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TECHNICAL SPECIFICATION

Access, Terminals, Transmission and Multiplexing (ATTM);
Plastic Optical Fibres;
Part 1: Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s;
Sub-part 2: 1 Gbit/s and 100 Mbit/s physical layer for Plastic Optical Fibres

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document is part 1, sub-part 2 of a multi-part deliverable covering Plastic Optical Fibre, as identified below:

Part 1: "Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s";

  Sub-part 1: "Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s";

  Sub-part 2: "1 Gbit/s and 100 Mbit/s physical layer for Plastic Optical Fibres".

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1 Scope

The present document provides a description of an OSI physical networking layer to communicate data over plastic optical fibre at 100 Mbit/s and 1 000 Mbit/s. A full duplex physical layer is described.

Multi data type interface is proposed, as well as its encapsulation, coding and modulation needed to achieve 1 Gbit/s link over a bandwidth limited optical channel like the plastic optical fibre. Multiple link speeds are handled by this physical layer.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

[1] IEC 60793-2-40: "Optical fibres - Part 2-40: Product specifications - Sectional specification for category A4 multimode fibres".

[2] ANSI/EIA/TIA-455-127-1991, FOTP-127/61.1 :"Spectral Characterization of Multimode Laser Diodes".

[3] IEC 61754-20: "Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces - Part 20: Type LC connector family".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ISO/IEC 11801: "Information technology - Generic cabling for customer premises".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

adaptive bit rate: capacity of PHY to adapt the bit rate as a function of the channel conditions and signal quality in coordination with the link partner

bose, ray-chaudhurim hocquenghem: in coding theory the BCH codes form a class of parameterized error-correcting codes, being its main advantage the ease with which they can be decoded using elegant algebraic methods

cyclic redundancy check: error detecting code designed to detect accidental changes to raw data

control cyclic redundancy check: CRC employed to check the integrity of data in PDB.CTRL blocks

data cyclic redundancy check: CRC employed to check the integrity of an encapsulated data packet and which is included in the PDB.CTRL block signalling the end of packet

error vector magnitude: measure of the deviation between the actual signals compared to the ideal signals, commonly defined in statistical terms

extinction ratio: ratio between the maximum and the minimum power of a given optical signal

forward error correction: technique used for controlling errors in data transmission over unreliable or noisy communication channels

jitter: time deviations of the signal arrival from its nominal timing

link: transmission path between any two interfaces of generic cabling, see ISO/IEC 11801 [i.1]

low power idle: time periods where the Physical Layer transmission is switched off to reduce the energy consumption, when no user data is available to transmit

multi-level cosset code: forward error correcting technique consisting on splitting the information bit stream among several levels, for each one a binary component code is employed with an error correction capability according to the reliability experienced by each level in data transmission over noisy channels

optical modulation amplitude: difference between the maximum and the minimum power of a given optical signal

pulse amplitude modulation: form of signal modulation where the message information is encoded in the amplitude of a series of signal pulses

physical data block: minimum data unit of 65 bits used to encapsulate the user information received from any PHY interface

physical control data block: special case of PDB used to carry control information between encapsulator and de-encapsulator to identify parameters of a data packet like length or protocol, and to check the data integrity

physical idle data block: special PDB.CTRL blocks used by encapsulator for continuous transmission over the physical communication channel when no user data are available for encapsulation received from the data interface

physical padding data block: special case of PDB.CTRL block inserted in user data encapsulation to carry out the rate matching between the PHY interfaces and PHY bit-rate, when PHY bit-rate is greater than the interface bit-rate

physical header data: information carried by the header sub-blocks inside the frame structure and used for control and negotiation of PHY parameters between both link ends

physical header subframe: block of 128 symbols prepended and appended by 16 zeroes that represents the minimum transmit unit in which the PHD is divided after encoding and modulation and used to spread the PHD information along one frame

signal to noise ratio: ratio between the average power of signal and the average power of noise in a given point

tomlinson-harashima precoding: coding technique by which the communication transmit signal pre-equalizes a known inter-symbol interference without power penalty, providing communication signal at the output of channel without post-cursor inter-symbol interference

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ABR	Adaptive Bit Rate
AC	Alternate Current
AOP	Average Optical Power
BCH	bose, ray-chaudhurim hocquenghem
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCRC	CRC of current PDB
CMB	Physical Coding and Modulation Blocks

CRC	Cyclic Redundancy Code
CW	Code Word
DAC	Digital to Analogue Converter
DCRC	CRC of Data PDB
EO	Electro Optical Interface
ER	Extinction Ratio
EVM	Error Vector Magnitude
FEC	Forward Error Correction
FER	Frame Error Rate
FS	Symbol Frequency
IDLE	Idle
IEC	International Electrotechnical Commission
IL	Insertion Losses
ISO	International Organization for Standardization
IT	Information Technology
LC	Little Connector
LED	Light Emitting
LFSR	Linear Feedback Shift Register
LPI	Low Power Idle
LSB	Less Significant Bit
MLCC	Multi Level Cosset Code
MLS	Maximum Length Sequence
NMLCC	Length of the MLCC code word in 1D (PAM) symbols
OFF	Off state
OMA	Optical Modulation Amplitude
ON	On state
OSI	Open Systems Interconnection
PAD	Padding
PAM	Pulse Amplitude Modulation
PDB	Physical Data Block
PDB-ER	PDB Error Rate
PHD	Physical Header Data
PHS	Physical Header Subframe
PHY	Physical
POF	Plastic Optical Fibre
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
RMS	Root-Mean-Square
RX	Reception
SF	Scaling Factor
SNR	Signal to Noise Ratio
TH	Tomlinson-Harashima
THP	Tomlinson-Harashima Precoder
TIA	Trans Impedance Amplifier
TX	Transmission
VCSEL	Vertical Cavity Surface-Emitting Laser

4 1 Gbit/s and 100 Mbit/s data rate physical layer for plastic optical fibre

4.1 Physical layer objectives

The following are the objectives of the PHY:

- Provide 1 Gbit/s and 100 Mbit/s full duplex data transmission.
- Provide speeds less than 1 Gbit/s and 100 Mbit/s with adaptive bit rate functionality if communication channel does not provide enough capacity.

- Support operation over Plastic Optical Fibres defined in IEC 60793-2-40 [1] types A4a.2 with the parameters specified in the respective annexes for each PHY.
- Provide a Bit Error Rate (BER) less than or equal to 10^{-12}.
- Provide low power operation mode for power management.

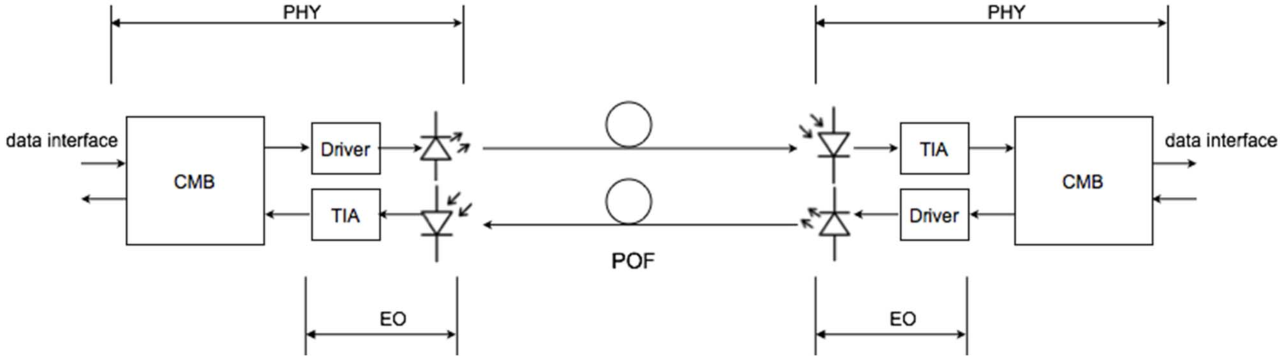

Figure 1: Link topology

Data to be transmitted is provided to the PHY via de TX interface. The PHY generates the linear electrical signal which is converted into optical by the light source via the driver. Optical signal is sent through the fibre and received in the receiver of the other side of the link.

In the receiver the Photo receiver transforms the optical signal into a linear electrical signal with a trans-impedance amplifier (TIA). The PHY transforms back this signal into the transmitted data, and provides it in the Rx interface.

