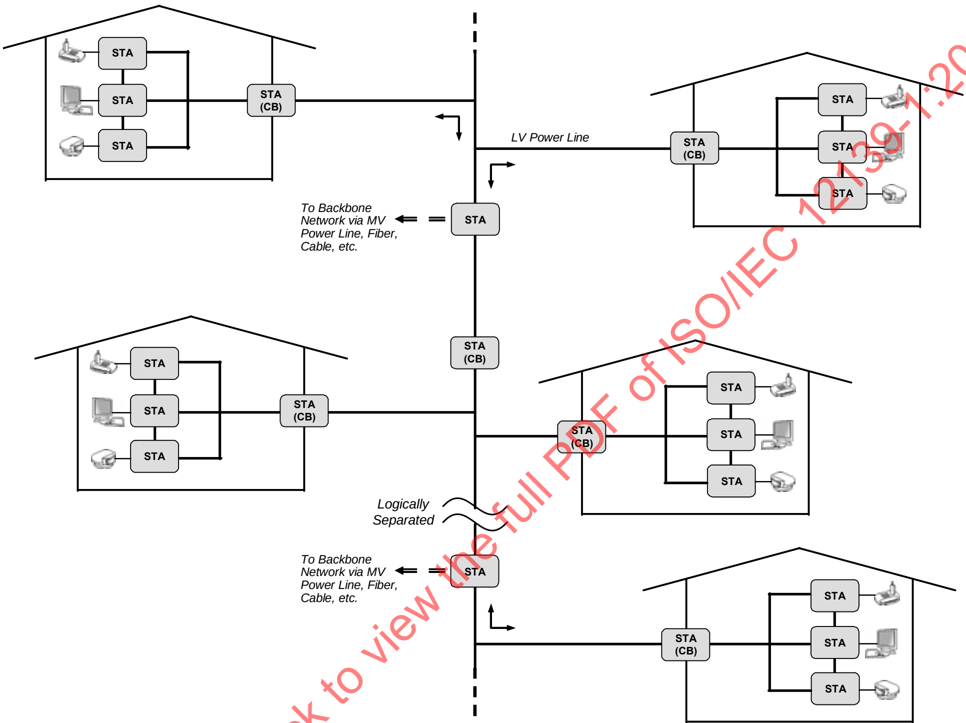

Fig. 4 - PLC Network Topology for Access Network

6 PHY Specification

The PHY specification presented in this chapter is for data network using high speed PLC.

6.1 Overview of PHY

The modulation-demodulation adopts DMT method. Table 1 shows the basic specification of PHY. Fig. 5 illustrates a DMT symbol to which cyclic prefix and pulse shaping are applied.

Table 1 - Specification of PHY

Item	Value
Bandwidth used	2.15 ~ 23.15 MHz
Forbidden band	*
Tone space (= 25MHz / 256)	97.65625 kHz
Sampling frequency	50 MHz
IFFT interval [Tfft]	512 sample
Cyclic prefix interval [Tcp]	128 sample

Rolloff interval [ßT]	16 sample
Symbol interval [Ts = Tfft + Tcp - ßT]	624 sample
Symbol rate	80.1282 kHz
Symbol period without CP	10.24 µs
Symbol period with CP	12.48 µs
Tone (or sub-channel) modulation	DBPSK, DQPSK, D8PSK
* This shall be subject to national regulations.	

DMT system presented in this standard shall adopt a bandwidth of 2.15~23.15MHz and each tone has a bandwidth of 97.65625kHZ (theoretical) with the exception of the bandwidth designated as the guard band in accordance with each national regulation. The cyclic prefix of 128 samples shall be used in order to remove interference between DMT symbols in powerline channels. In addition, in order to reduce the probability of a packet error caused by the noise generated in the powerline channel, Forward Error Correction (FEC) comprising the convolutional codes and Reed-Solomon codes shall be used. For the modulation method used in each tone, DBPSK, DQPSK and D8PSK shall be adopted according to the channel condition.

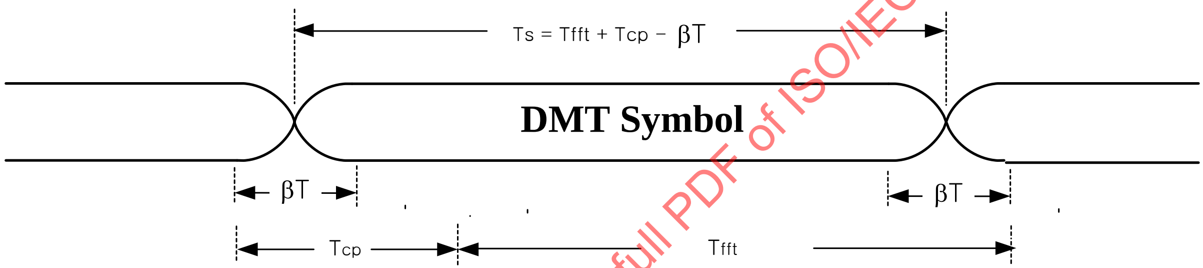

Fig. 5 - DMT Symbol

6.2 PSDU Format

The structure of PHY Service Data Unit (PSDU) used in this standard is shown in Fig. 6 and comprises delimiter and Data Frame (DF). The delimiter is composed of preamble and Control Frame (CF). DF may or may not exist according to the characteristics of the frame. The frame that has no DF is referred to as short PSDU and the frame that has DF is referred to as long PSDU. CF and DF are sub-frames existing in PSDU.

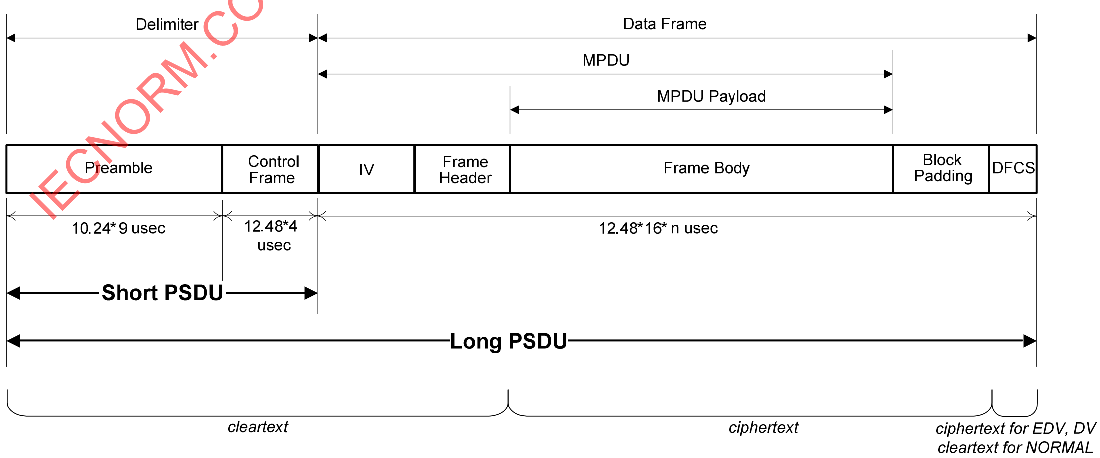

Fig. 6 - PSDU Format

6.2.1 Preamble

Preamble shall consist of 7 TRs followed by 2 ITRs without cyclic prefix. Using this, the reception end performs Physcial Carrier Sense (PCS), Automatic Gain Control (AGC) and synchronization. With the 256-tone of TR, the signals modulated into PSK shall be transmitted. The phase of each tone shall be determined as follows.

$$
\begin{aligned}
&PRS[n] = 1 && \text{for } 0 \le n \le 9 \\
&PRS[n] = PRS[n-10] \oplus PRS[n-8] \oplus PRS[n-6] && \text{for } 10 \le n \le 1022 \\
&\qquad \oplus PRS[n-4] \oplus PRS[n-2] \oplus PRS[n-1] && \\
&PRS[n] = 1 && \text{for } n = 1023
\end{aligned}
$$

Generated 1024 Pseudo-Random Sequence (PRS)s shall be grouped by 4 bits and mapped into 1 tone. The phase of each tone shall have a value among 0, 1*(π/8), 2*(π/8),....15*(π/8) according to the 4-bit value of the tone. Table 2 shows the mapping relationship of constellation point with generated PRS and Table 3 shows the phase value of each tone.

Table 2 - Mapping Relationship of bit PRS and Constellation Point

[PRS(4n) PRS(4n+1) PRS(4n+2) PRS(4n+3)]	Tone Phase	[PRS(4n) PRS(4n+1) PRS(4n+2) PRS(4n+3)]	Tone Phase
0000	0	1000	8x(π/8)
0001	1x(π/8)	1001	9x(π/8)
0010	2x(π/8)	1010	10x(π/8)
0011	3x(π/8)	1011	11x(π/8)
0100	4x(π/8)	1100	12x(π/8)
0101	5x(π/8)	1101	13x(π/8)
0110	6x(π/8)	1110	14x(π/8)
0111	7x(π/8)	1111	15x(π/8)

Table 3 - Standard Phase Value of Each Tone

Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)	Tone No.	Phase Value (x π/8)
0	15	1	15	2	13	3	8	4	11	5	2	6	9	7	1
8	14	9	6	10	8	11	10	12	3	13	4	14	3	15	8
16	7	17	6	18	7	19	1	20	9	21	8	22	1	23	2
24	9	25	12	26	13	27	12	28	7	29	12	30	7	31	1
32	4	33	11	34	11	35	13	36	15	37	8	38	8	39	11
40	4	41	0	42	12	43	9	44	13	45	10	46	8	47	8
48	13	49	13	50	13	51	11	52	2	53	15	54	8	55	3
56	1	57	3	58	8	59	1	60	15	61	10	62	6	63	2
64	10	65	3	66	9	67	0	68	2	69	8	70	0	71	3
72	4	73	14	74	11	75	13	76	9	77	1	78	5	79	12
80	15	81	2	82	14	83	2	84	4	85	4	86	13	87	4
88	9	89	5	90	4	91	1	92	11	93	13	94	2	95	11
96	2	97	4	98	2	99	4	100	9	101	14	102	14	103	6
104	3	105	0	106	4	107	12	108	14	109	14	110	0	111	10
112	13	113	3	114	7	115	12	116	12	117	11	118	3	119	3
120	6	121	11	122	8	123	4	124	2	125	9	126	10	127	4
128	1	129	0	130	7	131	5	132	3	133	15	134	2	135	5

136	8	137	3	138	12	139	0	140	2	141	14	142	9	143	14
144	3	145	5	146	9	147	15	148	2	149	8	150	11	151	9
152	3	153	6	154	6	155	11	156	14	157	13	158	15	159	14
160	1	161	6	162	3	163	11	164	14	165	11	166	6	167	3
168	6	169	13	170	1	171	9	172	5	173	2	174	8	175	6
176	10	177	9	178	9	179	0	180	15	181	11	182	10	183	12
184	2	185	10	186	14	187	10	188	10	189	13	190	14	191	4
192	6	193	3	194	13	195	7	196	6	197	1	198	8	199	4
200	15	201	10	202	0	203	11	204	7	205	4	206	2	207	2
208	0	209	3	210	9	211	13	212	1	213	2	214	15	215	5
216	0	217	11	218	12	219	14	220	5	221	10	222	13	223	5
224	14	225	1	226	11	227	0	228	1	229	1	230	13	231	2
232	6	233	1	234	14	235	13	236	2	237	13	238	11	239	9
240	5	241	15	242	11	243	12	244	5	245	15	246	13	247	5
248	8	249	8	250	6	251	7	252	10	253	3	254	15	255	9

The forbidden band designated in each national regulation shall not be used. The corresponding tone of the forbidden band refers to Table 6.

ITR shall use the signal of which is inverted 180 degrees from that of TR. The first 16-sample and last 16-sample of the preamble shall be shaped by using the first 16-sample and next 16-sample of 32-tap window function respectively. The 32-tap window function shall be used as follows.

$$w[n] = \sin^2\left(\frac{\pi}{2}(0.5 + (n-8)/16)\right) \qquad \text{for } 0 \le n \le 15$$

$$w[n] = w[31-n] \qquad \text{for } 16 \le n \le 31$$

6.2.2 Control Frame (CF)

The control frame comprises 4 DMT symbols with a cyclic prefix and each DMT symbol shall carry out differential BPSK encoding on the basis of standard phase value of each tone in Table 3. Each DMT symbol shall carry out shaping by using the 32-tap window function (refer to 6.2.1).

The control frame shall use 124 tones (refer to 6.3.5) and the tone numbers are shown in Table 4.

Table 4 - Tone Numbers for Control Frame

Tone Sequence	Tone Number									
1st ~ 10th	47	48	49	50	51	52	53	54	55	56
11th ~ 20th	57	58	59	60	61	62	63	64	78	79
21th ~ 30th	80	81	82	83	95	96	97	98	99	107
31th ~ 40th	108	109	110	111	112	113	114	115	116	117
41th ~ 50th	118	119	120	121	122	123	124	125	126	127
51th ~ 60th	128	129	130	131	132	133	150	151	152	153
61th ~ 70th	154	155	156	157	158	159	160	161	162	163
71th ~ 80th	164	165	166	167	168	169	170	171	172	173
81th ~ 90th	174	175	176	177	178	179	180	189	190	191
91th ~ 100th	192	193	194	195	196	197	198	199	200	201
101th ~ 110th	202	203	204	205	206	207	208	209	210	211

111th ~ 120th	212	223	224	225	226	227	228	229	230	231
121th ~ 124th	232	233	234	235	-	-	-	-	-	-

The tones other than the 124 tones used in the control frame shall be transmitted after generating the same value as the standard phase value in Table 3 or a 180 degree inverted phase value.

6.2.3 Data Frame (DF)

A DMT symbol block is composed of 16 DMT symbols with a cyclic prefix, and up to 15 DMT symbol blocks can be transmitted within one data frame. For each DMT symbol within a data frame, differential PSK encoding shall be carried out in reference to the previous DMT symbol, and for each tone, DBPSK, DQPSK and D8PSK shall be applied according to the channel condition. For each DMT symbol, shaping shall be carried out using the 32-tap window function (refer to 6.2.1).

6.3 DMT Transmitter

Fig. 7 illustrates the block diagram of a DMT transmitter.

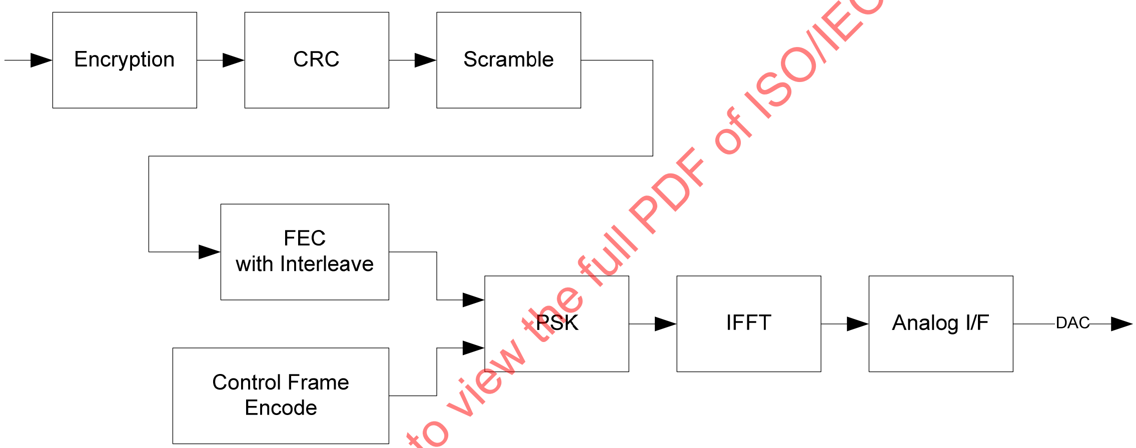

Fig. 7 - Block Diagram of a DMT Transmitter

6.3.1 Encryption

56-bit DES is used for encryption. Refer to Federal Information Processing Standards Publication 46-3 "Data Encryption Standard" for the specific implementation.

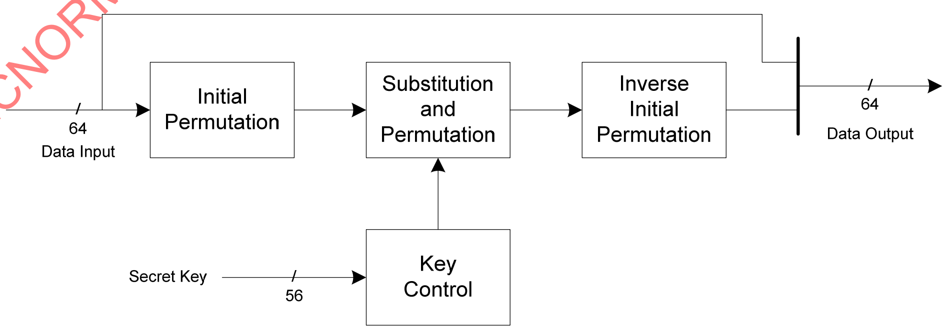

Fig. 8 - 56-Bit DES Block Diagram

128-bit AES is an optional encryption.

6.3.2 Cyclic Redundancy Check (CRC)

Data frame CRC encoder generates a 16-bit CRC of the frame header, the frame body, and the block padding. It is generated through the following formula.

$$CRC_1(x) = x^k * (x^{15} + x^{14} + x^{13} + \ldots + x^2 + x + 1) \bmod G(x)$$
$$CRC_2(x) = M(x) * x^{16} \bmod G(x)$$

CRC is obtained by taking the one's complement of the modulo-2 sum of CRC1 and CRC2. Every CRC register shall be first set to '1'.

The message polynomial is:

$$M(x) = m_{k-1}x^{k-1} + m_{k-2}x^{k-2} + \ldots + m_1 x + m_0$$

The generator polynomial is:

$$G(x) = x^{16} + x^{12} + x^5 + 1$$

The examination polynomial is:

$$DFCS(x) = c_{15}x^{15} + c_{14}x^{14} + c_{13}x^{13} + c_{12}x^{12} + \ldots + c_3 x^3 + c_2 x^2 + c_1 x + c_0$$

Every message shall be processed with MSB first. The total number of messages for CRC is expressed as k in the message polynomial. Here, m_{k-1} is MSB of the first byte of the entire message and m_0 is LSB of the last byte.

CRC shall be generated and transmitted at every frame. CRC calculation shall start after CRC is initialized at the first symbol of each frame. At the last symbol, the result shall be attached at the end and transmitted.

6.3.3 Scrambler

Of data bits, MSB shall be transmitted first and LSB later. The frame synchronous scrambler shall use the following generator polynomial S(x).

$$S(x) = x^7 + x^4 + 1$$

When the transmission end carries out scrambling or when the reception end carries out inverse scrambling, the same scrambler shall be used. The scrambler shall be initialized as binary number '1' for each symbol block unit.

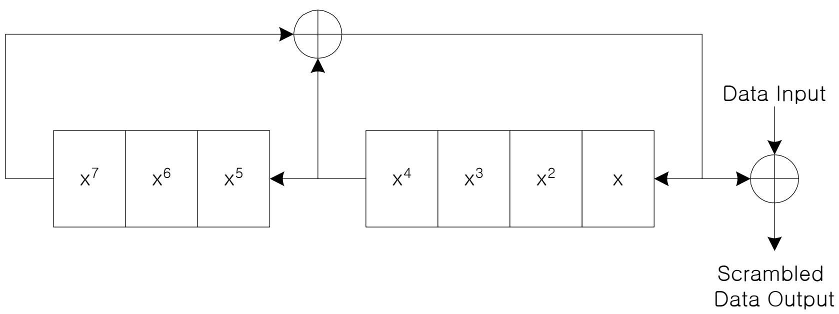

Fig. 9 - Scrambler

6.3.4 FEC and Interleaver

FEC and interleaver comprise Reed-Solomon coder, convolutional coder, puncturing and interleaver.

6.3.4.1 Reed-Solomon Encoding

The finite field of the Reed-Solomon codes shall be GF(256) and the generator polynomial shall be as follows. t of the following polynomial is the value expressing the ability to correct errors.

Code generator polynomial: $g(x) = \prod_{i=1}^{n} (x + \alpha^i)$, where $n = 2 * t$

Field generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$ (435octal)

The actually used Reed-Solomon codes shall be the shortened codes of the original (255, 255-2*t) codes.

For more stable communication in a powerline channel environment with a lot of impulse noises, t=8 shall be used in NORMAL mode transmission.

6.3.4.2 Convolutional Encoding and Puncturing

The convolutional coder shall use 1/2 code rate and 7 constraint length (K). Each tap connection shall be A=0b1111001 and B=0b1011011 as shown in Fig. 10.

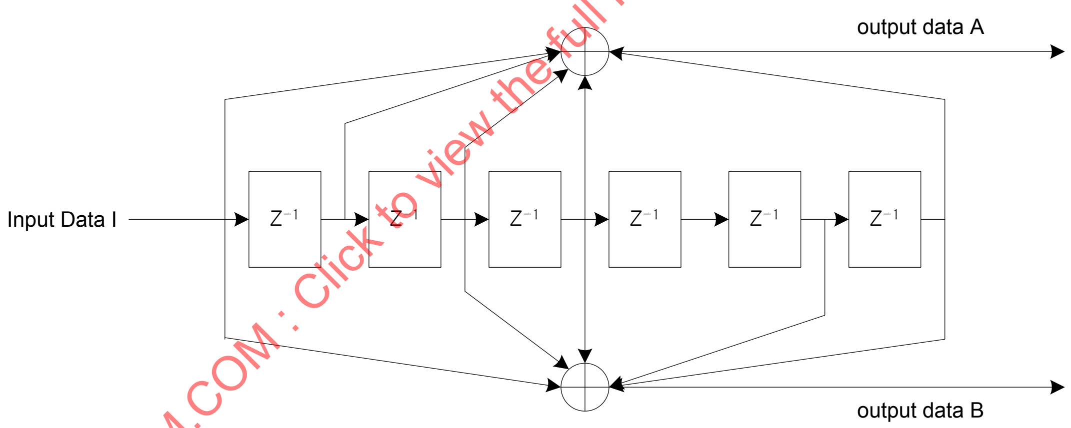

Fig. 10 - Convolutional Coder (code rate = 1/2, K=7)

The processing shall be carried out by each symbol block unit and if a symbol block is encoded, 6 tail bits (tail bit: all binary number ‘0’) shall be added and then the symbol block is transmitted. During this process, all the flip-flops within the coder shall be initialized as binary number ‘0’.

The code rate of a convolutional coder is 1/2 and puncturing is used to adjust it to 3/4. With respect to puncturing, refer to Fig. 11.

Source Data :

I0	I1	I2	I3	I4	I5	I6	I7	I8

Encoded Data :

A0	A1	A2	A3	A4	A5	A6	A7	A8
B0	B1	B2	B3	B4	B5	B6	B7	B8

: Stolen Bit (shaded: A1, A4, A7, B2, B5, B8)

Bit Stolen Data :
(send/receive data)

A0	B0	B1	A2	A3	B3	B4	A5	A6	B6	B7	A8

Fig. 11 - Puncturing Codes (code rate = 3/4)

6.3.4.3 Interleaver

Interleaving takes place in the form of a block interleaver, and shall vary as follows according to the size of the symbol block and the number of bits per symbol. If the size of the symbol block is N_{SB}(=16) and the number of bits per symbol is N_{BPS}, interleaver bit output D_{OUT}(k) shall have the following relationship with interleaver bit input D_{IN}(k). Interleaver is shown in Fig. 12. X(k) is the data before offset parameter N_O is applied, and the value N_O is 8.

$$X(k) = D_{IN}(N_C \times k - (N_C \times N_R - 1) \times floor(\frac{k}{N_R}))$$

$$D_{OUT}(k) = X(\mathrm{mod}((k + N_O \times floor(\frac{k}{N_R})), N_R) + N_R \times floor(\frac{k}{N_R}))$$

where,

$k = 0,1,2,\ldots, N_{SB} \times N_{BPS} - 1$

$N_C = N_{SB}$ (when code rate is 1/2), or $2 \times N_{SB}$ (when code rate is 3/4)

$N_R = N_{BPS}$ (when code rate is 1/2), or $N_{BPS}/2$ (when code rate is 3/4)

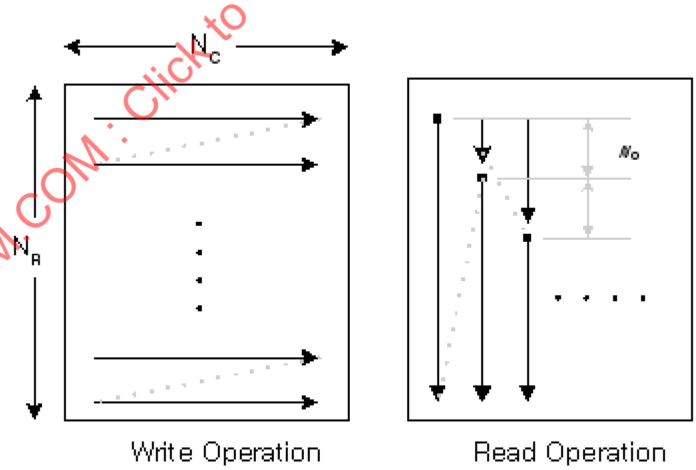

Fig. 12 - Reading/Writing Operation of Data Interleaver

6.3.5 Control Frame Encoding

Encoding of the control frame uses Reed-Solomon code and diversity mapping, and is constituted as Fig. 13.

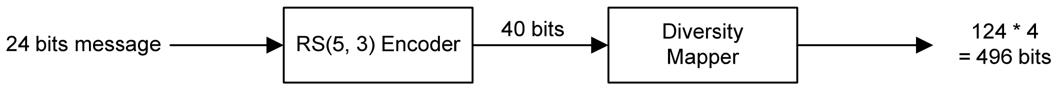

Fig. 13 - Control Frame Encoder

6.3.5.1 Reed-Solomon Code

The Reed-Solomon code is used as FEC for control frames.

The finite field of the Reed-Solomon code is GF(256), and the following generator polynomial is used.

Code generator polynomial: $g(x) = \prod_{i=1}^{n} (x + \alpha^{i})$, where $n = 2$

Field generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$ (435octal)

The Reed-Solomon code uses RS(5,3) code, i.e. it generates 5 bytes (40 bits) of code word to transmit 3 bytes (24 bits) of message.

6.3.5.2 Diversity Mapping

The method for diversity mapping of the control frame is as follows.

The 5 bytes (40 bits) of code word x(k) generated by Reed-Solomon code RS(5,3) can be expressed as a bit array like the following formula.

$$x(k) = (x_0, x_1, x_2, \ldots, x_{38}, x_{39})$$

If x(k) is transmitted via 4-symbol control frame, the number of bits per symbol is 10. The number of tones used for each symbol would be 124 as shown in Table 4. In these circumstances, $y_j(i)$ (the information loaded onto each symbol) is expressed as follows.

$$y_j(i) = x((j-1)*10 + (i-1)\bmod 10)$$

$$\text{where, } j = 1,2,3,4$$

$$i = 1,2,3,\ldots,122,123,124$$

In this formula, j represents the symbol number and i the order of tones used for each symbol.

6.3.6 Phase Shift Keying (PSK)

PSK performs signal constellation mapping to DBPSK, DQPSK, and D8PSK. The interface comprises bytes as the unit, and the bits of each byte are mapped to each tone for the allocated amount - the mapping shall start from LSB. Fig. 14 illustrates the signal constellation of each modulation method and Table 5 shows the encoded values.

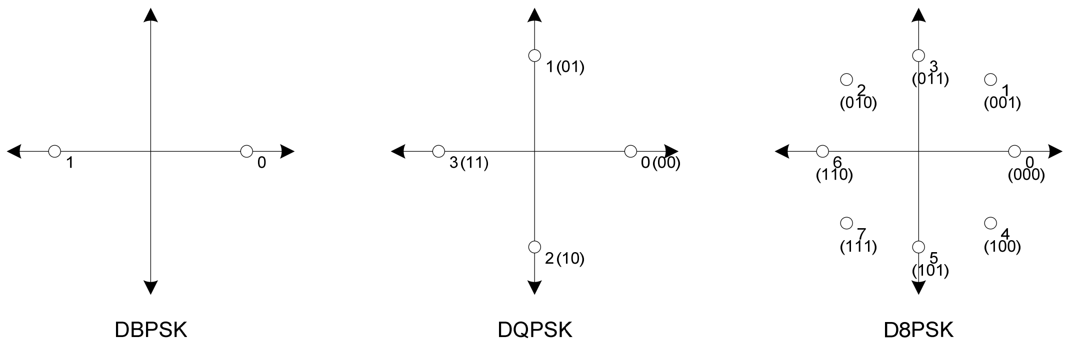

Fig. 14 - Signal Constellation of DBPSK, DQPSK and D8PSK

Table 5 - Encoded Values of Each Encoding Method

Modulation Method	Input Bit	Output Value
DBPSK	0	θ
	1	θ + π
DQPSK	00	θ
	01	θ + π/2
	11	θ + π
	10	θ + 3π/2
D8PSK	000	θ
	001	θ + π/4
	011	θ + π/2
	010	θ + 3π/4
	110	θ + π
	111	θ + 5π/4
	101	θ + 3π/2
	100	θ + 7π/4

※ Θ: the phase value transmitted in the same tone of the previous symbol

6.3.7 Inverse Fast Fourier Transform (IFFT)

IFFT is the block transforming the data of 256 tones, which has been mapped into signal constellation by PSK, into the time domain data of 512 samples. The reception end transforms the time domain data of 512 samples into the frequency domain data of 256 tones by using FFT.

Fig. 15 illustrates the relationship between input and output with respect to IFFT, and Table 6 shows the frequency value of each tone used in IFFT.