Baseband PAM signalling with a modulation rate that varies with the PHY speed is used. For example, when the speed is 1 000 Mbit/s, the symbol rate is 312,5 MSymbols/s, which results in a symbol period of 3,2 ns. The incoming bits are mapped to PAM symbols using a three level Multi-Level Cosset Code (MLCC). In the first two levels, blocks of bits are encoded using a Bose, Ray-Chaudhuri, Hocquenghem (BCH) code with different coding rates while in the third level bits are not coded.

The PHY can be divided into the following parts:

- Coding and Modulation Blocks (CMB).
- Electro Optical Interface (EO).

4.2 Coding and Modulation Blocks (CMB)

The PHY CMB couples the information in the data interface, to the Electro Optical interface (EO).

The functions performed by the CMB comprise the generation of frames and the mapping of the bits in those frames to PAM symbols using the Multi-Level Cosset Coding technique, and to send them into a Tomlinson-Harashima Precoder (THP), which maps the PAM input into a quasi-continuous discrete time value. Then a power-scaling factor is applied to the symbols and this THP-processed symbol stream is then passed onto a Digital to Analogue Converter (DAC). Finally the analogue signal is sent to the EO interface.

Frames are composed of pilots, a header and data blocks, all of them of fixed length. The pilots are intended to facilitate the receiver initialization and continuous tracking. The header is used to convey physical layer control information. Frames are transmitted continuously to ensure that the receivers are synchronized and the equalizers are aligned to the channel conditions. When no data is being received from the data interface, the blocks of data send the PDB.IDLE pattern described in clause 5.2.3.2. Optionally, the Low Power Idle (LPI) mode can be used together with the PDB.IDLE pattern to reduce energy consumption. The LPI mode is described in clause 5.2.2.

The incoming data is mapped to PAM symbols using a Multi-Level Cosset Coding technique. Depending on the configuration, the bits are divided in up to three levels. In the first two, the incoming bits are encoded using a BCH code while in the third level the bits are left uncoded. Then the resulting bits are mapped to PAM symbols, scrambled and passed to the THP pre-coder and the power adaptation block.

In the transmit direction the CMB receives data packets through the data interface and constructs CMB frames that are then mapped to PAM symbols. In the receive direction, the CMB extracts the information from the received CMB frames and maps them to data packets on the data interface. The receiver is responsible for acquiring symbol timing and equalizing the signal. Both linear and non-linear equalization may be used in the receiver. The reliability of the link is ensured by the CMB Link Monitor function. The CMB PHY Control function controls the CMB operations. PHY Control provides the start-up functions required for successful operation.

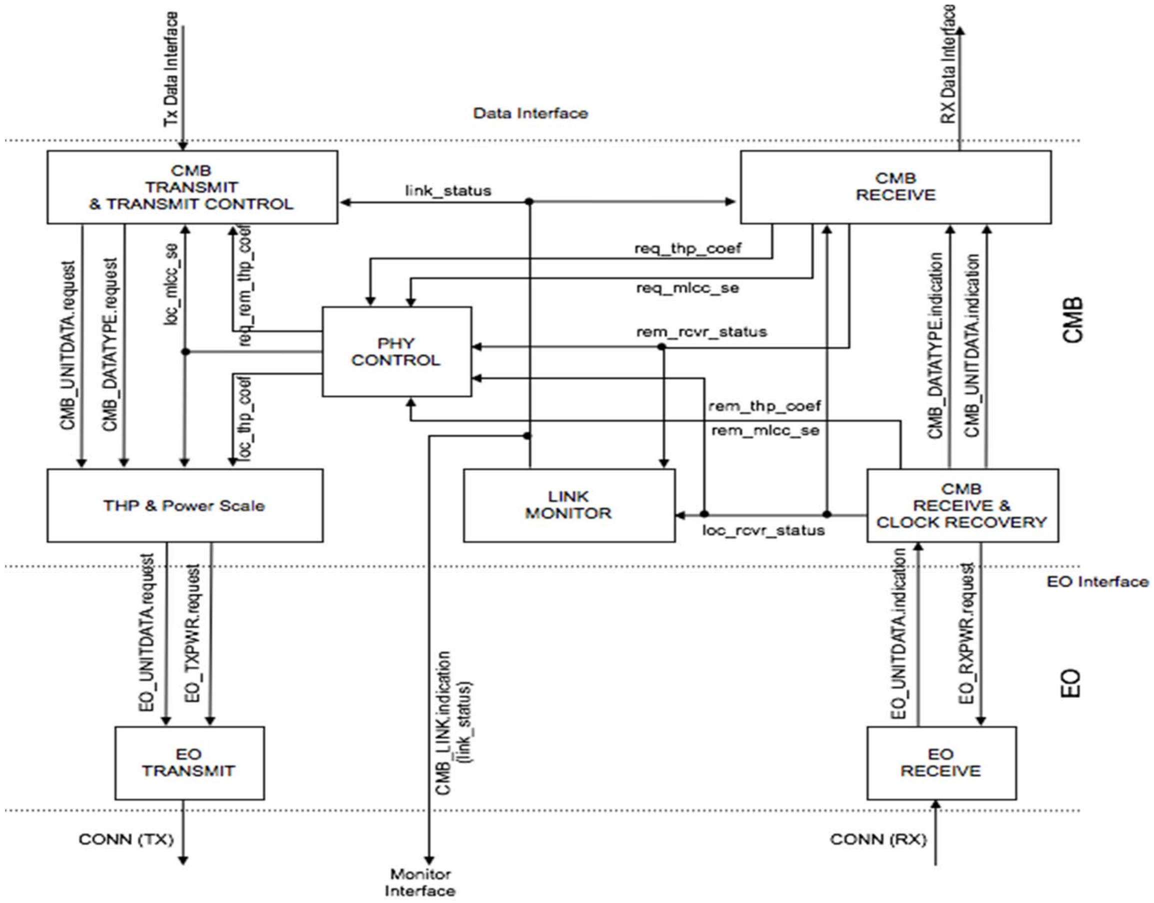

Figure 2: PHY functional block diagram

In figure 2 a block level description of the PHY is shown. Communication between different blocks is also shown. Three different areas are clearly described: the electro optical interface (EO), the coding and modulation blocks (CMB) and the data interface.

4.3 Electro Optical Interface (EO)

The EO specifications detail the characteristics of the optical transmitter and receiver and also of the optical cabling. These are specific for each PHY and are defined in the annexes from A to D specifying each particular PHY.

4.4 Signalling

PHY signalling is performed by the CMB generating symbols to be transmitted on to the EO interface. The signalling scheme achieves a number of objectives including:

a) Forward error correction (FEC) coded symbol mapping for data.

b) Uncorrelated symbols in the transmitted symbol stream.

c) Block framing and other control signals.

d) Energy Efficient operation through the use of the Low Power Idle (LPI) mode.

4.5 Data Interfaces

Several data interfaces can be implemented over the described PHY. The present document does not specify any interface. The present document assumes data transmitted through the data interface is packet oriented vs. continuous stream. On the other hand, there is no limitation on this aspect in the PHY description of the present document.

5 Coding Blocks (CMB)

5.1 CMB introduction

The CMB comprises two functions: CMB transmit and CMB receive.

The CMB couples the data interface to the EO interface. The CMB is defined only in abstract terms and does not imply any particular implementation. Regardless of the implementation used, the optical specifications at the optical output described in clause 7.2 and annexes from A to D shall be met.

The CMB comprises the following functions:

a) CMB Transmit.

b) CMB Receive.

c) PHY Control.

d) Link Monitor.

e) Clock Recovery.

The CMB Receive function receives an electrical signal from the EO and extracts the PAM symbols for the payload and the physical header of the frame. The CMB Receive function is also in charge of equalizing the signal received from the EO. The CMB receive function shall map incoming PAM symbols, decode and unpack the data to be sent to the data interface.

The PHY control function controls the operation of the PHY implementing the state machines for THP coefficients adaptation as well as the optional adaptive bit rate (ABR) to adapt the PHY rate to the channel conditions.

The Link Monitor function determines the status of the link as a function of the local and remote CMB receive status as well as PHY control.

The Clock recovery function is in charge of recovering the transmit clock of the remote PHY from the signal received from the EO, providing a recovered clock valid to properly sample the signal given by the EO_UNITDATA.indication(rx_signal) message.

5.2 CMB transmit function

5.2.1 Introduction to the CMB transmit function

The CMB transmit function maps the incoming data from the data interface onto PAM symbols that are sent to the THP precoder and to the power scaler. The transmission of data at the CMB is structured in frames. The CMB frames consist of pilots, a header and a payload that encodes the user data. All of them are of fixed length. The pilots are intended to aid in the receiver initialization and continuous tracking. The header provides mechanisms for PHY layer signalling between the local and remote devices.