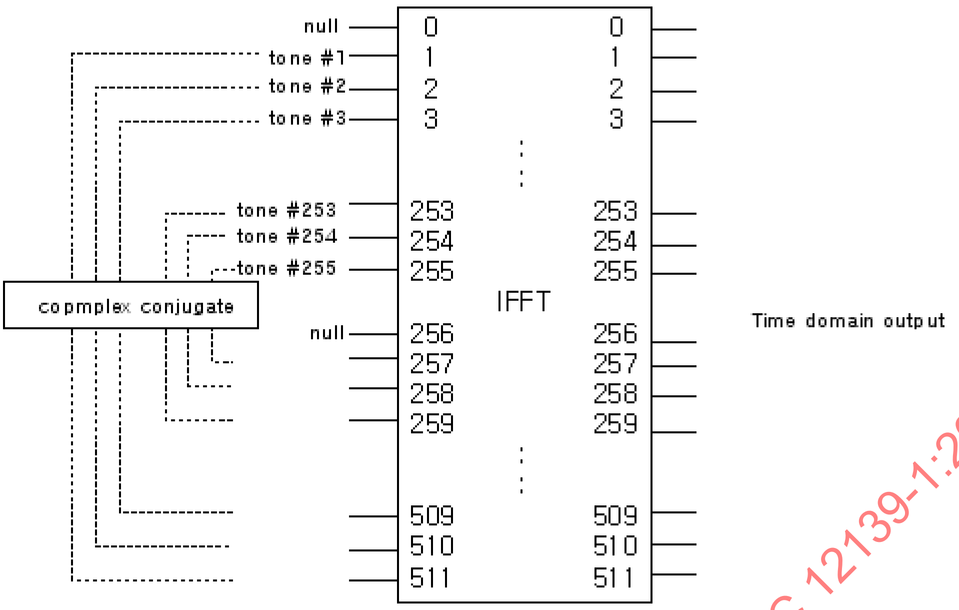

Fig. 15 - Input and Output of IFFT

Table 6 - Frequency Value of Each Tone

Tone No.	Freq. (MHz)	Tone No.	Freq. (MHz)	Tone No.	Freq. (MHz)	Tone No.	Freq. (MHz)	Tone No.	Freq. (MHz)	Tone No.	Freq. (MHz)
0	0	1	0.0977	2	0.1953	3	0.2930	4	0.3906	5	0.4883
6	0.5859	7	0.6836	8	0.7813	9	0.8789	10	0.9766	11	1.0742
12	1.1719	13	1.2695	14	1.3672	15	1.4648	16	1.5625	17	1.6602
18	1.7578	19	1.8555	20	1.9531	21	2.0508	22	2.1484	23	2.2461
24	2.3438	25	2.4414	26	2.5391	27	2.6367	28	2.7344	29	2.8320
30	2.9297	31	3.0273	32	3.1250	33	3.2227	34	3.3203	35	3.4180
36	3.5156	37	3.6133	38	3.7109	39	3.8086	40	3.9063	41	4.0039
42	4.1016	43	4.1992	44	4.2969	45	4.3945	46	4.4922	47	4.5898
48	4.6875	49	4.7852	50	4.8828	51	4.9805	52	5.0781	53	5.1758
54	5.2734	55	5.3711	56	5.4688	57	5.5664	58	5.6641	59	5.7617
60	5.8594	61	5.9570	62	6.0547	63	6.1523	64	6.2500	65	6.3477
66	6.4453	67	6.5430	68	6.6406	69	6.7383	70	6.8359	71	6.9336
72	7.0313	73	7.1289	74	7.2266	75	7.3242	76	7.4219	77	7.5195
78	7.6172	79	7.7148	80	7.8125	81	7.9102	82	8.0078	83	8.1055
84	8.2031	85	8.3008	86	8.3984	87	8.4961	88	8.5938	89	8.6914
90	8.7891	91	8.8867	92	8.9844	93	9.0820	94	9.1797	95	9.2773
96	9.3750	97	9.4727	98	9.5703	99	9.6680	100	9.7656	101	9.8633
102	9.9609	103	10.0586	104	10.1563	105	10.2539	106	10.3516	107	10.4492
108	10.5469	109	10.6445	110	10.7422	111	10.8398	112	10.9375	113	11.0352
114	11.1328	115	11.2305	116	11.3281	117	11.4258	118	11.5234	119	11.6211
120	11.7188	121	11.8164	122	11.9141	123	12.0117	124	12.1094	125	12.2070
126	12.3047	127	12.4023	128	12.5000	129	12.5977	130	12.6953	131	12.7930
132	12.8906	133	12.9883	134	13.0859	134	13.1836	136	13.2813	137	13.3789
138	13.4766	139	13.5742	140	13.6719	141	13.7695	142	13.8672	143	13.9648
144	14.0625	145	14.1602	146	14.2578	147	14.3555	148	14.4531	149	14.5508
150	14.6484	151	14.7461	152	14.8438	153	14.9414	154	15.0391	155	15.1367

156	15.2344	157	15.3320	158	15.4297	159	15.5273	160	15.6250	161	15.7227
162	15.8203	163	15.9180	164	16.0156	165	16.1133	166	16.2109	167	16.3086
168	16.4063	169	16.5039	170	16.6016	171	16.6992	172	16.7969	173	16.8945
174	16.9922	175	17.0898	176	17.1875	177	17.2852	178	17.3828	179	17.4805
180	17.5781	181	17.6758	182	17.7734	183	17.8711	184	17.9688	185	18.0664
186	18.1641	187	18.2617	188	18.3594	189	18.4570	190	18.5547	191	18.6523
192	18.7500	193	18.8477	194	18.9453	195	19.0430	196	19.1406	197	19.2383
198	19.3359	199	19.4336	200	19.5313	201	19.6289	202	19.7266	203	19.8242
204	19.9219	205	20.0195	206	20.1172	207	20.2148	208	20.3125	209	20.4102
210	20.5078	211	20.6055	212	20.7031	213	20.8008	214	20.8984	215	20.9961
216	21.0938	217	21.1914	218	21.2891	219	21.3867	220	21.4844	221	21.5820
222	21.6797	223	21.7773	224	21.8750	225	21.9727	226	22.0703	227	22.1680
228	22.2656	229	22.3633	230	22.4609	231	22.5586	232	22.6563	233	22.7539
234	22.8516	235	22.9492	236	23.0469	237	23.1445	238	23.2422	239	23.3398
240	23.4375	241	23.5352	242	23.6328	243	23.7305	244	23.8281	245	23.9258
246	24.0234	247	24.1211	248	24.2188	249	24.3164	250	24.4141	251	24.5117
252	24.6094	253	24.7070	254	24.8047	255	24.9023	-	-	-	-

6.3.8 Analog Interface

Analog interface shall add the cyclic prefix to the data transmitted from IFFT, shall carry out shaping, and shall transmit the result samples to the Digital to Analog Converter (DAC).

The cyclic prefix shall be generated by copying the last 128 samples among the 512 samples of data and pasting them to the front. Shaping applies to 16 samples of each symbol.

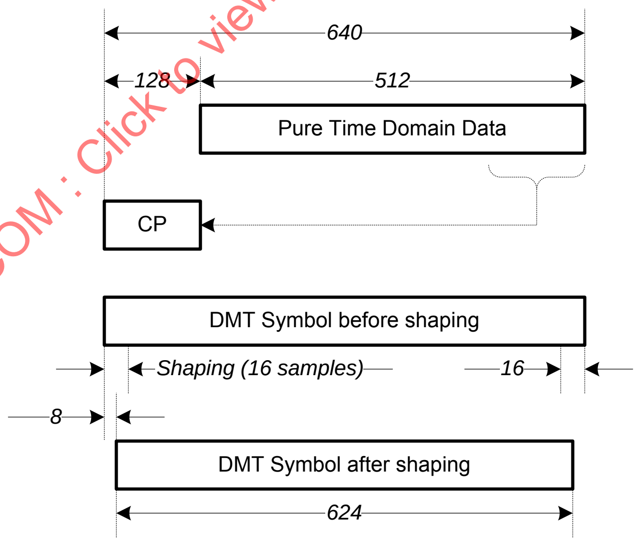

Fig. 16 - Cyclic Prefix and Shaping

6.4 Transmission Mode

The transmission mode is a frame-based transmission method. Three types of modes exist to enable more reliable communication within the powerlines. Transmission mode is divided into Diversity (DV), Extended Diversity (EDV), and NORMAL modes according to the channel condition, information type included in the frame, and the process to be performed.

6.4.1 Diversity (DV) Mode

Encoding in DV mode uses Reed-Solomon code and diversity mapping, and is constituted as Fig. 17.

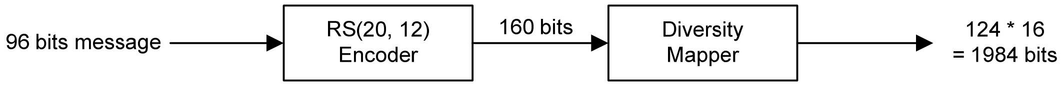

Fig. 17 - Diversity Mode Encoder

6.4.1.1 Reed-Solomon Code

The Reed-Solomon code is used as FEC for DV mode.

The finite field of the Reed-Solomon code is GF(256), and the following generator polynomial is used.

Code generator polynomial: $g(x) = \prod_{i=1}^{n} (x + \alpha^i)$, where $n = 8$

Field generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$ (435octal)

The Reed-Solomon code uses RS(20,12) code, i.e. it generates 20 bytes (160 bits) of code word to transmit 12 bytes (96 bits) of message.

6.4.1.2 Diversity Mapping

The method for diversity mapping of DV mode is as follows.

The 20 bytes (160 bits) of code word x(k) generated by Reed-Solomon code RS(20,12) can be expressed as a bit array like the following formula.

$$x(k) = (x_0, x_1, x_2, \ldots, x_{158}, x_{159})$$

If x(k) is transmitted via a symbol block of 16 symbols, the number of bits per symbol is 10. The number of tones used for each symbol would be 124 as shown in Table 4. In these circumstances, $y_j(i)$ (the information loaded onto each symbol) is expressed as follows.

$$y_j(i) = x((j-1)*10 + (i-1)\,\mathrm{mod}10)$$

$$\text{where, } j = 1,2,3,\ldots,14,15,16$$

$$i = 1,2,3,\ldots,122,123,124$$

In this formula, j represents the symbol number and i the order of tones used for each symbol.

Each DMT symbols utilizes differential BPSK modulation in reference to the previous DMT symbol.

DV mode can transmit 12 bytes of information per DMT symbol block. It is the most reliable transfer mode and enables communication between STAs without having to perform channel estimation.

DV mode is used for transmitting MAC Management Information (MMI) such as channel estimation results. It can also be used for transmitting MAC Service Data Unit (MSDU) if necessary.

6.4.2 Extended Diversity (EDV) Mode

Encoding in EDV mode uses Reed-Solomon code and diversity mapping, and is constituted as Fig. 18.

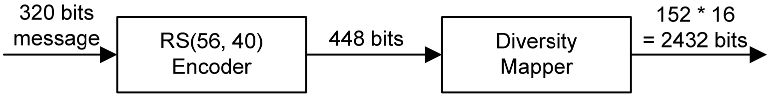

Fig. 18 - Extended Diversity Mode Encoder

6.4.2.1 Reed-Solomon Code

The Reed-Solomon code is used as FEC for EDV mode.

The finite field of the Reed-Solomon code is GF(256), and the following generator polynomial is used.

Code generator polynomial: $g(x) = \prod_{i=1}^{n} (x + \alpha^i)$, where $n = 16$

Field generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$ (435octal)

The Reed-Solomon code uses RS(56,40) code, i.e. it generates 56 bytes (448 bits) of code word to transmit 40 bytes (320 bits) of message.

6.4.2.2 Diversity Mapping

The method for diversity mapping of EDV mode is as follows.

The 56 bytes (448 bits) of code word x(k) generated by Reed-Solomon code RS(56,40) can be expressed as a bit array like the following formula.

$$x(k) = (x_0, x_1, x_2, \ldots, x_{446}, x_{447})$$

If x(k) is transmitted via a symbol block of 16 symbols, the number of bits per symbol is 28. The number of tones used for each symbol would be 152 as shown in Table 7. In these circumstances, $y_j(i)$ (the information loaded onto each symbol) is expressed as follows.

$$y_j(i) = x((j-1)*28 + (i-1) \bmod 28)$$

$$\text{where, } j = 1,2,3,\ldots,14,15,16$$

$$i = 1,2,3,\ldots,150,151,152$$

In this formula, j represents the symbol number and i the order of tones used for each symbol.

EDV mode can transmit 40 bytes of information per DMT symbol block. It is used for cases such as transmitting broadcast frames, etc.

Table 7 - Tone Numbers for Extended Diversity Mode

Tone Sequence	Tone Number									
1st ~ 10th	45	46	47	48	49	50	51	52	53	54
11th ~ 20th	55	56	57	58	59	60	61	62	63	64
21th ~ 30th	65	66	76	77	78	79	80	81	82	83
31th ~ 40th	84	85	93	94	95	96	97	98	99	100
41th ~ 50th	101	105	106	107	108	109	110	111	112	113
51th ~ 60th	114	115	116	117	118	119	120	121	122	123

61th ~ 70th	124	125	126	127	128	129	130	131	132	133
71th ~ 80th	134	135	148	149	150	151	152	153	154	155
81th ~ 90th	156	157	158	159	160	161	162	163	164	165
91th ~ 100th	166	167	168	169	170	171	172	173	174	175
101th ~ 110th	176	177	178	179	180	181	182	187	188	189
111th ~ 120th	190	191	192	193	194	195	196	197	198	199
121th ~ 130th	200	201	202	203	204	205	206	207	208	209
131th ~ 140th	210	211	212	213	214	221	222	223	224	225
141th ~ 150th	226	227	228	229	230	231	232	233	234	235
151th ~ 152th	236	237	-	-	-	-	-	-	-	-

6.4.3 NORMAL Mode

NORMAL mode is the most generalized transmission mode using the tone maps produced through channel estimation.

NORMAL mode is used between two STAs that have successfully obtained tone maps through interactive channel estimations.

7 MAC Specification

The MAC layer specification presented in this chapter is for in-home/access data network using high speed PLC.

7.1 Structure of MAC

7.1.1 Overview

MAC is a logical interface between PHY and a link (or upper) layer. For more reliable communication, MAC controls all the communication performed in PHY.

In general, the data communication between STAs starts after the channel estimation is carried out. In this process, the two STAs calculate and exchange the tone map, data throughput and parameters with FEC that are most suitable for the current channel condition. The tone map shall be renewed regularly and in the case of packet error, to maintain communication performance over powerline. After channel estimation, 56-bit DES or 128-bit AES shall be used to encrypt data for security. For the secure system, 128-bit AES is recommended.

7.1.2 Multiple Access

CSMA/CA, a distribution access mechanism, is used for multiple access. Each STA shall sense the state of the medium by sensing the physical carrier and virtual carrier before starting transmission. If the medium proves to be IDLE, transmission can begin. But if another STA is transmitting (BUSY) STAs shall wait until the current transaction ends. When the transaction ends, STA to access the medium shall start multiple access through backoff procedure. Details on multiple access are described in "7.2 Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)".

7.1.3 Frame Transmission

After capsulation of the data generated in the MAC layer or downloaded from the MI, the MAC transmits the data through PHY. In this specification, "frame" is synonymous to "PSDU", and "service block" refers to Frame Body Block (FBB) including MSDU or MMI. The capsulation procedure of transmitting MSDU and MMI through the PLC network is shown in Fig. 19.

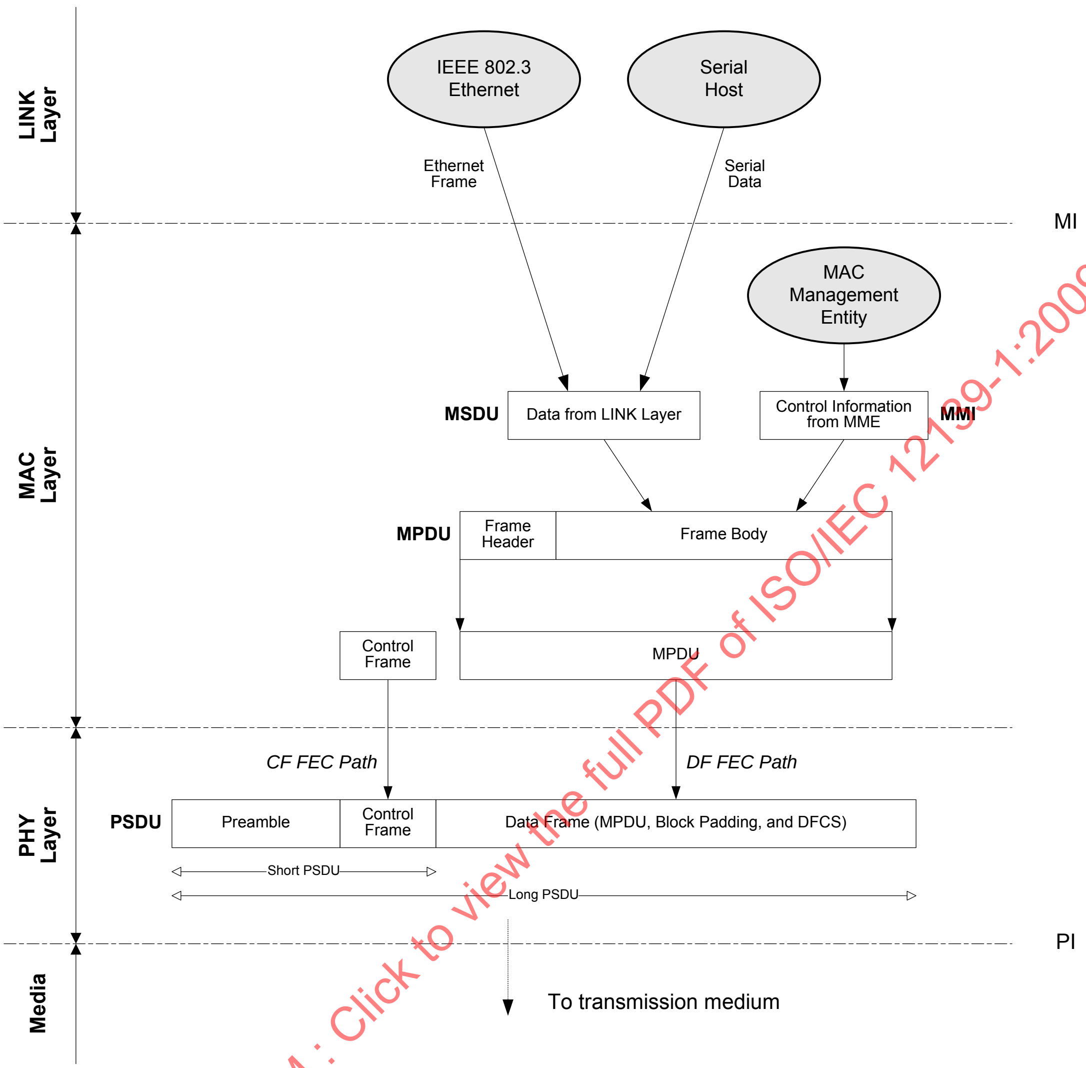

Fig. 19 - Capsulation Procedure of the Transmission End

MI is for application interface. It provides Media Independent Interface (MII) based on the ethernet packet and serial interface through UART (MII follows IEEE standard 802.3 2000 edition "22.2.2 MII Signal Functional Specification" and UART is implemented so that the baud rate supports 1200 bps, 2400 bps, 4800 bps, 9600 bps, 19200 bps, 38400 bps, 57600 bps and 115200 bps.)

MSDU refers to the data including the part other than the 8-byte long ethernet preamble of the ethernet frame received from IEEE 802.3 ethernet, or the serial data received from the serial host. Each MSDU composes FBB and is included in the frame body, which is a payload of MPDU. A frame body usually includes single MSDU and if destination STA is identical, several MSDUs can be included in one frame body.

MMI, the control information generated in MAC management entity, forms FBB like MSDU and is included in the frame body which is the MPDU payload. One frame body can include more than one MMI.

The frame body including more than one FBB shall be combined with the frame header to form MPDU. Besides MPDU, after the control frame - which may be referred to as the MPDU header - is generated, both the control frame and MPDU are sent to PHY. The control frame and MPDU shall be processed through CF FEC and DF FEC, respectively, of PHY, and be combined with the preamble to finally form PSDU, and be transmitted to the medium. The data frame, which only exists in PHY, is composed of MPDU that has been processed through DF FEC, block padding overheads that are generated while MPDU is processed into DMT symbol block units, and Data Frame Check Sequence (DFCS).

The inverse capsulation process from PHY to MI shall proceed in a manner that is inverse to the capsulation process.

7.1.4 MAC Parameter

The parameters used in MAC are shown in Table 8. The symbol period here all refer to the symbols (= 12.48 usec) with cyclic prefix.

Table 8 - MAC Parameters

Item	Value
symbol period (SYMBOL_PERIOD)	12.48 usec/symbol
time slot duration (TSD)	7 symbol
short response interframe space (SRIFS)	5±1 symbol *
short contention interframe space (SCIFS = SRIFS + TSD)	12±1 symbol *
long response interframe space (LRIFS)	20±1 symbol *
long contention interframe space (LCIFS = LRIFS + TSD)	27±1 symbol *
delimiter length (DELIM_LENGTH)	12 symbol
symbol block length (SYMBLOCK_LENGTH)	16 symbol
maximum symbol block number per PSDU (MAX_SYMBLOCK_NUM)	15 symbol block
maximum length of the data frame (MAX_DF_LENGTH = SYMBLOCK_LENGTH * MAX_SYMBLOCK_NUM)	240 symbol
maximum length of PSDU (MAX_PSDU_LENGTH = DELIM_LENGTH + MAX_DF_LENGTH)	252 symbol
minimum ethernet byte (MIN_ETHERNET_BYTES)	64 byte
maximum ethernet byte (MAX_ETHERNET_BYTES)	1522 byte **
frame header byte (FH_BYTES)	20 byte
frame body block header byte (FBBH_BYTES)	12 byte
maximum competitive window size (MAX_CWS)	512 time slot
contention window coefficient (CW_COEFFICIENT)	8 time slot
periodic contention window duration (PERIODIC_CW_DURATION)	1000 time slot
weighted factor of channel estimated contention window (WF_CECW)	0.6
collision recovery duration (CRD = MAX_PSDU_LENGTH)	252 symbol
last estimated node number (LAST_EST_NODE_NUM)	10
short periodic channel estimation duration (SHORT_PERIODIC_CE_DURATION)	10^6 symbol(=12.48 sec)
long periodic channel estimation duration (LONG_PERIODIC_CE_DURATION)	5 * 10^6 symbol(=1.04 min)
maximum normal trial number (MAX_NORMAL_TRY_NUM)	10
maximum extended diversity trial number (MAX_EDV_TRY_NUM)	10

maximum diversity trial number (MAX_DV_TRY_NUM)	10
maximum service block lifetime (MAX_SB_LIFETIME)	10^6 symbol(=12.48 sec)
maximum link life time (MAX_LINK_LIFETIME)	10^7 symbol(=2.08 min)
periodic proxy demand duration (PERIODIC_PD_DURATION)	10^5 symbol(=1.248 sec)
* "±1 symbol" means acceptable error range. ** This value includes 4 bytes VLAN tag.	

7.2 Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)

For the multiple access method presented in this standard, refer to ISO/IEC 8802-11 "A wireless LAN utilizing carrier sense multiple access with collision avoidance (CSMA/CA) as the access method". CSMA/CA is a distributed access mechanism transmitting the frame using carrier sense and backoff procedure to reduce collision. STAs perform one-to-many communication within the cell, which is a logical network classified by GID.

All communication shall be carried out on the basis of the transaction in which frames are exchanged between STAs.

7.2.1 Carrier Sense Mechanism

Carrier sense is divided into physical carrier sense and virtual carrier sense. The physical carrier sense is a function provided by PHY and refers to sensing the preamble. The virtual carrier sense, a function of estimating the channel occupation length of the frame currently transmitted by another STA by using Number of Symbol Block (NSB), shall be provided by MAC.

The medium state determined by the physical carrier sense, virtual carrier sense, and backoff procedure shall be divided into IDLE, BUSY and CONTENTION as shown in Fig. 20.

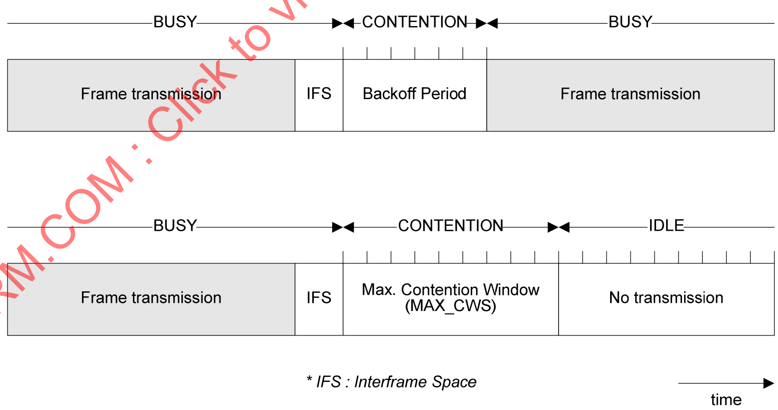

Fig. 20 - Example of Medium State

7.2.2 InterFrame Space (IFS)

IFS refers to the fixed time space between frames. According to the length, the interframe space shall be divided into 4 types as illustrated in Fig. 21.

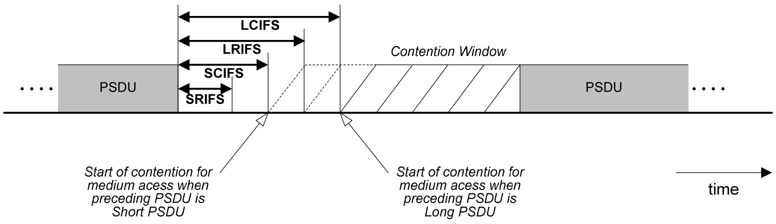

Fig. 21 - Various Interframe Space

7.2.2.1 Short Response InterFrame Space (SRIFS)

SRIFS is the shortest interframe space. It is the time space between the end of transmitted short frame and the start of its associated response frame.

7.2.2.2 Short Contention InterFrame Space (SCIFS)

SCIFS is the time space between the end of a transmission of a short frame and the start of a new contention. The length of SCIFS shall be SRIFS + TSD. SCIFS guarantees the time for checking whether or not the corresponding response is transmitted after the transmission of a short frame. When the transmission of a frame is not sensed during SCIFS after transmission of a short frame, the medium state shall be converted from BUSY to CONTENTION and all STAs that wish to access the medium shall carry out the backoff procedure and start contention.

7.2.2.3 Long Response InterFrame Space (LRIFS)

LRIFS is the time space between the end of a transmission of a long frame and the start of its associated response frame. LRIFS guarantees the time for processing long frames.

7.2.2.4 Long Contention InterFrame Space (LCIFS)

LCIFS is the longest interframe space and indicates the time space between the end of a transmission of a long frame and the start of a new contention. The length of LCIFS shall be LRIFS+TSD and it guarantees the time for checking whether or not a corresponding response to the long frame is transmitted. When the transmission of a frame is not sensed during LCIFS after a long frame transmission, the medium state shall be converted from BUSY into CONTENTION and all STAs to access the medium shall immediately carry out the backoff procedure and start contention.

7.2.3 Transaction

Transaction is defined as the minimum set of the frames transmitted between two STAs. The communication over powerline is based on transactions, IFSs and backoff periods.

7.2.3.1 Single Transaction

Single transaction is composed of a long frame and a short frame, which is the response. In a very rare case, transaction may not include a response. In such a case, transaction is only composed of a long frame; the short frame and LRIFS do not exist. Fig. 22 illustrates the transaction which STA A starts.

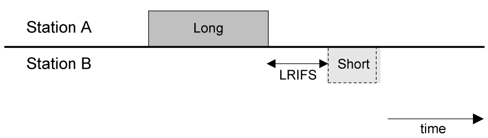

Fig. 22 - Example of Transaction

7.2.3.2 Transaction Combo

Transaction combo is defined as the transmission of more than two jointly combined transactions without participating in contention. With respect to transaction combo, it is assumed that, if the first transaction has been successfully transmitted without collision, the following transactions will not collide.

Fig. 23 illustrates an example in which 3 transactions constitute a transaction combo. In such a case, the second and the last transactions shall start without contention.

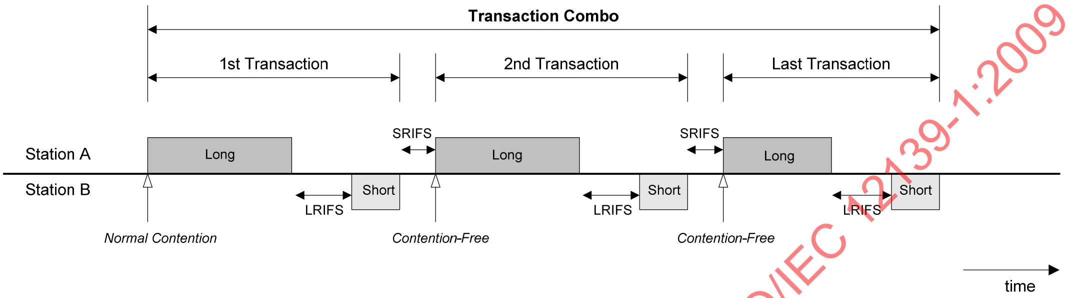

Fig. 23 - Transaction Combo

Transaction combo is used in case of segmentation, etc.

7.2.4 Access Procedure

7.2.4.1 Overview of Access

Every STA shall estimate the current medium state by sensing the physical carrier and virtual carrier. In case the medium is IDLE, STAs can start transaction in any time slot. In case the medium is BUSY, the medium access shall be delayed until the transaction ends. When the transaction ends, STAs shall carry out physical carrier sense during SCIFS or LCIFS according to the terminated transaction. If the frame transmission is not sensed during this period, STAs immediately start the backoff procedure, and then STA that has won the contention starts transaction. If the start of frame transmission of another STA has been sensed while waiting for its own transmission time slot, the current backoff procedure shall be delayed to the next medium contention and virtual carrier sense shall be started. If the transaction started by another STA has ended, the delayed backoff procedure shall be started again and medium access is retried.

7.2.4.2 Backoff Procedure

Backoff procedure is defined as the distribution of the transmission time of STAs attempting to transmit, so as to reduce the collision between frames. STAs with frames to transmit shall generate backoff values by themselves and attempt to transmit in the designated time slot within their own contention windows. STA carrying out the backoff procedure shall check whether or not the frame transmission of another STA has been started through sensing the physical carrier until its own time slot arrives, and decide whether to delay the current backoff procedure to the next medium contention. In case the medium is IDLE, the backoff procedure is skipped.