The incoming data from the data interface is encapsulated prior to transmission. Due to the use of the pilots and header, incoming data may need to be buffered before it can be transmitted. The encapsulated data is then scrambled and mapped to PAM symbols using the multilevel cosset coding (MLCC) technique. The CMB Transmit function then, performs THP filtering on the incoming PAM symbols that correspond to the payload data of a frame. Then power scaling is performed to ensure that the Optical Modulation Amplitude (OMA) is the same across the entire frame. Finally, the resulting signal is mapped to an electrical signal that is sent to the EO.

Frames are transmitted continuously in both directions. When there is no data from the data interface the PDB.IDLE pattern is transmitted in the payload of the frame. Optionally, the Low Power Idle (LPI) mode can be used concurrently with the PDB.IDLE pattern to reduce energy consumption.

The CMB Transmit function also carries out the power scaling of all the parts composing the frame, as S1, S2, PHS and payload, as well as the frame building and ordering. Then the resulting signal is mapped to an electrical signal that is sent to the EO.

In addition, the CMB transmit function is in charge of generating the EO_TXPWR.request(tx_pwr) message to the EO, in order to turn off and turn on the transmit optical power when the CMB requests the CMB_DATATYPE.request(PAYLOAD_OFF) message.

5.2.2 Frame structure

A frame comprises pilots, a header and a fixed payload of 225 792 symbols. The pilots and header are divided in sub-blocks and inserted in between the payload sub-blocks. Each header or pilot sub-block is composed of 160 symbols. For pilot and header sub-blocks, the first 16 symbols and the last 16 symbols take value zero. Each payload sub-block is composed of 8 064 symbols that extend an integer number of MLCC code words. The transmission of MLCC code words is aligned with the start of the payload sub-blocks. The code word has a length of 2 016 PAM symbols by default, although this may be configured before CMB initiates the transmission. Other lengths different from 2 016 symbols are reserved for future extensions (see clause 5.2.4.2). For 2 016 symbols length, every payload sub-block consists of 4 MLCC code words.

The frame structure is illustrated in figure 3. The frame is composed of one S1 pilot sub-block, 13 S2 pilot sub-blocks, 14 header sub-blocks and 28 payload sub-blocks. This gives a total of 230 272 symbols. For a symbol frequency of 312,5 MHz the transmission of a frame requires 736,870 4 µs.

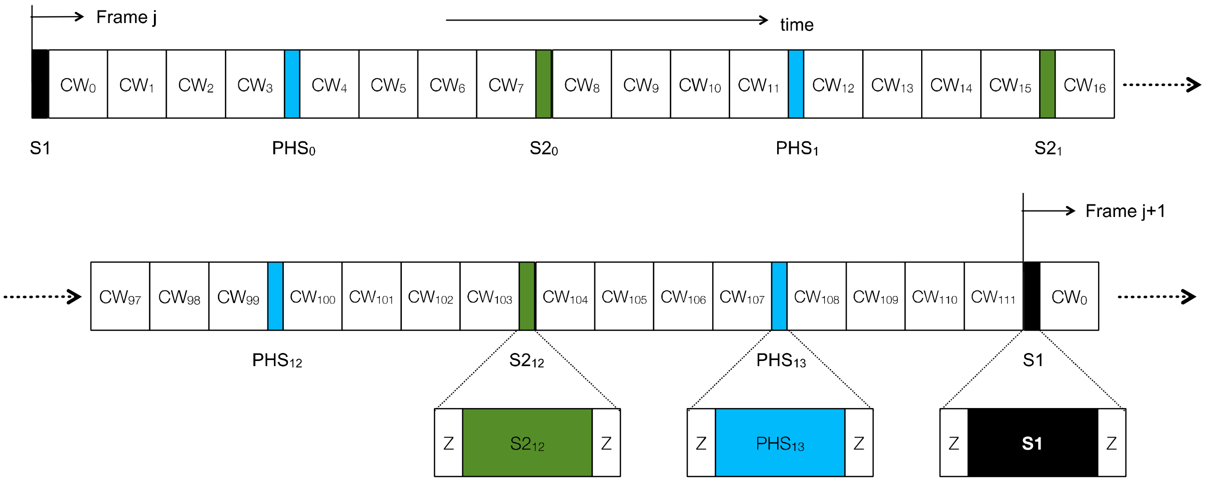

Figure 3: Illustration of the frame structure

As illustrated in figure 3, the pilot (S1, S2x) and header (PHSx) sub-blocks are transmitted once per payload sub-block. The frame always follows the same pattern starting by a S1 block and alternating S2 and PHS sub-blocks, even when the Low Power Idle mode is used.

When both link ends have signalled support for the Low Power Idle mode using the procedure described in clause 5.3.2 the Low Power Idle mode may be used when there is no user data to transmit. The Low Power Idle (LPI) mode shall be signalled by CMB transmit function with parameter tx_type with value PAYLOAD_OFF. The frame with Low Power Idle is illustrated in figure 4. When LPI mode is used all pilot and header sub-blocks are transmitted, but the transmission can be stopped during the payload sub-block frames. This mode always affects complete payload sub-blocks so it is not possible to stop or restart the transmission in the middle of a payload sub-block. The algorithms to determine when to signal LPI as a function of incoming user data from the data interface are left to the implementer.

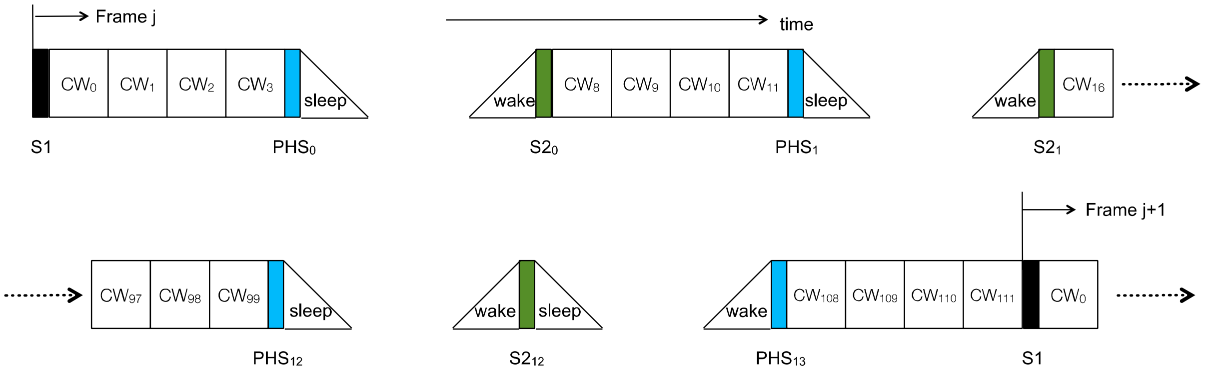

Figure 4: Illustration of the Low Power Idle (LPI) mode

All the sub-blocks of a frame are mapped to PAM symbols for transmission but a different mapping is used in each case. Figure 5 illustrates the process of building a frame showing the mapping for each of the parts of the frame. The figure 5 also shows which sub-clause (CMB or EO) defines each function needed to build a frame.