If Contention Window Size (CWS) is 8 time slots and the generated backoff value is 3, the backoff procedure is illustrated in Fig. 24. The interframe space between the end of transmitted PSDU and the point of time when the contention window starts is SCIFS in case of PSDU being a short frame, or LCIFS in case of PSDU being a long frame.

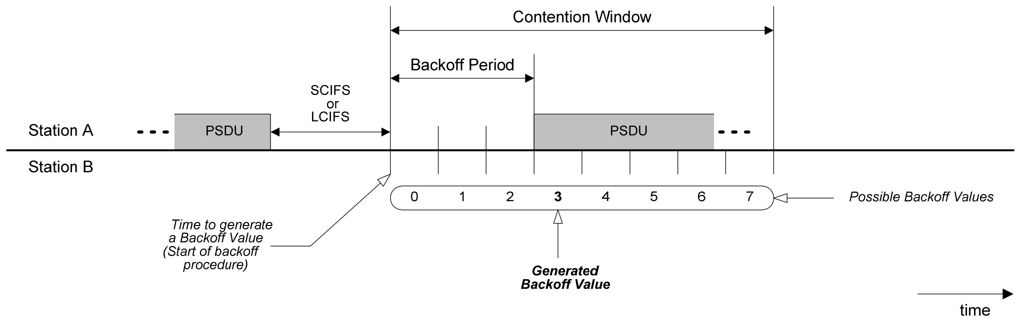

Fig. 24 - Example of Backoff Procedure

7.2.4.2.1 Backoff Value

The backoff value shall be defined as the number of time slots for which each STA has to wait within the contention window before starting transaction. STA attempting to transmit a new frame shall generate a backoff value in [0, CWS-1] through a random number generator and deduct one by one from the backoff value for each time slot in the contention window as time goes.

STA can start transaction when its backoff value is 0. Before starting transaction, or before the backoff value is 0, if the frame transmission of another STA is sensed, the backoff procedure underway is deferred to the next medium contention. If the backoff procedure has been deferred, the backoff value is not regenerated by a random number generator. Instead, the value which has stopped decreasing in the previous medium contention shall be used. This means that STAs attempting transmission generate new backoff values through a random number generator only when the backoff value is 0.

7.2.4.2.2 Adaptive Contention Window Size (CWS) by Traffic Monitoring

Each STA has its own contention window. CWS shall be determined after a certain period of monitoring the network traffic through the following formula.

$$\overline{n}(t) \approx 1 + \frac{E[c(B)](W(t)+1)}{2B}$$

$$\hat{n}(t+1) = \alpha\overline{n}(t) + (1-\alpha)\frac{\sum_{i=1}^{q}\hat{n}(t-i)}{q}$$

$$W(t+1) = \hat{n}(t+1)\sqrt{2T}$$

The variables are defined as follows.

B	: Period for estimating the next CWS (PERIODIC_CW_DURATION)
E[c(B)]	: Number of BUSY slots of B
W(t)	: Current CWS
$\overline{n}(t)$	: Estimated number of nodes
α	: Weight of the currently estimated CWS (WF_CECW)
q	: Last estimated number of nodes (LAST_EST_NODE_NUM)
$\hat{n}(t)$	: Expected number of nodes
$\sqrt{2T}$	: CW coefficient (CW_COEFFICIENT)
W(t+1)	: New CWS

Adjustment of CWS is based on the proposition that the collision probability shall be less than 10^{-1}.

7.2.4.3 Use of Transaction

The transaction started by STAs through the backoff procedure is shown in Fig. 25.

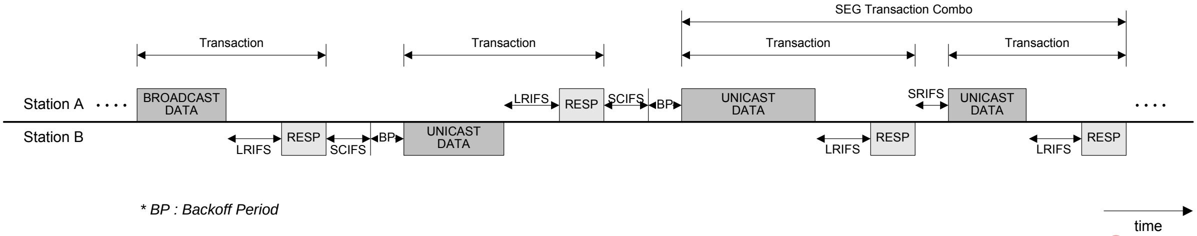

Fig. 25 - Example of Frame Transmission

The communication over powerline is carried out through transaction. STA starting transaction transmits a long frame like the unicast data frame, after LRIFS, receives a response frame (or a short frame) and then ends transaction.

In transaction, there is MAC-level response to the transmitted long frame. The response is divided into ACK and FAIL, and guarantees reliable communication through ARQ. In case of an error of the transmitted long frame due to collision or interference in the channel, the destination of the frame is unknown and so, STAs wait for the response timeout or carry out virtual carrier sense and participate in contention again.

7.2.4.4 Automatic Repeat reQuest (ARQ) Mechanism

In case of a failure of long frame transmission because of collision or interference in the channel, ARQ is provided. This chapter explains ARQ mechanism from the standpoint of STA that receives a response. STA receiving a response refers to STA that has transmitted a long frame, or STA that has started the transaction.

7.2.4.4.1 ARQ

In all transactions, retransmission by ARQ shall be carried out through the backoff procedure. The definition of response in transaction and the ARQ mechanism are shown in Table 9.

Table 9 - Classification of Response

Response	Transaction State	Transmission State	Status of transmitted long frame	Action
ACK	Completed	Succeeded	No collision or no CFCS /DFCS error(Note 1)	Set the retransmission counter to 0 and notify that transmission is successful
FAIL	Completed	Incompleted	No collision or CFCS /DFCS error, but the reception end has no resources to deal with it	Retransmit but do not increase the retransmission counter(Note 2)
None	Incompleted	Failed	CFCS/DFCS error or collision is expected(Note 3)	Retransmit and increase the retransmission counter if conditions in Fig. 26 are met. In other cases, discard service block, set the retransmissin counter to 0, and notify that transmission has failed (Note 2)

ACK or FAIL with wrong SN(4)	Incompleted	Failed	Collision expected(Note 5)	Identical response as in the case of 'None'
Response other than ACK or FAIL	Incompleted	Failed	Collision expected(Note 5))	Identical response as in the case of 'None'
CFCS error of PSDU received before response time out	Incompleted	Failed	Collision expected(Note 6)	Identical response as in the case of 'None'

Note 1.- CFCS error and DFCS error each indicate control frame error and data frame error, respectively.
Note 2.- If 'FAIL' or 'None' has been received during transaction combo (with the exception of the first transaction), the segments are retransmitted from the first segment on, following the backoff procedure.
Note 3.- There is no response when 1) destination STA is out of operation or turned off, 2) a CFCS or DFCS error has occurred due to poor channel state, 3) CFCS or DFCS error has occurred due to collision.
Note 4.- Refer to "7.3.2.2.4.3 Sequence Number (SN)" and "7.3.3.1.2.8. Sequence number (SN)".
Note 5.- Reception of the aforementioned responses is because of an unknown malfunction, and it is assumed that collision has occurred.
Note 6.- It is assumed that CFCS error has occurred because of collision.

Transmitting STA shall carry out various ARQ mechanisms according to the situation and the type of service block it is transmitting. The ARQ flowchart from the standpoint of STA transmitting a long frame is shown in Fig. 26.

As shown in Fig. 26, each service block can be retransmitted MAX_NORMAL_TRY_NUM or MAX_EDV_TRY_NUM or MAX_DV_TRY_NUM times according to the transmission mode.

The Service Block (SB) timer starts when the service block from the upper layer is cumulated on the transmission queue. The SB timer increases at every symbol and is for giving the concept of time stamp to each service block. The service block that has not been transmitted until the SB timer reaches MAX_SB_LIFE_TIME shall be discarded.

Proxy setting procedure shall be carried out whenever the system is turned on. Each STA shall set its proxy STA for the communication over powerline (refer to 7.7).

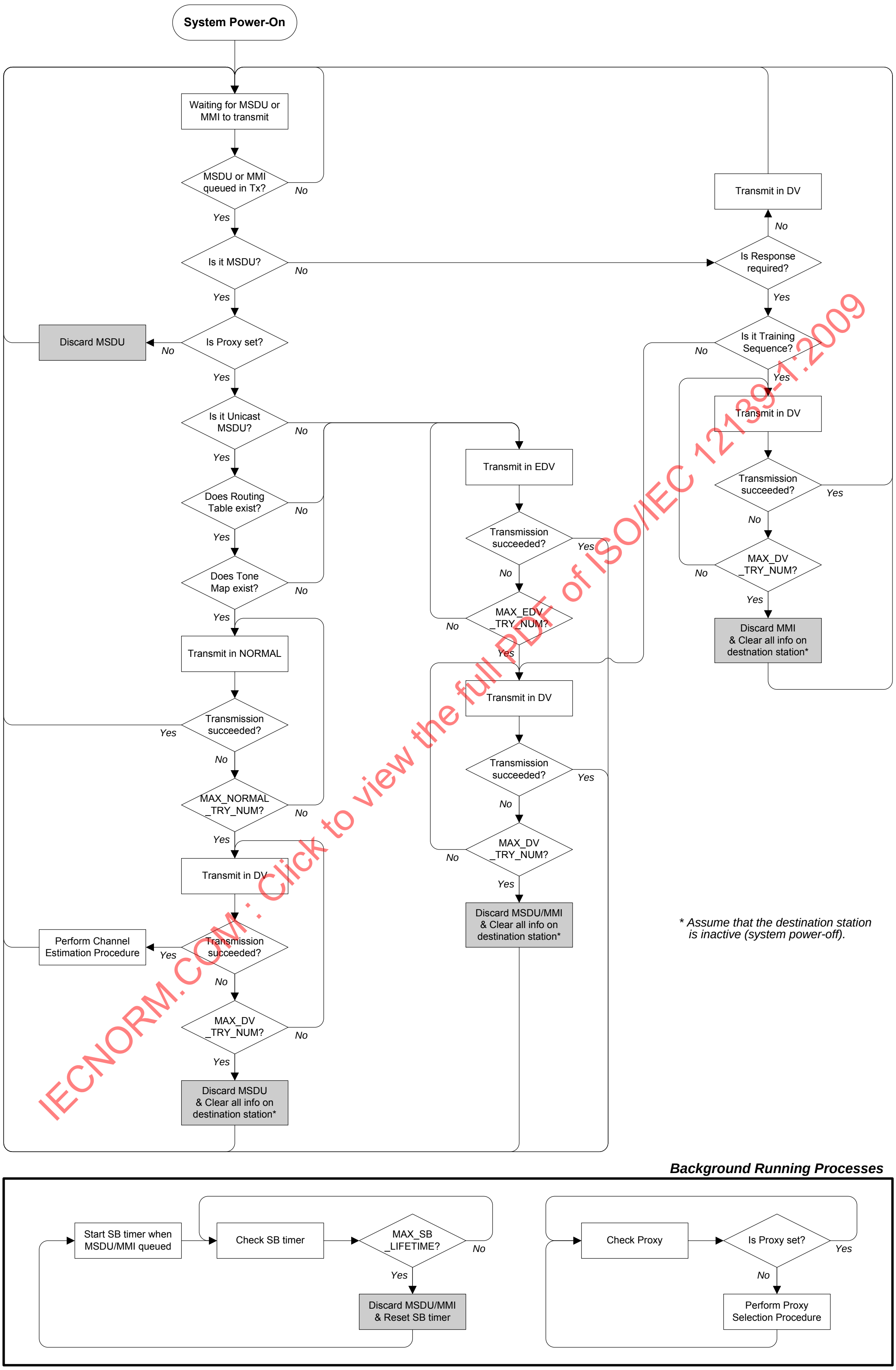

Fig. 26 - ARQ Flow chart in Case of Long Frame Transmission

7.2.4.4.2 Partial ARQ for Broadcast

Partial ARQ is used in broadcast to prevent all STAs from transmitting response frame at the same time, which can cause a collision.

In partial ARQ, which enhances reliability of broadcast, proxy STA that have received a broadcast frame shall send a response on behalf of other STAs. Proxy STA setting is described in "7.7 Proxy Setting Procedure".

Every STA shall set its proxy STA as its destination when transmitting a broadcast frame. STA receiving a broadcast frame sends responses only when the destination of the frame is the STA itself.

7.2.4.5 Segmentation

There may be some cases when a block can not be transmitted in a single frame because of the size of the service block and the amount of data that can be transmitted per frame. In such a case, segmentation is defined as dividing the service block into many pieces and transmitting them. The inverse procedure of segmentation is reassembly.

Segmentation is processed as SEG transaction combo comprising more than two transactions. When a service block is segmented into three pieces, the entire transaction is shown in Fig. 27.

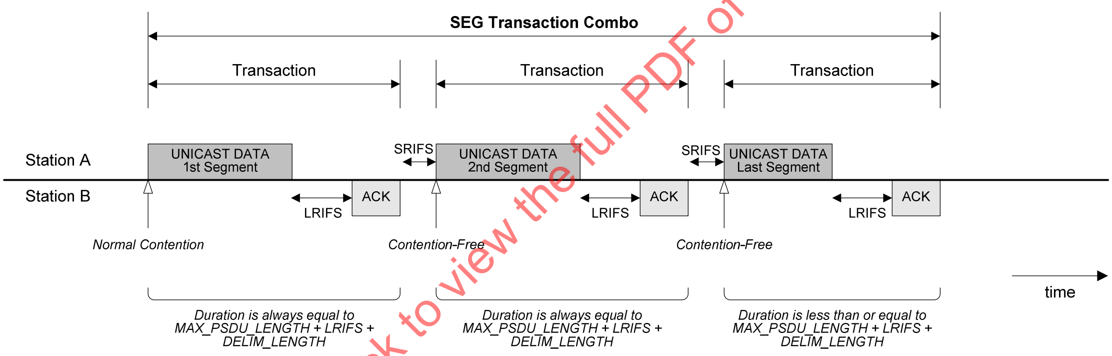

Fig. 27 - Example of Segmentation

In case of segmentation, the length of transactions except the last one is MAX_PSDU_LENGTH + LRIFS + DELIM_LENGTH and the interframe space between transactions shall be always SRIFS.

In case of segmentation, ACK and retransmission shall be independently carried out by using the segment count field of the frame header and the last segment flag field. Receiving STA shall reassemble the received segments in the order of the segment count until the last segment flag of the received segment is set to binary number ‘1’.

Transmitting STA that has started SEG transaction combo retransmits the whole segments through a new contention when a no-response error has occurred to the second segment after the first segment was successfully transmitted. Retransmission and deletion of the service block are carried out in accordance with the ARQ flowchart in Fig. 26. Because the transactions other than the first transaction in transaction combo do not participate in the contention, the no-response error occurring after the first transaction occurs due to the DFCS error caused by a bad channel, not by collision.

Receiving STA discards the service blocks that have been reassembled up until then when transaction combo ends without completing the transaction combo to the last segment. In case of a DFCS error during receiving segments, the service blocks that have been received up until then are discarded.