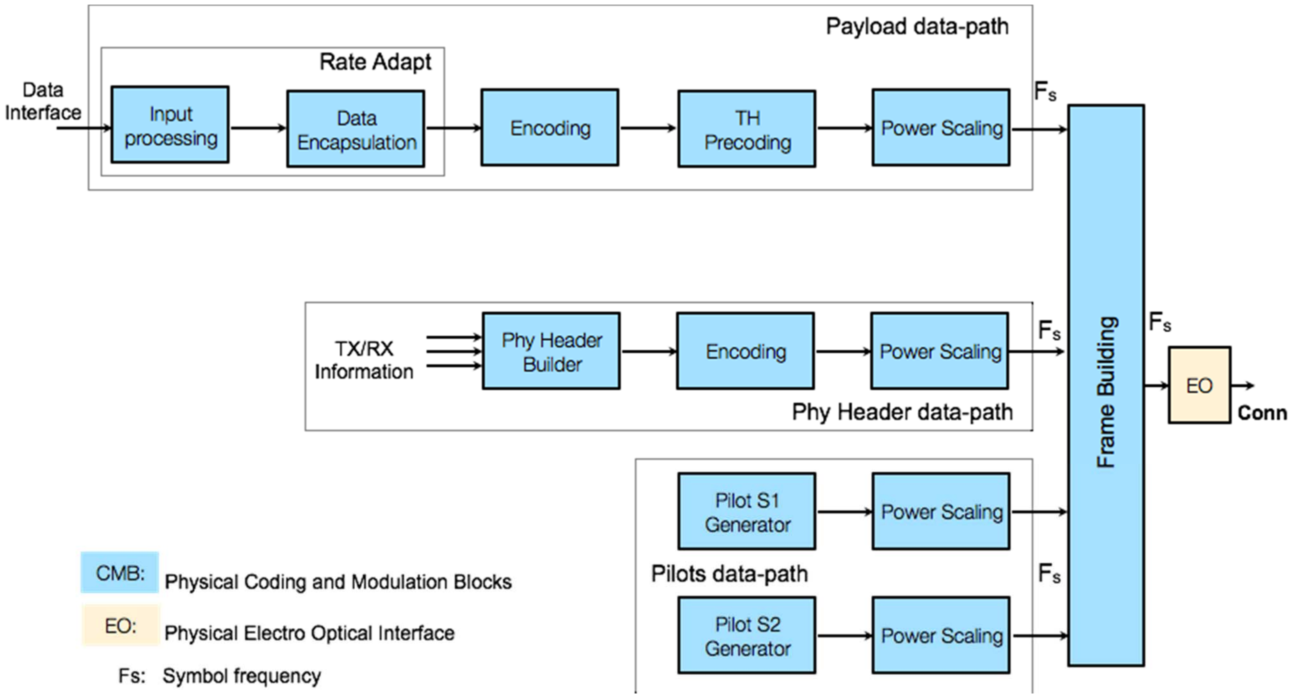

Figure 5: Illustration of the frame building process and the different functional blocks

5.2.3 Payload encoding

5.2.3.1 Introduction to payload encoding

The incoming data from the data interface is first encapsulated for transmission. Then the data is scrambled and mapped to PAM symbols using the MLCC technique. The parameters of the MLCC mapping depend on the speed and reach of the PHY. They are specified for each particular PHY in the corresponding annexes from A to D.

5.2.3.2 Data encapsulation

The incoming data is encapsulated using the two kinds of blocks illustrated in figure 6. The input data is segmented and encapsulated in blocks of 64 bits. One control bit is added at the beginning of each block to mark it as a control or data block.

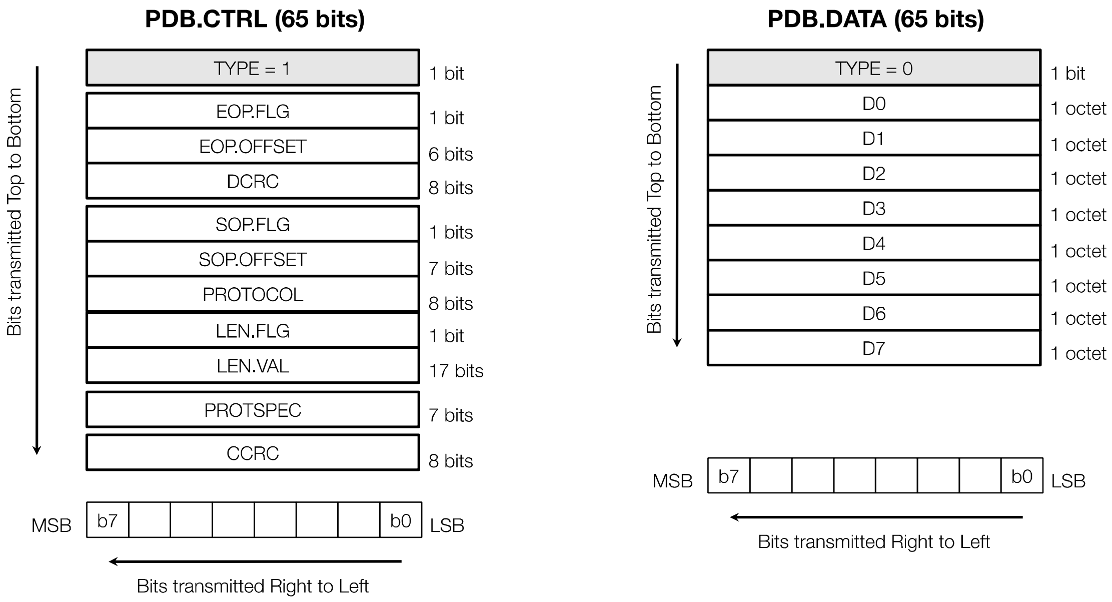

Figure 6: Data encapsulation data blocks

The control blocks (PDB.CTRL) are used to signal the start and the end of data packets. There are also special PDB.CTRL blocks that do not signal start/end of data packets and are used for other purposes. The PDB.CTRL block has the PDB.TYPE bit set to 1 and it is specified in table 1.

Table 1: PDB.CTRL block definition for data encapsulation control

Symbol	Description	# of bits	Valid values
PDB.TYPE	Indicates the type of PDB (for control or user data)	1	1: The current PDB is PDB.CTRL
PDB.CTRL.EOP.FLG	Indicates a packet end in the next PDB.DATA block. Offset where the packet ends is indicated by PDB.CTRL.EOP.OFFSET.	1	0: No end of packet in the next PDB.DATA 1: End of packet in the next PDB.DATA
PDB.CTRL.EOP.OFFSET	When PDB.CTRL.EOP.FLG is 1, this field indicates offset in number of bits to the last bit of the packet in the next PDB.DATA. PDB.TYPE is not counted.	6	0x00 to 0x3F
PDB.CTRL.DCRC	When PDB.CTRL.EOP.FLG is 1, this field indicates the CRC8 of data (contained in PDB.DATA units) corresponding to the packet referred by PDB.CTRL.EOP.FLG and PDB.CTRL.EOP.OFFSET.	8	0x00 to 0xFF
PDB.CTRL.SOP.FLG	Indicates a packet start in the next PDB.DATA block. Offset where the packet starts is indicated by PDB.CTRL.SOP.OFFSET.	1	0: No start of packet in the next PDB.DATA 1: Start of packet in the next PDB.DATA
PDB.CTRL.SOP.OFFSET	When PDB.CTRL.SOP.FLG is 1, this field indicates offset in number of bits to the first bit of the packet in the next PDB.DATA. PDB.TYPE is not counted. The value 0x40 indicates a packet start two PDB.DATA packets after the current PDB.CTRL. This allows for a more efficient back-to-back packet encapsulation, when PDB.CTRL.EOP.OFFSET of the previous packet takes value 0x3F.	7	0x00 to 0x40

Symbol	Description	# of bits	Valid values
PDB.CTRL.PROTOCOL	When PDB.CTRL.SOP.FLG is 1, this field indicates the encapsulated protocol identifier of the packet referred by PDB.CTRL.SOP.FLG and PDB.CTRL.SOP.OFFSET.	8	0x00: reserved for future extensions 0x01: Ethernet 0x02 to 0xFF: reserved for future extensions
	When both PDB.CTRL.SOP.FLG and PDB.CTRL.EOP.FLG are 0 this field identifies the type of special PDB.CTRL packet.	8	0x00: reserved for IDLE PDBs 0x01 to 0xFE: reserved for future extensions 0xFF: reserved for PAD PDBs
PDB.CTRL.LEN.FLG	When PDB.CTRL.SOP.FLG is 1, this field indicates that the length of encapsulated packet is known a priori, so the receiver can use it. The length is announced in PDB.CTRL.LEN.VAL. This information refers to the next data packet that will be encapsulated and indicated by PDB.CTRL.SOP.FLG and PDB.CTRL.SOP.OFFSET.	1	0: Encapsulated packet length is not indicated 1: Encapsulated packet length is announced
PDB.CTRL.LEN.VAL	When PDB.CTRL.SOP.FLG is 1, this field indicates the length of encapsulated packet in number of bits. This information refers to the packet referred by PDB.CTRL.SOP.FLG and PDB.CTRL.SOP.OFFSET.	17	0 to 131 071 Only valid if PDB.CTRL.LEN.FLG = 1
PDB.CTRL.PROTSPEC	When PDB.CTRL.SOP.FLG is 1, protocol specific information.	7	0x00 to 0x7F: reserved for future extensions
CCRC	CRC8 of the current PDB.CTRL, from PDB.TYPE to PDB.CTRL.PROTSPEC	8	0x00 to 0xFF
Total (bits)		65	

The PDB.CTRL.EOP.FLAG and PDB.CTRL.EOP.OFFSET fields are used to signal the end of a data packet in the next PDB.DATA block. A PDB.CTRL shall always be inserted before the last PDB.DATA carrying data belonging to a data packet, to indicate where the data packet ends. If data of next packet is already available, it is possible to perform back-to-back packet encapsulation by indicating in the PDB.CTRL block where the next packet starts.