7.2.4.6 Duplicate Detection and Recovery

Duplicate detection is carried out by receiving STAs that received long frames including MSDU. The duplication of long frames occurs when there is an error in the response frame transmitted by receiving STA. STA that has received a duplicated long frame shall transmit ACK as usual, and discard the duplicated frame that has been received.

Duplicate detection is carried out in general by using Sequence Number (SN) of the frame header, Segment Count (SC) and Last Segment Flag (LSF). SN is a 7 bit number distinguishing each service block. SEG transaction combo is a transmission of service block divided into many segments, so all the long frames within the SEG transaction combo have the same SN. SC is a number distinguishing each segment in SEG transaction combo and increases by one in each segment, starting from 0. LSF indicates the last segment of the SEG transaction combo by being set to be binary number '1' in the last long frame, and is always set to be binary number '1' when segmentation does not occur.

In order to detect duplicated frames, every STA stores SN of the most recently received long frame that has been transmitted to the STA itself. STA manages SN for each linked STA. On the contrary, in the case of SC, it is only necessary to store SC of the most recently received long frame regardless of STA. This is because more than two STAs can't proceed the SEG transaction combo simultaneously.

SN is used for duplicate detection of service blocks. In this case, duplicate detection is carried out by receiving STA receiving unicast data frame that have been transmitted in NORMAL mode. A long frame that includes a service block is initially transmitted in {SN=0, SC=0, LSF=1}. STA that received the long frame successfully sets SNstored=1 and transmits corresponding ACK. If there is an error in transmitted ACK, transmitting STA retransmits the frame in {SN=0, SC=0, LSF=1}. Because SNreceived(0)≠SNstored(1) in the received long frame of receiving STA, it is acknowledged as a duplicate frame and the frame shall be discarded after transmission of ACK. In order to prevent consecutive errors of SN due to miscalculation, receiving STA always adjusts SNstored to transmitting STA that has transmitted the long frame. SNstored is determined by SN of the received long frame. It is the sum of SNreceived and the number of service blocks included in the received long frame. For instance, when a long frame including three service blocks has been received, SNstored is set to SNreceived+3. STA receiving broadcast data frame with a response stores Destination STA ID (DSID) and SN included in the frame header, and when the broadcast data frames with same DSID and SN are consecutively received, STA processes them as duplicate frames.

In SEG transaction combo, duplicate detection is carried out by using SC and LSF. The first segment in the SEG transaction combo is transmitted through the backoff procedure, so except for LSF being '0', it is the same as a single transaction in which segmentation has not occurred. From the second segment on, when SCstored and SCreceived of the received frame are the same, it is deemed to be a duplicated frame and the frame shall be discarded. In such SCreceived<SCstored or SCreceived<(SCstored+1) case, receiving STA shall send FAIL and discard the received frame and service blocks which have been reassembled up until then. If STA that started a SEG transaction combo receives FAIL during the process, it ends the SEG transaction combo, returns to the backoff procedure, and starts retransmission from the first segment of the service block.

The particular SN of STA becomes 0 whenever channel estimation with STA is carried out successfully (refer to 7.8).

7.2.5 Virtual Carrier Sense (VCS) Timer Setting

VCS shall be carried out by STAs other than the source STA and destination STA transmitting and receiving frames. It enhances the reliability of medium access. STAs shall make decisions about the current medium state, ending point of the transaction underway, and the point of time when the backoff procedure can be started through VCS.

Each STA decides whether or not to perform VCS by taking a look at the control frame in the received long frame. Accurate information on source STA is contained in the frame header in the data frame. This means that only when the tone map index of the control frame of the unicast data frame in NORMAL mode does not indicate the tone map of receiving STA, VCS is carried out. VCS is also carried out when the version control field on the control frame is not the binary number '00'.

The VCS timer shall be calculated through NSB field within the control frame of the received frame. Setting the VCS timer starting from the end of the control frame is shown in Fig. 28.

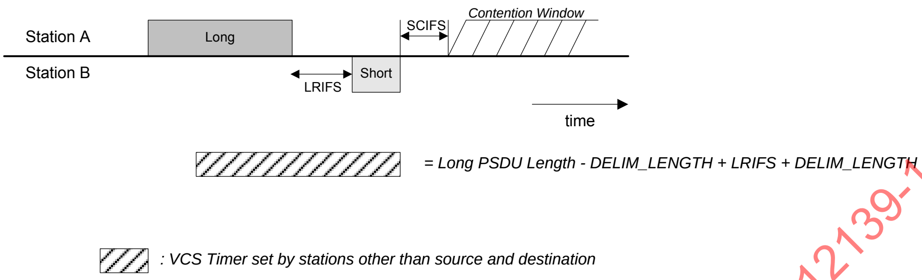

Fig. 28 - Setting of VCS Timer

VCS, applied on the basis of transaction, is only used for long frames with a response. To long frames without response, VCS cannot be applied because the frame header shall be decoded by every STA.

STA carrying out VCS cannot participate in network contention before the VCS timer ends. STA carrying out VCS can start the backoff procedure after SCIFS when the VCS timer ends.

7.2.6 Collision Detection and Restoration

In communication of CSMA/CA, when two or more STAs start transaction at the same time, collision occurs. Collision can be classified into two cases according to the standpoint of STAs. One is the collision detected by transmitting STA that started transaction by transmitting a long frame, and the other is the collision detected by receiving STA that received a long frame of the transaction.

7.2.6.1 Standpoint of the Transmitting STA

Collision is defined as follows from the standpoint of transmitting STA that started transaction.

·Case A: When transmitting STA has not received a response.
·Case B: Although transmitting STA has received a right response, SN is not correct.
·Case C: When transmitting STA has received something other than the expected response.
·Case D: When there is a CFCS error in the response that transmitting STA has received.

Case A is automatically resolved by Collision Recovery Duration (CRD) and response timeout.

CRD, the period starting from the very beginning of the frame transmitted by transmitting STA, contains contents concerning response timeout. Every STA starting transaction waits for a response while carrying out PCS during "CRD - length of transmitted long frame + LCIFS". This is for making every STA start multiple access at the same point of time in case there is a collision into a frame with length as long as MAX_PSDU_LENGTH. CRD in case of two STAs starting transactions of different length at the same time and colliding into each other is shown in Fig. 29. The medium state during CRD is defined as BUSY.

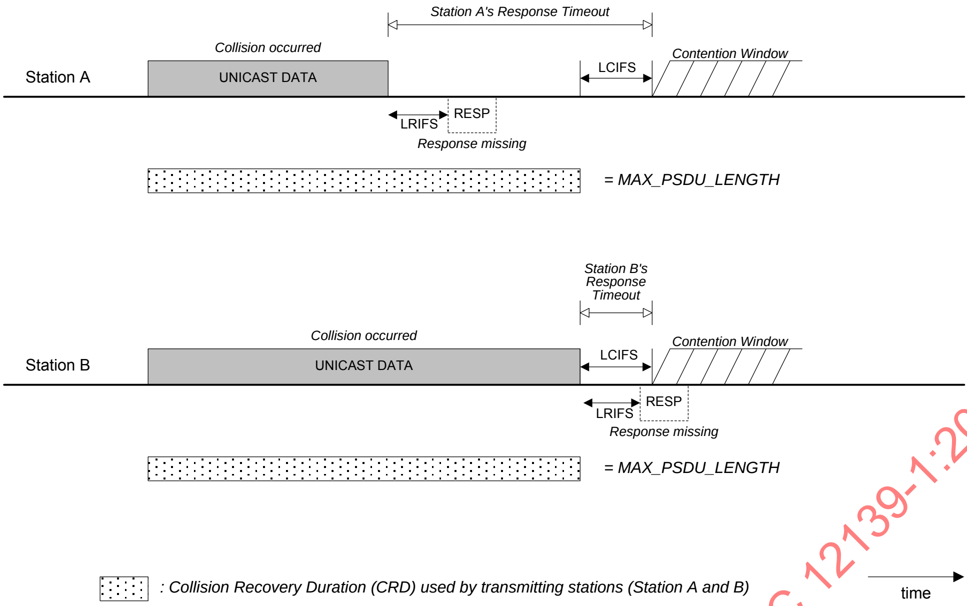

Fig. 29 - Example of Collision Recovery Duration in Case A

As illustrated in Fig. 29, the response timeout is not fixed. Transmitting STA can start the backoff procedure after SCIFS when it has received a response frame before the response timeout is over.

Case A occurs not only in the case of collision but also when there is a DFCS error in the transmitted long frame. Therefore, in this specification, the Case A is not divided into collision and DFCS error but is treated equally.

The response received by transmitting STA in Cases B and C means the frame received before the end of response timeout after transmission of the long frame by transmitting STA. Such an unexpected frame is caused by unexplainable malfunction, therefore receiving the unexpected frame is defined as a collision. After reception of the unexpected frame, retransmission is attempted through the backoff procedure after SCIFS or LCIFS.

In Case D, STA carries out physical carrier sense during the remaining CRD which has started at the point of time when the response with CFCS error has been first received. In such a case, the timeout does not apply. If a new frame is received before the end of CRD, retransmission is attempted through the backoff procedure after SCIFS or LCIFS from the received frame ends. If a new frame has not been received until the end of CRD, retransmission is tried through the backoff procedure after CRD and LCIFS.

7.2.6.2 Standpoint of the Receiving STA

In case of receiving STA, collision is defined as a CFCS or DFCS error occurring in the received frame. Actually, DFCS error may have occurred not because of collision but due to bad channel, but these two are not distinguished and are treated equally.

In case of a collision, receiving STA carries out PCS and medium monitoring until CRD, which started at the beginning of the received frame, is over. CRD used by receiving STA has the same start and end points of time as CRD used by transmitting STA in Fig. 29. This means that in case of a collision, receiving STA and transmitting STA can start new multiple access at the same point of time.

Receiving STA can start the backoff procedure after SCIFS or LCIFS from the received frame end if a new frame has been received before the end of CRD, just like transmitting STA's restoration operation at Case D. If a new frame hasn't been received until the end of CRD, the backoff procedure may start after CRD and LCIFS.

7.2.7 Frame Processing in Case of an Error

Same as 7.2.6.2

7.3 PSDU Format

PSDU is composed of the preamble, control frame, and data frame. The data frame is composed of the frame header, frame body, block padding, and DFCS. The delimiter comprising preamble and control frame is the minimum unit that can form PSDU. The existence of the data frame is determined by the form of the preceding delimiter of the control frame; with a data frame, it is long PSDU and without a data frame, it is short PSDU.

The length of short PSDU shall be always fixed at 12 symbols (Actually, preamble is composed of 9 symbols without cyclic prefix. If preamble is considered as symbols with cyclic prefix, however, it becomes 7.4 symbols. 8-symbol preamble is assumed for processing in units of symbols with cyclic prefix.), but the length of long PSDU changes according to the channel condition and size of data included in the frame body. The symbol length of the data frame shall be expressed in units of symbol blocks, so it shall be always a multiple of 16 symbols, and the size of the data contained in each symbol block shall be always a multiple of 4 bytes regardless of the transmission mode. PSDU format is illustrated in Fig. 30.

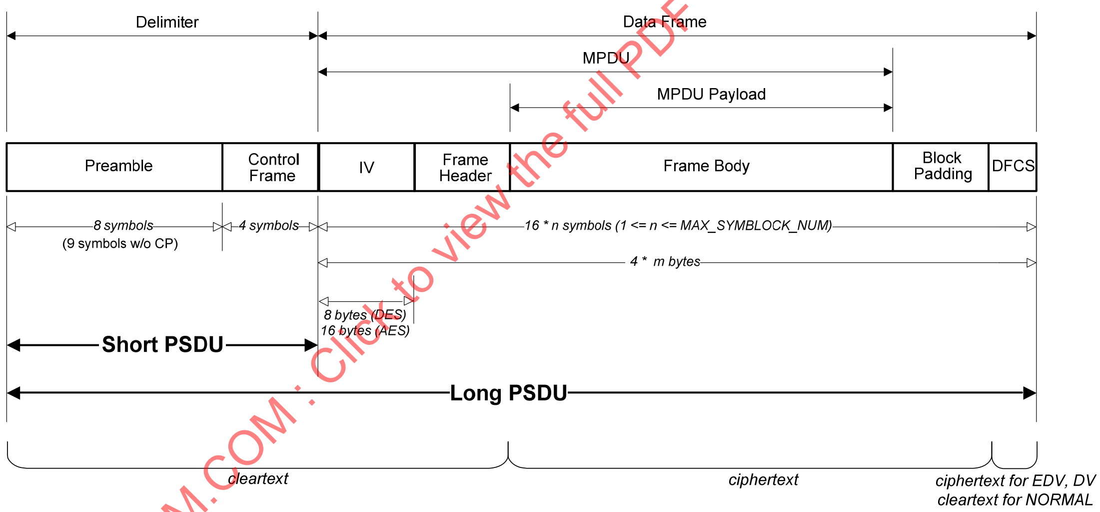

Fig. 30 - PSDU Format

7.3.1 Preamble

The preamble shall be an 8-symbol long predefined Pseudo-Random Sequence (PRS) and is used for the following purposes:

- Physical Carrier Sense (PCS)
- Automatic Gain Control (AGC)
- Synchronization

Preamble is further described in "6.2.1 Preamble".

7.3.2 Control Frame (CF)

The control frame, which shall be composed of 24 bits and plays a role of the header of all PSDUs, has the basic information on PSDU and transmitting/receiving STAs. The information contained in the control frame can be decoded by all STAs existing in the network. The format of a control frame is shown in Fig. 31.

MSB																							LSB
DT			VF											VC		CFCS							
23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3 bits			11 bits											2 bits		8 bits							

Fig. 31 - Control Frame Format

7.3.2.1 Form of Delimiter

The form of a delimiter refers to the type of PSDU. The definition of delimiter form is shown in Table 10.

Table 10 - Definition of Delimiter Form

Form of Delimiter	Definition	Length of PSDU	Transmission Mode	Contents of Frame Body
000	Unicast data	Long frame	NORMAL mode DV mode EDV mode	MSDU(S)
010	Management	Long frame	EDV mode DV mode	MMI(S)
011	Broadcast data	Long frame	EDV mode DV mode	MSDU
101	Response	Short frame	N/A	N/A
001,100,110,111	Reserved	N/A	N/A	N/A

7.3.2.1.1 Unicast Data

Unicast data is for transmitting MSDU from the upper link layer to the MAC layer through MI via unicast. Unicast data PSDU is transmitted in NORMAL mode by using the tone map obtained through channel estimation procedure. When the tone map cannot be used or the channel is poor, it can be transmitted in EDV mode or DV mode.

One frame body of unicast data PSDU can contain up to three MSDUs if there is no segmentation.

Unicast data PSDU can be transmitted only when destination STA and source STA are definitely defined. Therefore, if there is no DFCS error or collision, a response to transmitted unicast data PSDU always exists.

7.3.2.1.2 Management

Management is used for transmission of MMI generated in MME (MAC Management Entity). All management PSDUs are transmitted in DV mode and in some situation, there may be no response.

One frame body of management PSDU can contain more than one MMI.

Segmentation never occurs in management PSDU.

7.3.2.1.3 Broadcast Data

Broadcast data is used for transmitting MSDU from the upper link layer to the MAC layer through MI via broadcast. The broadcast data is transmitted in EDV mode or DV mode and may not have a response in some situations.