For each data-packet being transmitted, a cyclic redundancy check is calculated and sent at the PDB.CTRL.DCRC field of the PDB.CTRL that signals the end of the packet.

Similarly, the PDB.CTRL.SOP.FLAG and PDB.CTRL.SOP.OFFSET are used to signal the start of a packet in the next PDB.DATA block. The value 0x40 in PDB.CTRL.SOP.OFFSET indicates a packet start two PDB.DATA packets after the current PDB.CTRL.

The PDB.CTRL.PROTOCOL is an identifier of the protocol to be encapsulated in the next PDB.DATA blocks representing a data packet.

The PDB.CTRL as defined in table 1 is able to encapsulate several different protocols from different interfaces over a single POF link. Values of PDB.CTRL.PROTOCOL 0x00 and 0x02 to 0xFF as well as the field PDB.CTRL.PROTSPEC are reserved for future extensions.

The PDB.CTRL.LEN.FLG and PDB.CTRL.LEN.VAL are used to convey the data packet length if it is known a priori. As it will be explained later on, the length information is useful for reducing the latency and buffering of de-encapsulation in the cases when the PHY data-rate is less than the data interface data-rate.

Finally, the field PDB.CTRL.CCRC contains the CRC8 calculated for the current PDB.CTRL and allows validating the integrity of each PDB.CTRL block in de-encapsulation.

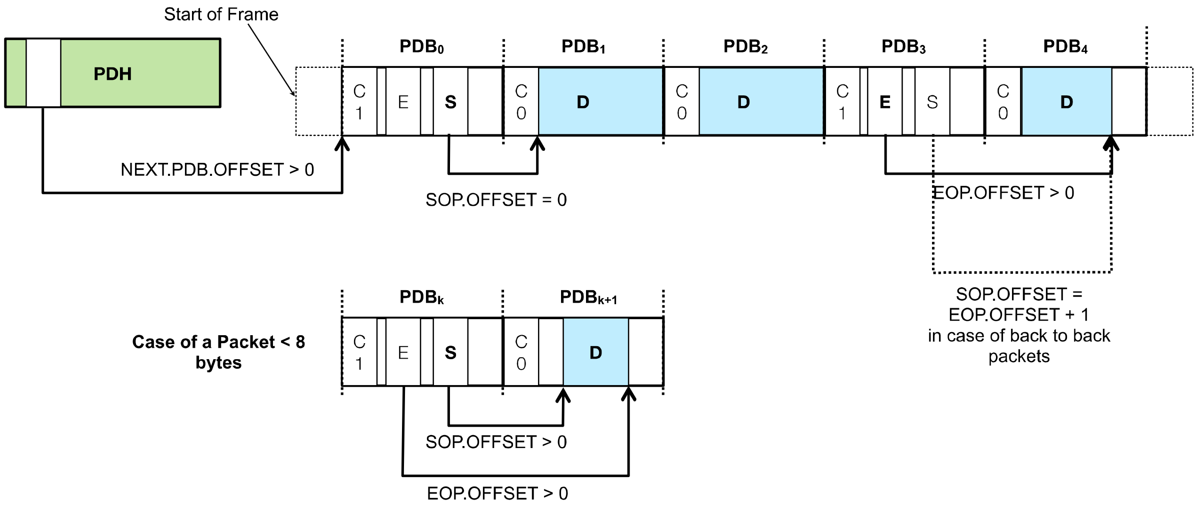

Figure 7: Illustration of the data encapsulation scheme

Additionally, a pointer PHD.TX.NEXT.PDB.OFFSET to the first PDB block that starts in every frame is included in the frame header. This pointer gives the position for the first bit of the first PDB that starts in the next frame. This information is intended to provide fast encapsulation alignment in the receiver.

The overall encapsulation scheme is illustrated in the figure 7. The use of packet sizes less than 64 bits is also shown. In that case the PDB.DATA block following the PDB.CTRL block shall contain the whole packet and the rest of the bits shall be set to zero. Similarly, when a packet ends in the middle of a PDB.DATA block and no other packet follows, the rest of the block shall be set to zero.

When there is no user data to transmit the PDB.IDLE block is transmitted continuously. The PDB.IDLE is a special case of PDB.CTRL where both PDB.CTRL.SOP and PDB.CTRL.EOP are 0 and PDB.CTRL.PROTOCOL = 0x00 as it is specified in table 2.

Table 2: PDB.IDLE block definition used for data encapsulation

Symbol	Description	# of bits	Valid values
PDB.TYPE	Indicates the type of PDB (for control or user data)	1	1: The current PDB is PDB.CTRL
PDB.CTRL.EOP.FLG	(Described in table 1)	1	0: No end of packet in next PDB.DATA
PDB.CTRL.EOP.OFFSET	(Described in table 1)	6	0x00
PDB.CTRL.DCRC	(Described in table 1)	8	0x00
PDB.CTRL.SOP.FLG	(Described in table 1)	1	0: No start of packet in next PDB.DATA
PDB.CTRL.SOP.OFFSET	(Described in table 1)	7	0x00
PDB.CTRL.PROTOCOL	(Described in table 1)	8	0x00
PDB.CTRL.LEN.FLG	(Described in table 1)	1	0: Encapsulated packet length is not indicated
PDB.CTRL.LEN.VAL	(Described in table 1)	17	0
PDB.CTRL.PROTSPEC	(Described in table 1)	7	0x00
CCRC	CRC8 of PDB.CTRL including from PDB.TYPE to PDB.CTRL.PROTSPEC	8	0x87
Total (bits)		65	

Another special PDB.CTRL is defined as PDB.PAD. PDB.PAD blocks shall be inserted by the transmitter between consecutive PDB.DATA blocks to carry out the rate matching between the data interface and PHY when PHY data-rate is greater than interface data-rate. The PDB.PAD is specified in table 3 as special case of PDB.CTRL block where both PDB.CTRL.SOP and PDB.CTRL.EOP are 0 and PDB.CTRL.PROTOCOL = 0xFF.

Table 3: PDB.PAD block used for data encapsulation and rate matching

Symbol	Description	# of bits	Valid values
PDB.TYPE	Indicates the type of PDB (for control or user data)	1	1: The current PDB is PDB.CTRL
PDB.CTRL.EOP.FLG	(Described in table 1)	1	0: No end of packet in next PDB.DATA
PDB.CTRL.EOP.OFFSET	(Described in table 1)	6	0x00
PDB.CTRL.DCRC	(Described in table 1)	8	0x00
PDB.CTRL.SOP.FLG	(Described in table 1)	1	0: No start of packet in next PDB.DATA
PDB.CTRL.SOP.OFFSET	(Described in table 1)	7	0x00
PDB.CTRL.PROTOCOL	(Described in table 1)	8	0xFF
PDB.CTRL.LEN.FLG	(Described in table 1)	1	0: Encapsulated packet length is not indicated
PDB.CTRL.LEN.VAL	(Described in table 1)	17	0
PDB.CTRL.PROTSPEC	(Described in table 1)	7	0x00
CCRC	CRC8 of PDB.CTRL including from PDB.TYPE to PDB.CTRL.PROTSPEC	8	0x90
Total (bits)		65	

The user data received from the interface is encapsulated in PDB.DATA blocks. The PDB.DATA block has the PDB.TYPE bit set to 0 and it is specified in table 4.

Table 4: PDB.DATA block used for data encapsulation

Symbol	Description	# of bits	Valid values
PDB.TYPE	Indicates the type of PDB (for control or user data)	1	0: The current PDB is PDB.DATA
PDB.DATA.D0	First data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D1	Second data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D2	Third data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D3	Fourth data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D4	Fifth data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D5	Sixth data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D6	Seventh data octet of PDB.DATA	8	0x00 to 0xFF
PDB.DATA.D7	Eighth data octet of PDB.DATA	8	0x00 to 0xFF
Total (bits)		65	

The encapsulation method defined allows that a data packet may start and/or end in any bit of the PDB.DATA.D[0..7] fields. Therefore, the packet length is not required to be multiple of 8 bits (octet), making possible bit aligned packets. However, it can be useful for other kind of interfaces where bit-alignment enables a reduction in data encapsulation latency.