One frame body of the broadcast data contains only one MSDU.

7.3.2.1.4 Response

Response PSDU, which is used as a response to long PSDU in transaction, reports the reception situation of transmitted long PSDU.

7.3.2.2 Variant Field (VF)

The contents of an 11-bit long variant field are determined by the form of the delimiter.

7.3.2.2.1 Unicast Data

VF format of unicast data PSDU is shown in Fig. 32.

NSB				DVF	TMI					
20	19	18	17	16	15	14	13	12	11	10
4 bits				1 bit	6 bits					

Fig. 32 - VF Format of Unicast Data (DT=000)

7.3.2.2.1.1 Number of Symbol Blocks (NSB)

NSB field is a 4-bit field expressing the length of a data frame in the number of symbol blocks. [MIN, MAX] of NSB field is [1, MAX_SYMBLOCK_NUM]. STAs can carry out virtual carrier sense by using this field.

7.3.2.2.1.2 Diversity Flag (DVF)

DVF field lets us know whether DV mode has been used as unicast data PSDU transmission mode. Unicast data PSDU is transmitted in EDV mode in case of binary number '0' and in DV mode in case of binary number '1'.

7.3.2.2.1.3 Tone Map Index (TMI)

TMI field indicates the reception TMI for receiving STA to decode received unicast data PSDU. Every STA receiving unicast data PSDU checks whether the reception tone map indicated in TMI field is stored, and decodes unicast data PSDU only when corresponding TMI exists.

In TMI field, TMIs from 0 to 63 can be expressed. TMI that unicast data PSDU transmitted in NORMAL mode can have is from 1 to 63, which means that one STA can communicate in NORMAL mode with up to 63 STAs at the same time. When TMI is 0, it shows that unicast data PSDU is transmitted in EDV mode.

TMI field is effective only when DVF field is binary number '0'. If DVF field is binary number '1', TMI is '0' and then ignored.

7.3.2.2.2 Management

VF format of management PSDU is shown in Fig. 33.

NSB				TSF	RF	BF	Rsvd			
20	19	18	17	16	15	14	13	12	11	10
4 bits				1 bit	1 bit	1 bit	4 bits			

Fig. 33 - VF Format of Management (DT = 010)

7.3.2.2.2.1 Number of Symbol Blocks (NSB)

It is equal to NSB field of unicast data PSDU.

7.3.2.2.2.2 Training Sequence Flag (TSF)

If TSF field is binary number ‘1’, management PSDU refers to TS for channel estimation. STA receiving TS obtains the tone map by calculating channel Signal-to-Noise Ratio (SNR).

If TSF field is binary number ‘1’, NSB field is always MAX_PSDU_LENGTH.

7.3.2.2.2.3 Response Flag (RF)

RF field indicates whether there is response PSDU to transmitted management PSDU. If there is a response, it is binary ‘1’ and if not, it is ‘0’.

7.3.2.2.2.4 Broadcast Flag (BF)

BF field shows whether management PSDU is transmitted via broadcast. If BF field is binary number ‘1’, it means broadcast. If it is ‘0’, it means unicast.

Management PSDU is divided into unicast management PSDU and broadcast management PSDU by BF field.

7.3.2.2.3 Broadcast Data

VF format of broadcast data PSDU is shown in Fig. 34.

NSB				DVF	RF	Rsvd				
20	19	18	17	16	15	14	13	12	11	10
4 bits				1 bit	1 bit	5 bits				

Fig. 34 - VF Format of Broadcast Data (DT = 011)

7.3.2.2.3.1 Number of Symbol Blocks (NSB)

NSB is the same as NSB field of unicast data PSDU.

7.3.2.2.3.2 Diversity Flag (DVF)

DVF field lets us know whether DV mode is used as broadcast data PSDU transmission mode. It indicates EDV mode in case of binary number ‘0’ and DV mode in case of ‘1’.

7.3.2.2.3.3 Response Flag (RF)

RF field indicates whether there is response PSDU to transmitted broadcast data PSDU. If there is a response, it is binary '1' and if not, it is '0'.

7.3.2.2.4 Response

VF format of response PSDU is shown in Fig. 35.

RET	Rsvd		SRB	SN						
20	19	18	17	16	15	14	13	12	11	10
1 bit	2 bits		1 bit	7 bits						

Fig. 35 - VF Format of Response (DT = 101)

7.3.2.2.4.1 Return (RET)

The definition of RET is shown in Table 11.

Table 11 - Types of Response Form

RET	Definition	Contents
0	ACK	No DFCS error in the received long PSDU.
1	FAIL	Receiving STA has no resources to process the received long frame.

7.3.2.2.4.2 Slot Reservation Bit (SRB)

SRB is used to reserve N number of slots within the contention window starting after response PSDU followed by SCIFS. If SRB of response PSDU is binary number '1', STAs that have sensed it shall not participate in contention for the time period indicated in SN, and either enable STA that have transmitted response PSDU to start transaction in time slot #0 or enable STA supporting Quality of Service (QoS) to transmit a packet without contention in N number of time slots reserved in advance.

SR can be used only when the last segment flag field of the frame header of the received long frame is binary number '1'. (refer to 7.6)

7.3.2.2.4.3 Sequence Number (SN)

If SRB is '0', this field is a 7-bit SN for ARQ. Its value shall be copied from SN field in the frame header of received long PSDU.

If SRB is '1', this field indicates the time slots for which STAs that have received it shall wait without participating in contention. In this standard, SN shall be fixed to '1' if SRB is '1'.

7.3.2.3 Version Control (VC)

VC field of 2-bit length is always binary number '00'. All STAs, when receiving a frame with VC field of not '00', discards the frame and carries out virtual carrier sense.

7.3.2.4 Control Frame Check Sequence (CFCS)

CFCS, which is an 8-bit CRC to the 16-bit control frame information, is obtained through the following formula.

$$CRC_1(x) = x^k * (x^7 + x^6 + x^5 + \ldots + x^2 + x + 1) \bmod G(x)$$
$$CRC_2(x) = M(x) * x^8 \bmod G(x)$$

CRC is obtained by taking the one's complement of the modulo-2 sum of CRC1 and CRC2. Every CRC register shall be first set to ‘1’.

Here, the message polynomial is

$$M(x) = m_{23}x^{15} + m_{22}x^{14} + \ldots + m_9 x + m_8$$

The generator polynomial is

$$G(x) = x^8 + x^2 + x + 1$$

The check polynomial is

$$CRC(x) = c_7x^7 + c_6x^6 + c_5x^5 + c_4x^4 + c_3x^3 + c_2x^2 + c_1x + c_0$$

7.3.3 Data Frame (DF)

DF, which only exists in long PSDUs, is composed of frame header, frame body, block padding, and DFCS as shown in Fig. 30.

7.3.3.1 Frame Header

7.3.3.1.1 Frame Header Format

The 20-byte long frame header is included in all kinds of long PSDU. The frame header contains information about long PSDU not dealt with in the control frame. Its format is shown in Fig. 36.

MSB LSB

SN	LSF	SC	NFBB	FPV	GID	DSID	SSID
159 . . 153	152	151 . 148	147 . 144	143 142	141 . . 96	95 94 . . . 49 48	47 46 . . . 1 0
7 bits	1 bit	4 bits	4 bits	2 bits	46 bits	48 bits	48 bits

Fig. 36 - Frame Header Format

7.3.3.1.2 Field Definitions

7.3.3.1.2.1 Source STA Identifier (SSID)

SSID field indicates the STA identifier of source STA that has transmitted PSDU. The STA identifier is a 6-byte long unique STA identifier designated to each STA in advance.

7.3.3.1.2.2 Destination STA Identifier (DSID)

DSID field indicates the STA identifier of destination STA to receive PSDU.

When the response flag of the variant field is binary number ‘1’ within broadcast data PSDU and broadcast management PSDU, DSID field indicates STA ID of proxy STA to transmit response PSDU. Proxy STA enables partial ARQ, enhancing the reliability of broadcast communication.

If the response flags of VF in broadcast data PSDU or broadcast management PSDU are ‘0’, DSID field shall be ‘0’ and then ignored.

7.3.3.1.2.3 Group Identifier (GID)

46-bit long GID given to each STA distinguishes cells - logical groups existing in the same physical network. GID enables unlimited number of logical groups to coexist within the same physical network.

STA can communicate with only STAs that have same GID of the STA itself.

7.3.3.1.2.4 Frame Protocol Version (FPV)

FPV indicates the version of the currently using frame protocol. It is binary number ‘00’ in the current protocol version; all frames with any other version shall be ignored.

7.3.3.1.2.5 Number of FBB (NFBB)

NFBB indicates the number of FBBs contained in the frame body. NFBB field is always greater than or equal to ‘1’.

7.3.3.1.2.6 Segment Count (SC)

Segment count is the sequence number increasing for each segment transmitted in case of segmentation. The segment count is used for STA receiving long PSDU in SEG transaction combo to sense duplicate or erroneous sequence number.

The first segment begins with binary number ‘0000’ and increases by one in case of segmentation. If segmentation has not occurred, it is always binary number ‘0000’.

7.3.3.1.2.7 Last Segment Flag (LSF)

LSF field lets us know whether PSDU to be transmitted in case of segmentation is the last segment or not. Binary number ‘1’ indicates that it is the last segment. If segmentation has not occurred, it always indicates binary number ‘1’.

7.3.3.1.2.8 Sequence number (SN)

SN is a 7-bit sequence number for duplicate detection and ARQ. SN is the sequence number increasing after being classified by service block (i.e FBB).

For ARQ, STA which transmitted long PSDU shall check whether SN field of response PSDU has an equal value with the transmitted SN value and it is the response to transmitted long PSDU, and decides whether to carry out retransmission or not.

Duplicate detection shall be carried out by STA receiving a long frame containing MSDU. STA receiving unicast data PSDU transmitted in NORMAL mode shall carry out duplicate detection by using SN field. For this, each STA shall manage SN separately with each STA that has been linked to the STA itself when it has a tone map for linked STA. On the contrary, STA receiving broadcast data PSDU in which the VF response flag is binary number ‘1’ stores DSID and SN to carry out duplicate detection.

In cases of broadcast data PSDU and broadcast management PSDU, where both of them do not have a response, SN field shall be binary number ‘0000000’ and then ignored.

7.3.3.2 Frame Body

The frame body, referring to MPDU payload, indicates the data state before being processed in PHY in symbol block units. Each frame body contains either MSDU or MMI. This means that MSDU and MMI cannot co-exist in one long PSDU.

Whether the frame body contains MSDU or MMI is determined by the form of the delimiter. For example, the frame body of unicast data PSDU and broadcast data PSDU contain MSDU, and that of management PSDU contains MMI.

7.3.3.2.1 Frame Body Format

The frame body is composed of more than one FBB as in Fig. 37. The size of the entire frame body is a multiple of 4 bytes and each FBB means a service block.

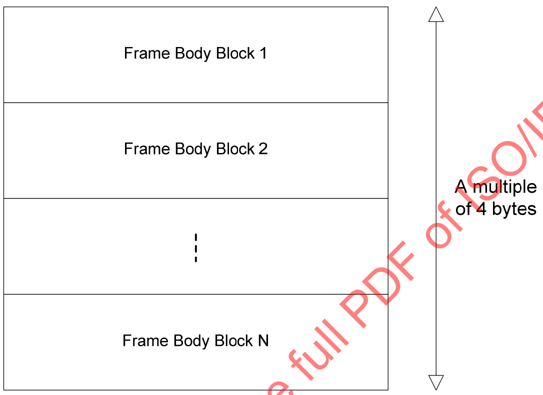

Fig. 37 - Frame Body Format

7.3.3.2.2 Frame Body Block (FBB) Format

FBB, which refers to a service block, is composed of FBB header, payload, and padding. The format of FBB is shown in Fig. 38.

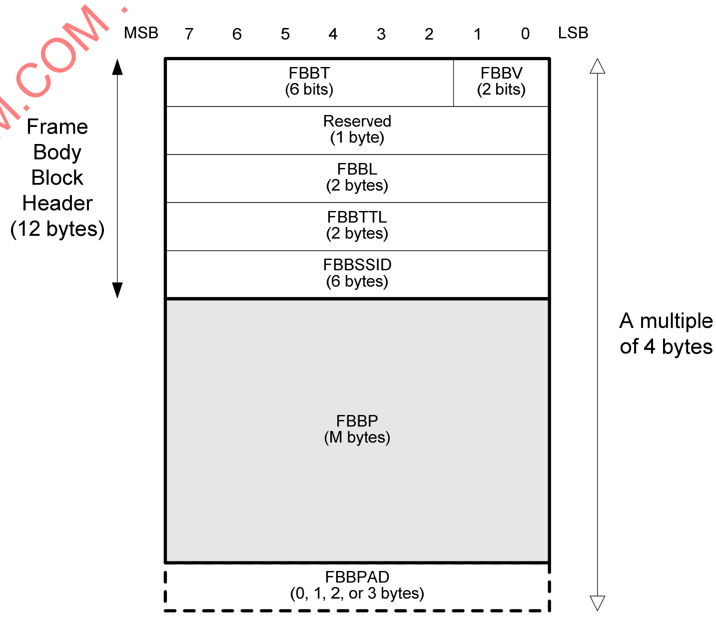

Fig. 38 - FBB Format

7.3.3.2.2.1 Frame Body Block Version (FBBV)

FBBV is the field indicating the FBB version and changes when new FBBT is added. If FBBV is not binary number '00', corresponding FBB is discarded through FBBL field and the next FBB is processed.

7.3.3.2.2.2 Frame Body Block Type (FBBT)

FBBT indicates the type of FBB. FBBT is defined as follows in Table 12.

Table 12 - Definition of FBBT

FBBT	Definition	Data Form	Related PSDU	FBBL (byte)	FBBPAD*
000000	Ethernet Frame	MSDU	Unicast Data & Broadcast Data	Variable	Variable
000001	Serial Data	MSDU	Broadcast Data	Variable	Variable
000010	TS	MMI	Unicast Management (Management)	144	0
000011	CE Result	MMI	Unicast Management (Management)	63	1
000100	Proxy Demand	MMI	Broadcast Management (Management)	0	0
000101	Proxy Supply	MMI	Broadcast Management (Management)	0	0
000110	TM Unavailable	MMI	Unicast Management (Management)	0	0
000111~111111	Reserved	N/A	N/A	N/A	N/A

* The size of FBBPAD indicates the minimum number added to make the size of FBB a multiple of 4 bytes. The size of FBBPAD can have the values of 0,1,2 or 3 bytes.

If FBBT can not be recognized, corresponding FBB is discarded through the following FBBL field and the next FBB is processed.

7.3.3.2.2.3 Frame Body Block Length (FBBL)

FBBL is the field expressing the length of FBB payload in byte units.

7.3.3.2.2.4 Frame Body Block Time To Live (FBBTTL)

FBBTTL indicates the maximum number of cells that FBB can move through a cell bridge. FBBTTL decreases by one when FBB moves from a cell to another through a cell bridge. If FBBTTL is '0', FBB shall be discarded.

FBBTTL is used to prevent broadcast FBB from being stuck in infinite retransmission through the cell bridge.

7.3.3.2.2.5 Frame Body Block Source STA Identifier (FBBSSID)

FBBSSID indicates the STA identifier which has generated corresponding FBB first.