Decisions about when to insert PDB.PAD blocks as well as PDB.IDLE blocks are left to the implementer.

5.2.3.3 DCRC

The DCRC cyclic redundancy parity check bits for each data packet are generated using the following cyclic generator polynomial.

$$1 + x + x^3 + x^4 + x^7 + x^8$$

The DCRC implementation shall produce the same result as the implementation shown in figure 8. In figure 8, there are eight delay elements: S0 to S7. They shall be initialized to zero. Afterwards the data packet is used as serial data input to compute the DCRC with the switch connected, which is setting DCRCgen in figure 8. After all the data packet bits have been processed, the switch is disconnected (setting DCRCout) and the eight values stored in the delay elements are transmitted in the order illustrated, i.e. first S7, followed by S6, and so on until the final value S0.

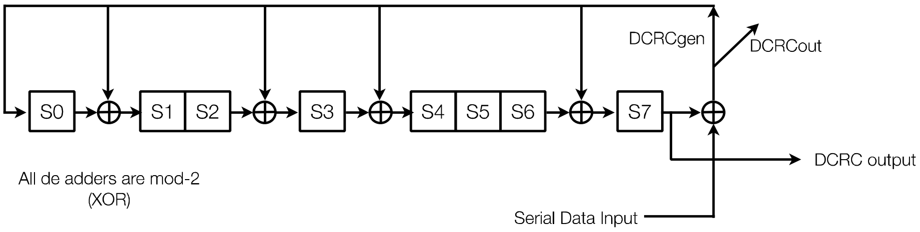

Figure 8: DCRC reference implementation

5.2.3.4 CCRC

The CCRC cyclic redundancy parity check bits for PDB.CTRL are generated using the following cyclic generator polynomial.

$$1 + x + x^5 + x^6 + x^8$$

The CCRC implementation shall produce the same result as the implementation shown in figure 9. In figure 9 there are eight delay elements: S0 to S7. They shall be initialized to zero. Afterwards the PDB-CTRL block, from bit 0 (PDB.TYPE) to bit 56 (PDB.CTRL.PROTSPEC), is used as serial data input to compute the CCRC with the switch connected, which is setting CCRCgen. After all the PDB.CTRL bits have been processed, the switch is disconnected (setting CCRCout) and the eight values stored in the delay elements are transmitted in the order illustrated, i.e. first S7, followed by S6, and so on until the final value S0.

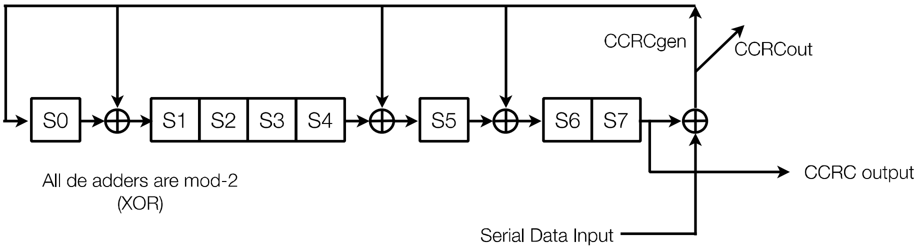

Figure 9: CCRC reference implementation

5.2.3.5 Data packet encapsulation

5.2.3.5.1 Data packet transmit encapsulation

The physical layer device defined in the present document is able to optionally receive data packets from any generic data interface.

Conditions in the PHY data interface Idle, Start, Terminate, Normal data transmission and Transmit Error propagation shall be considered by the PHY.

The PHY shall propagate the Transmit Error by deliberately corrupting data or DCRC when data is encapsulated, as defined in clause 5.2.3.3. It is left to the implementer how to corrupt the data for error propagation, as long as the receiver is able to detect it by means of DCRC checking.

The net physical rate is that obtained once the overheads caused by both header and pilots (160/8 224) as well as PDB.DATA encapsulation (1/65) are eliminated.

The data packets may include information about its length. This information shall be included in the PDB.CTRL block that precedes the data packet. The PDB.CTRL.LEN.FLAG shall be set to 1 and the PDB.CTRL.LEN.VAL to the number of bits equivalent to the total number of bits of the data packet.

Examples of data packets encapsulations are illustrated in figure 10 and figure 11. In figure 10, the encapsulation of a single frame is shown, while the figure 11 illustrates the encapsulation of back-to-back frames.

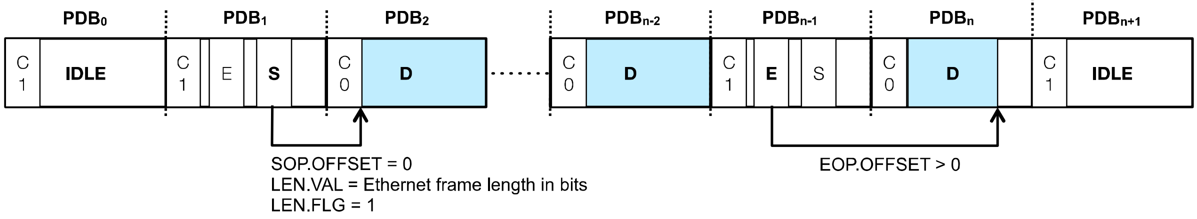

Figure 10: Encapsulation of a single data packet

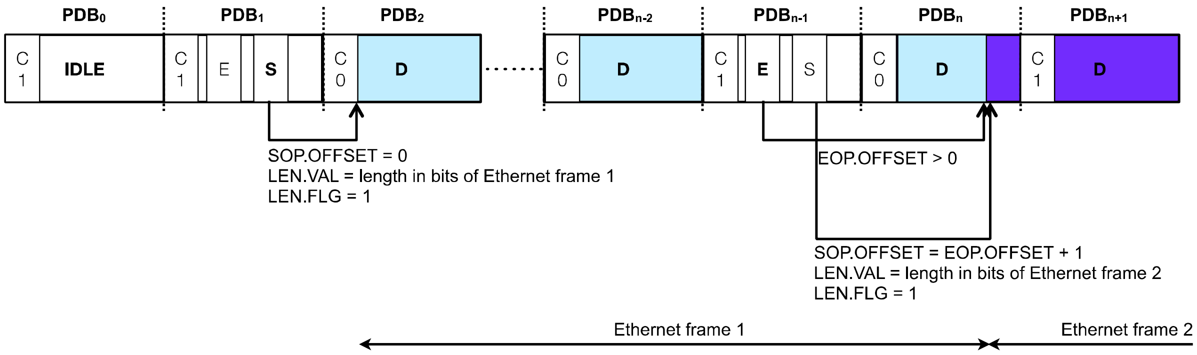

Figure 11: Encapsulation of back-to-back data packets

5.2.3.5.2 Rate matching

5.2.3.5.2.1 Introduction to rate matching

As defined in successive clauses, the PHYs defined in the present document and its annexes optionally support adaptive bit rate, being possible to have a PHY data rate greater or lower than the data interface. The PHY data rate shall depend on channel conditions and physical layer parameters negotiated by both communication endpoints. In addition, the PHY data-rate in many MLCC configurations does not exactly match the data interface rate.

The rate matching functionality, matches the PHY data rate with the rate at the data interface.

Three different rate-matching cases are considered in the following subclauses.

5.2.3.5.2.2 Rate matching when PHY data rate is greater than data interface data rate

It shall be solved by means of PDB.PAD blocks insertion between consecutive PDB.DATA blocks. Minimum buffers are required in the CMB transmit function to implement the 64/65 encapsulation defined in clause 5.2.3.2 and the MLCC encoding defined in clause 5.2.3.7. Algorithms for PDB.PAD insertion are left to the implementer.

5.2.3.5.2.3 Rate matching when PHY data rate is equal to data interface data rate

Only PDB.IDLE insertion between data packets shall be needed, being data packet transmission done in consecutive PDB.DATA blocks. Algorithms for PDB.IDLE insertion are left to the implementer.

5.2.3.5.2.4 Rate matching when PHY data rate is less than data interface data rate

A mechanism based on local false pause packets generation to stop the data interface transmission is defined in order to avoid the overflow of PHY buffers.

Pause packets as special case of Control Packets. Pause Packets are defined for flow control between two sides of a data communication link. Pause Packets are local to a link, being not retransmitted by any external device.