FBBSSID is used to prevent the transmitted FBB from returning to source STA through the cell bridge.

7.3.3.2.2.6 Frame Body Block Payload (FBBP)

The format of FBBP is divided as follows according to FBBT.

7.3.3.2.2.6.1 Ethernet Frame

The ethernet frame of MSDU refers to the data that have descended from IEEE 802.3 layer through MI. The ethernet frame defined in this standard means the ethernet frame of IEEE 802.3 or DIX 2.0 without 8-byte long preamble.

The [MIN, MAX] of the ethernet frame transmitted in unicast data PSDU or broadcast data PSDU is [MIN_ETHERNET_BYTES, MAX_ETHERNET_BYTES].

7.3.3.2.2.6.2 Serial Data

The serial data classified as MSDU refers to the data that have descended from the serial host through the MI.

7.3.3.2.2.6.3 Training Sequence (TS)

The FBBT format of TS used for channel estimation is shown in Table 13.

Table 13 - FBBP Format of TS

Field	Byte	Bit	Number of Bits	Definition
TSR	0	[0:0]	1	TS request
Reserved		[7:1]	7	Reserved
PRS	1	[7:0]	1144	Pseudo-Random Sequence
	2	[7:0]		
	:	:		
	142	[7:0]		
	143	[7:0]		

● Training Sequence Request (TSR)
TSR field is used when source STA transmitting TS requests TS from destination STA receiving it. If TSR field is binary number '1', STA that has received it transmits TS immediately after the channel estimation procedure has been successfully finished and completes the interactive channel estimation.

TSR field is used for initial link connection with new STA.

● Pseudo-Random Sequence (PRS)
1144-bit long PRS field uses the pre-designated sequence of which the period is 511 for accurate channel SNR measurement. (refer to 7.8.3)

7.3.3.2.2.6.4 Channel Estimation (CE) Result

The FBBP format of the channel estimation result is shown in Table 14.

Table 14 - FBBP Format of Channel Estimation Result

Field	Byte	Bit	Number of Bits	Definition
SID	0	[7:0]	48	STA ID

	1	[7:0]		
	2	[7:0]		
	3	[7:0]		
	4	[7:0]		
	5	[7:0]		
Reserved	6	[0:0]	1	Reserved
PUNCI		[1:1]	1	Puncturing Index
AG		[7:2]	6	AGC Gain
TMI	7	[5:0]	6	Tone Map Index
BPS		[7:6]	10	Bits Per Symbol
	8	[7:0]		
Reserved	9	[7:0]	24	Reserved
	10	[7:0]		
	11	[7:0]		
TM	12	[1:0]	2	Tone Map(Tone #0)
		[3:2]	2	Tone Map(Tone #1)
		[5:4]	2	Tone Map(Tone #2)
		[7:6]	2	Tone Map(Tone #3)
	13	[1:0]	2	Tone Map(Tone #4)
		[3:2]	2	Tone Map(Tone #5)
		[5:4]	2	Tone Map(Tone #6)
		[7:6]	2	Tone Map(Tone #7)
	:	:	:	:
	74	[1:0]	2	Tone Map(Tone #248)
		[3:2]	2	Tone Map(Tone #249)
		[5:4]	2	Tone Map(Tone #250)
		[7:6]	2	Tone Map(Tone #251)
	75	[1:0]	2	Tone Map(Tone #252)
		[3:2]	2	Tone Map(Tone #253)
		[5:4]	2	Tone Map(Tone #254)
		[7:6]	2	Tone Map(Tone #255)

- STA Identifier (SID)

This indicates the STA identifier that has generated the Channel Estimation (CE) result.

- Puncturing Index (PUNCI)

This is the field indicating whether puncturing has been used or not. If it is set, it means that puncturing has been used when tone map is generated. If it is binary number '0', the convolutional code rate is 1/2, and if it is '1', the convolutional code rate is 3/4.

- AGC Gain (AG)

This is the reception AGC gain value to TS used for channel estimation.

- Tone Map Index (TMI)

TMI field contains the index that indicates the generated tone map. STA receiving the CE result uses the index at TMI field of the control frame when transmitting unicast data PSDU in NORMAL mode to STA that generated the CE result.

- Bits Per Symbol (BPS)

This indicates the number of bits allocated to the entire tone at the time of the tone map being generated.

- Tone Map (TM)

This indicates the number of bits that have been allotted to each tone. D8PSK is given 3-bit, so the [MIN, MAX] of the bits that can be allotted to each tone is [0, 3]. The tone map contained in the CE result indicates the reception tone map for STA that generated the CE result, or the transmission tone map for STA that received the CE result.

7.3.3.2.2.6.5 Proxy Demand

Proxy demand, used by STAs without configured proxy STA, shall be always transmitted as a broadcast management PSDU. FBBP and Frame Body Block Padding (FBBPAD) do not exist for proxy demands, for it has FBBL 0.

7.3.3.2.2.6.6 Proxy Supply

Proxy supply, a response to the proxy demand, is transmitted as broadcast management PSDU by STAs that have received proxy demand. Proxy supply does not have FBBP or FBBPAD, for it has FBBL 0.

7.3.3.2.2.6.7 Tone Map (TM) Unavailable

TM unavailable shall be transmitted instead of the CE result when there is no space for storing a new tone map for NORMAL mode communication because STA that received TS is linked with more than 63 STAs. STAs that received and transmitted TM unavailable shall use EDV mode when transmitting unicast data PSDU. STA that transmitted TM unavailable registers receiving STA on the routing table. After that, if STA that transmitted TM unavailable becomes to have any space for storing tone map, it shall carry out interactive channel estimation by transmitting TS to STA that received TM unavailable.

TM unavailable has no FBBP or FBBPAD, for it has FBBL 0.

7.3.3.2.2.6.8 Frame Body Block Padding (FBBPAD)

FBBPAD, the additional byte making FBB a multiple of 4-bytes, changes according to FBBL. The size of FBBPAD is always 0,1,2, or 3.

7.3.3.3 Block Padding

MPDU is processed in 16-symbol-long symbol blocks through FEC in PHY to form a data frame. Block padding is the supplementary bytes that are attached if the data byte size of the last symbol block is less than the number of maximum data bytes per symbol block. The block padding shall be removed at the reception end through FBBL field of each FBB and NFBB field of the frame header.

The length of the block padding is always $2 + 4*m$ ($m \geq 0$) bytes and guarantees that the size in bytes of the entire data frame including 2-byte long DFCS is a multiple of 4.

7.3.3.4 Data Frame Check Sequence (DFCS)

DFCS is a 16-bit CRC of frame header, frame body and block padding, and is contained in all long PSDUs. The implementation of DFCS is described in "6.3.2 Cyclic Redundancy check (CRC)".

7.4 Address Resolution

Address resolution is carried out as follows through GID, SID and routing table allotted to each STA.

7.4.1 Basic Rules on Communication

All communication shall be carried out only between STAs with identical GID. GID distinguishes logical groups (cells) that can co-exist in the identical physical network. If a frame contains different GID, STAs shall discard it and carry out virtual carrier sense.

Address resolution between STAs with identical GID is achieved through SID, a unique STA identifier. If there is ethernet in the upper link layer, the STA identifier mapped with the upper layer MAC address is included in SSID and DSID fields within the frame header and is used as the source and destination address in the communication between STAs.

From the standpoint of receiving STA, every STA shall decode the data frame and take proper measures if VC field of the control frame of received long PSDU is binary number '00' and at the same time, DSID field of frame header of PSDUs with same GID indicates its own STA identifier. STAs that have received broadcast data PSDU and broadcast management PSDU shall decode the data frame even when DSID field does not indicate their own STA ID. Unicast data PSDU transmitted in NORMAL mode can be decoded only when the tone map presented by TMI field of the control frame is stored. If STA that received unicast data PSDU does not have the tone map indicated by TMI, it shall carry out virtual carrier sense. If two or more STAs have the same TMI but different tone map, a DFCS error occurs in STA without the correct tone map, and only actual destination STA can decode the data frame.

7.4.2 Routing Table (RT) Management

Every STA shall have a routing table storing the following information with respect to each STA linked to it.

- SID
- MAC address (when the link layer is IEEE 802.3 ethernet)
- My Tone Map Index (MTMI)
- Partner Tone Map Index (PTMI)
- link timer

Each STA shall store and manage the information on other STAs in their own routing table for various kinds of communication. Basically, when there is ethernet in the link layer, every STA doesn't have to know what its own MAC address is. Therefore, the routing table only has the information on other STAs.

STA registration with the routing table is performed through the reception of long PSDU. SID, MTMI and PTMI are stored through the process of channel estimation. Such information enables NORMAL mode communication. MAC address exists when there is ethernet in the link layer and it means the source MAC address of MSDU received from partner's STA. The link timer is the value increasing per symbol after link connection with partner's STA and is used to disconnect the link if there is no communication for a long time.

The information stored in the routing table is renewed when long PSDU is received. Deletion of information registered on the routing table is carried out in the following cases.

- Case 1: When the link timer exceeds the MAX_LINK_LIFETIME
- Case 2: Transmission of long PSDU to STA registered on the routing table has been failed

Deletion of the information registered on the routing table means that STA's system is turned off. In case 1, STA determines whether the system is turned off or not by using the link timer that keeps increasing after link connection is formed with STA. The link timer becomes 0 when unicast MSDU to be transmitted to STA on the routing table descends from the upper layer, or unicast MSDU is received from STA. Case 2 is when there is no response while trying to retransmit MAX_EDV_TRY_NUM or MAX_DV_TRY_NUM number of times, and is described in Fig. 26.

If there is no space for storing a new tone map or there is no tone map because it is the instance before initial channel estimation, there might be an instance when STA exists in the routing table with only SID, MAC address and link timer.

Transmission and reception of long PSDU including MMI is not related to the upper layer, so it is carried out only through SID regardless of the MAC address.

7.5 Interactive Operation with Link Layer

MAC presented in this standard is a method supporting the ethernet and serial host. From the upper link layer viewpoint, the PLC network is seen as a LAN. The MAC layer transmits MSDU descending from the link layer through PHY and MSDU ascending from PHY to the link layer. In this chapter, only MSDU including the ethernet frame descending from the IEEE 802.3 ethernet is dealt with.

7.5.1 Flow From Link Layer to PHY

When MSDU including the ethernet frame descending from the link layer is transmitted to PHY, the form of delimiter and transmission mode are determined as in Fig. 39.

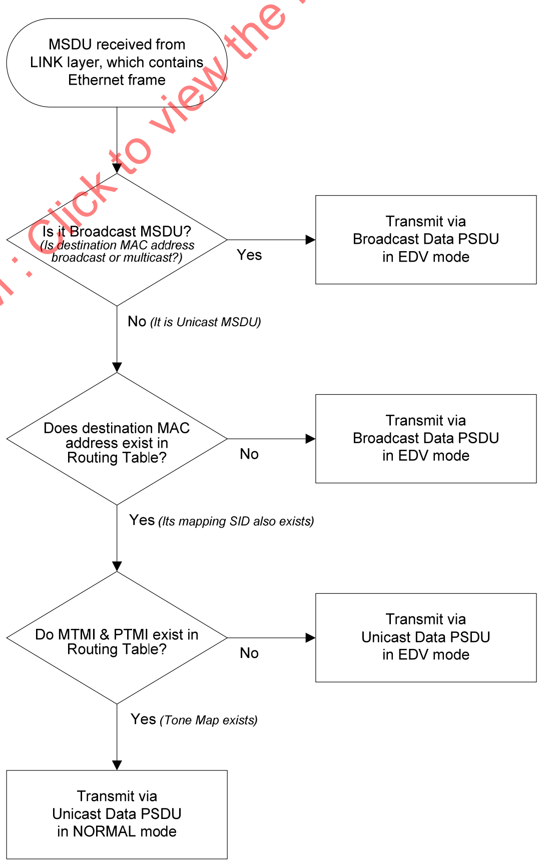

Fig. 39 - Flowchart for Settlement of Delimiter Form and Initial Transmission Mode

When destination address exists in the routing table but there is no MTMI and PTMI, i.e. no tone map, NORMAL mode transmission shall be carried out by carrying out channel estimation and generating transmission/reception tone map. Between two STAs receiving TM unavailable, unicast data PSDU is transmitted in EDV mode as shown in Fig. 39.

7.5.2 Flow From PHY to Link Layer

When receiving STA receives non-duplicate unicast data PSDU with DSID field indicating its own SID, or when it receives non-duplicate broadcast data PSDU, STA sends MSDU included in PSDU to an upper link layer regardless of the source/destination MAC address.

7.6 Priority Classification

Slot reservation method shall be used for priority classification. Slot reservation shall be the process of STA transmitting PSDU in response to long PSDU, reserving in advance the time slot of the contention window that starts after SCIFS. The process of STA B receiving long PSDU from STA A and transmitting long PSDU to STA A through slot reservation method is illustrated in Fig. 40.

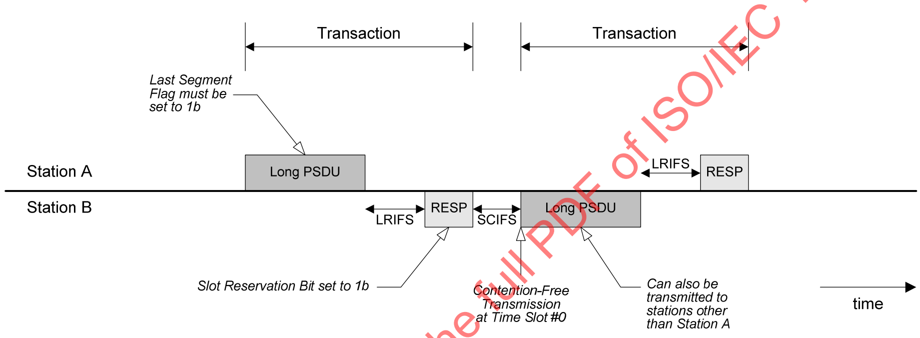

Fig. 40 - Priority Classification by Slot Reservation

Slot reservation shall be available when the last segment flag of long PSDU, received by STA to carry it out, is binary number ‘1’. STA carrying out slot reservation shall make the slot reservation bit field of control frame of response PSDU binary number ‘1’. Every STA that senses it shall not participate in contention for the time slot indicated in SN. Therefore, STA that transmitted response PSDU with SRB field set to ‘1’ can start transaction at time slot #0 or transmit a packet without contention at N number of time slots.

There is no limitation on the destination of long PSDU transmitted through the slot reservation method. This means that, unlike the example in Fig. 40, the destination of long PSDU transmitted through slot reservation by STA B may become STA other than STA A.

The slot reservation method can be used by any STAs, and is used when STA transmitting response PSDU has in its transmission queue management PSDU that must be transmitted immediately. For example, STA that received TS through channel estimation transmits the result of the channel estimation corresponding to it by using the slot reservation method.

CB, which is STA connecting two separate cells (two logical networks), always uses the slot reservation method when it is necessary to relay received long PSDU to another cell. (refer to 7.10)

7.7 Proxy Setting Procedure

Proxy STA is STA that replies - as the representative of all STAs within a logical network that receive broadcast data PSDUs or broadcast management PSDU with RF field set to ‘1’ - response PSDU. Proxy STA enables partial ARQ for broadcast.