The data interface transmits data at a rate of 100 Mbit/s or 1 000 Mbit/s, which is buffered by the CMB before being transmitted onto the medium. The CMB transmit function shall generate a false Pause Packets to the external transmitter locally connected by using the CMB reception function. Therefore, the locally connected external transmitter shall receive this Pause Packet as if sent by the other side of communication link. Reception of a Pause Packet stops the external transmission during the time defined in Pause Time field in the Pause Packet.

The Pause Packet content (Pause Time) shall be calculated by the CMB transmit function as function of CMB buffer space and the difference between the data interface data rate and actual PHY data rate, to avoid packet loss due to buffer overflow. A Pause Packet with Time = 0 may be generated and sent to the local transmitter to resume the transmission during a Pause period generated by a previous Pause Packet. The Flow control algorithms and the values of the Pause Time should be selected to minimize frame transmission latency and ensure that the link can be fully utilized. Flow control algorithms using pause frames are left to the implementer.

The CMB receive function shall intercept the Pause frames received from the other side of the link, being Pause Time value overwritten when the actual value is less than the one currently calculated by CMB transmit function.

In links where the PHY rate is not symmetric, being the PHY rate greater than or equal to the data interface rate in one direction and less than the data interface rate in the other direction, the transmitting end on the slower direction shall set a maximum data rate limit on the data interface, in order to allow the receiving end introducing the Pause Packets required for flow control. The data interface rate limit shall be selected to avoid losing any frame in the slower direction in a worst-case scenario with maximum Pause Packet rate. The maximum Pause Packet rate mainly depends on the PHY rate on the slower direction and the maximum data packet length of the data interface. Algorithms needed to perform the data interface rate limitation are left to the implementer.

5.2.3.6 Binary Scrambler

The incoming data after encapsulation is scrambled using a Maximum Length Sequence (MLS) generator defined by the following polynomial $1+x^{22}+x^{25}$. The implementation shall produce the same result as the implementation in figure 12. The scrambler shall be initialized to 0x17C_9C58 (given in hexadecimal base representation) where the left most digit corresponds to the initial value of register 0.

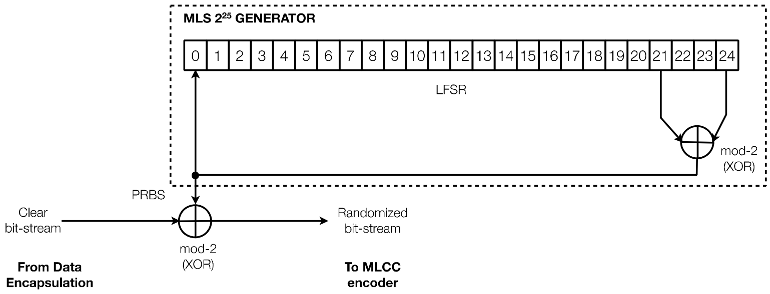

Figure 12: Binary scrambler reference implementation

5.2.3.7 Multi-Level Cosset Coding

5.2.3.7.1 Introduction to Multi-Level Cosset Coding

The scrambled data is mapped to PAM symbols using the MLCC technique. The overall scheme is shown in figure 13. Depending on the configuration used by a particular PHY, the data bits are divided in up to three groups. The first group is coded with a (2 016, 1 664) BCH code. The second is coded with a (2 016, 1 994) or a (1 008, 986) BCH code depending on the configuration and the last group is not coded. The resulting bits are then mapped to PAM symbols using a number of processing steps as shown in figure 13.

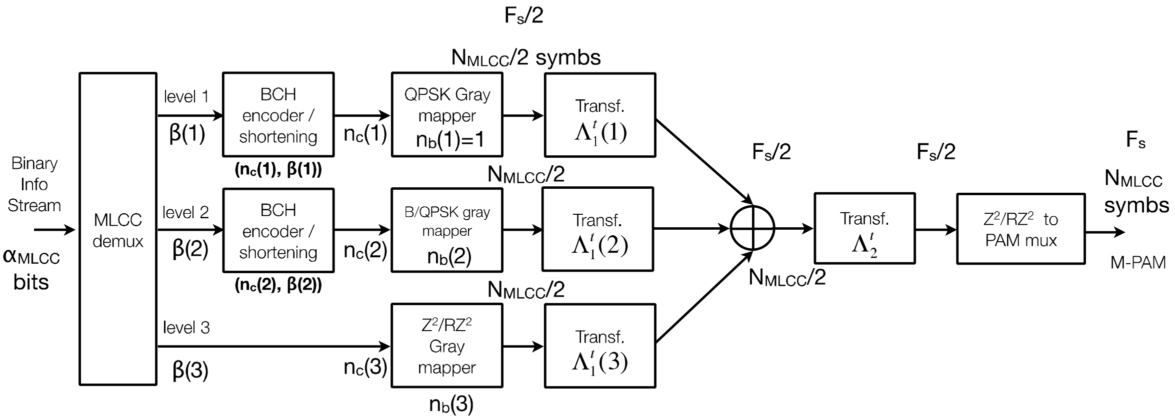

Figure 13: Multi-Level Cosset Coding block diagram

The terms in figure 13 are defined as follows:

a) N_{MLCC}: length of the MLCC code word in 1D (PAM) symbols, i.e. 2 016.

b) $n_b(i)$: nº of coded bits per dimension for the ith level; it defines constellation; i = 1..3.

c) $n_c(i)$: nº of bits per code-word for the ith binary component code.

d) $k_c(i)$: nº of information bits per code-word for the ith binary component code; $k_c(i) = n_c(i)$ for i = 3.

e) ξ: total number of coded bits per dimension: $\xi = \sum_{i=1}^{3} n_b(i)$.

f) k_{PAM}: nº of bits per PAM constellation at the encoder output: $k_{PAM} = \lceil \xi \rceil$.

g) α_{MLCC}: nº of information bits per MLCC code word.

h) β(i): nº of information bits per MLCC code-word for ith level; β(i) = $k_c(i)$ for i = 1..2 and β(i) = $n_c(i)$ for i = 3.

i) $r_c(i)$: code-rate for the ith level: $r_c(i) = k_c(i) / n_c(i)$.

j) η: spectral efficiency per dimension: $\eta = \sum_{i=1}^{3} n_b(i) r_c(i)$.

k) Fs: symbol frequency (baud-rate).

By design $n_b(1) = 1$ and $n_b(2) = 0,5$ or 1 bits/dim.

The encoder shown in figure 13 can be configured to provide a number of data bits per symbol. The possible options are given in table 5. The selected option determines the number of levels of the PAM symbol to be sent. Each particular PHY type may use one or a number of those configurations. The parameters for each PHY type are defined in the corresponding annexes from A to D.

Table 5: Configurations for the Multi-Level Cosset Coding

NMLCC (1D symbols)	α (bits/code-word)	β(1) (bits/code-word)	β(2) (bits/code-word)	β(3) (bits/code-word)	η (bits/s/Hz/D)	M-PAM	nb(1) (bits/1D)	nb(2) (bits/1D)	nb(3) (bits/1D)
2 016	1 664	1 664	0	0	0,825 4	2	1	0	0
2 016	2 650	1 664	986	0	1,314 5	4	1	0,5	0
2 016	3 658	1 664	1 994	0	1,814 5	4	1	1	0
2 016	4 666	1 664	1 994	1 008	2,314 5	8	1	1	0,5
2 016	5 674	1 664	1 994	2 016	2,814 5	8	1	1	1,0
2 016	6 682	1 664	1 994	3 024	3,314 5	16	1	1	1,5
2 016	7 690	1 664	1 994	4 032	3,814 5	16	1	1	2,0
2 016	8 698	1 664	1 994	5 040	4,314 5	32	1	1	2,5
2 016	9 706	1 664	1 994	6 048	4,814 5	32	1	1	3,0
2 016	10 714	1 664	1 994	7 056	5,314 5	64	1	1	3,5
2 016	11 722	1 664	1 994	8 064	5,814 5	64	1	1	4,0

5.2.3.7.2 MLCC Demultiplexer

The MLCC encoder processes blocks of αMLCC bits. The size of the block depends on the particular configuration as shown in table 5. In the first step of processing those bits are divided into three MLCC levels. The number of bits assigned to each level are denoted as β(1), β(2) and β(3).

Then for an input block $x = [x_0 x_1 \cdots x_{\alpha_{MLCC}-1}]$ the sub-blocks assigned to each level are as follows: $y_1 = [x_0 x_1 \cdots x_{\beta(1)-1}]$, $y_2 = [x_{\beta(1)} x_{\beta(1)+1} \cdots x_{\beta(1)+\beta(2)-1}]$ and $y_3 = [x_{\beta(1)+\beta(2)} x_{\beta(1)+\beta(2)+1} \cdots x_{\alpha_{MLCC}-1}]$. The sub-indexes also denote time ordering.

The demultiplexing process is illustrated in figure 14.

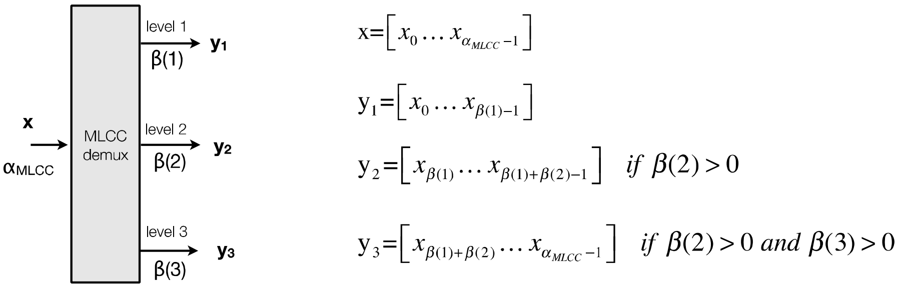

Figure 14: MLCC demultiplexing process

5.2.3.7.3 BCH Encoders

The sub-blocks y1 and y2 are encoded with BCH codes.

For y1 the BCH encoding takes a 1 664 input block and shall generate a 2 016 bit code word c1. Prior to the BCH encoding 31 zeroes are added at the beginning of the input block. The resulting 1 695 bit block is then encoded.

For both y1 and c1 the encoder shall follow the convention that the LSB (leftmost element of the vectors y1 and c1) is the first bit in time.

The BCH code is specified by the coefficients of its generator polynomial, which are:

0x0001_E29B_5C67_999C_F994_D38A_6AFF_BF44_78C7_B5F1_8669_0A41_5AFD_FE3C_5497_E86F_B13E_F329_0634_9A49_61D2_D63A_14A3,

being g(0) the rightmost bit.

For y2 the BCH encoding takes either a 1 994 or 986 bits input block and shall generate a 2 016 or a 1 008 bits code word c2. For both y2 and c2 the encoder shall follow the convention that the LSB (leftmost element of the vectors y2 and c2) is the first bit to transmit.

Prior to the BCH encoding 31 zeroes are added at the beginning of the input block in the first case. In the second case, 1 039 zeroes are added. The resulting 2 025 bit block is then encoded.

The BCH code is specified by the coefficients of its generator polynomial which are: 0x0049_05B1, being g(0) the rightmost bit.

The BCH encoders shall produce the same result that the implementation in figure 15. All the elements S_x are initialized to zero. After the information bits block has been serially processed with the switch connected to BCHgen, the S_x bits shall be transmitted from S_{p-1} to S_0 starting with S_{p-1}, with switch unconnected (BCHCout).

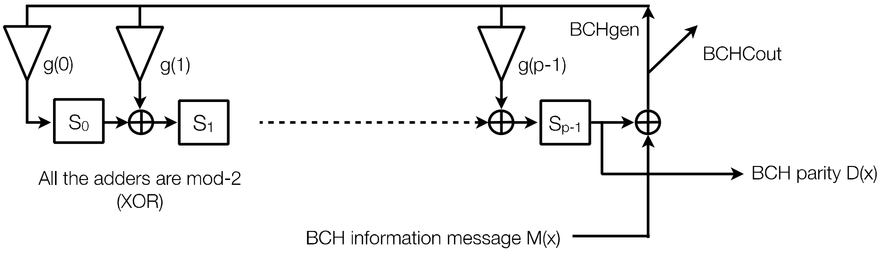

Figure 15: BCH reference encoder

5.2.3.7.4 Gray mapping

For each level, the n_c (i) bits blocks are mapped to NMLCC / 2 = 1 008 two-dimensional symbols using a mapper. The mapper for the i^th level (i = 1, 2 or 3) is defined in terms of the parameter k_{QAM} (i) = 2 n_b (i), where n_b (i) is defined as the number of coded bits mapped per dimension.

When k_{QAM} is greater than one, the mapping shall be performed as illustrated in figure 16.

The input bit stream is demultiplexed into two substreams. One of the substreams maps onto the In-phase (I) component of the two-dimensional constellation and the other substream maps onto the quadrature (Q) component of the constellation. The In-phase component corresponds to the real part of a complex symbol and the Quadrature part corresponds to the imaginary part of a complex symbol. The consecutive input bits in din are assigned to the respective components in accordance with the configuration of kQAM. The demultiplexer A is controlled by the least significant bit of a free counter B counting from 0 to kQAM-1 clocked at the same input bit rate. If kQAM is even, the same number of bits is assigned to each component. If it is odd, the In-phase component receives more bits that the Quadrature component. Thus, the number of bits per dimension assigned to each component is $k_I = \lceil k_{QAM} \rceil$ and $k_Q = \lfloor k_{QAM} \rfloor$ wherein $\lceil . \rceil$ denotes rounding up and $\lfloor . \rfloor$ denotes rounding down. In the two substreams, the bits are then converted from serial to parallel (S/P) to symbols with kI and kQ bits in the In-phase and Quadrature component, respectively. The most right bit is the most significant bit.

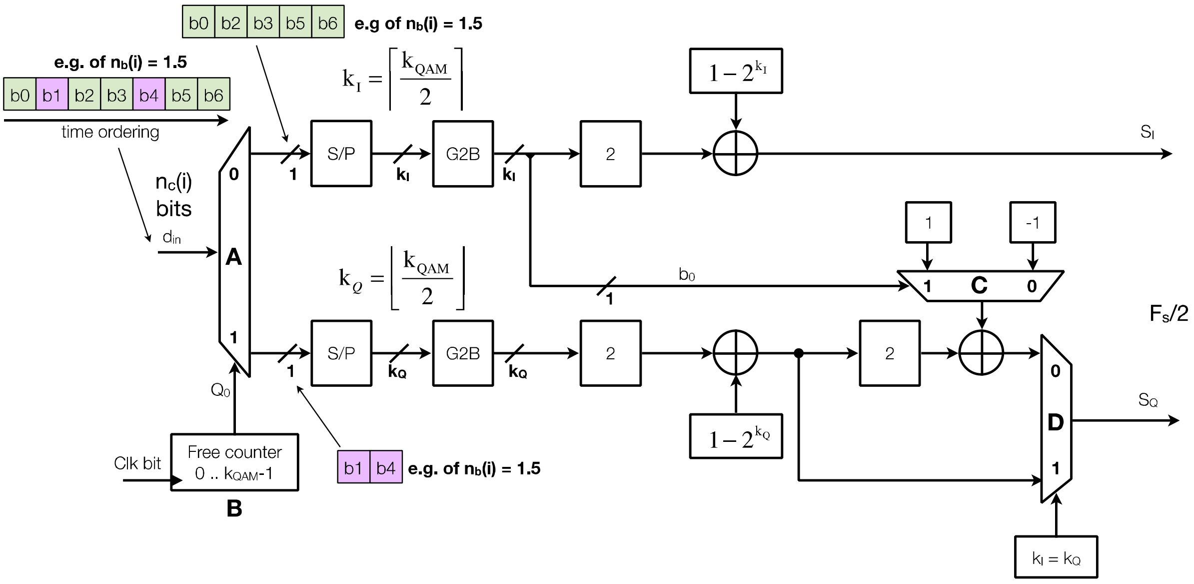

Figure 16: Gray mapper block diagram for kQAM > 1

After the serial to parallel conversion a Gray-to-Binary converter (G2B) is applied. The converter transforms an input vector g of k bits into an output vector b also of k bits by performing the following operations:

$$b[k-1] = g[k-1]$$
$$b[k-1-j] = g[k-1-j] \quad \text{xor} \quad b[k-j]$$

where $j \in [1, k-1]$. The vectors obtained in the G2B conversion are then processed as shown in Figure 17. The vectors are considered integers and both components are multiplied by 2.

The least significant bit b0 output from the G2B in the In-phase component is used to control the multiplexer C, which sets 1 or -1 to the input of the last adder. Finally, the last multiplexer D outputs symbols to the Quadrature branch. For constellations where $k_I = k_Q$, the arithmetic operations carried out on both branches (In-phase and Quadrature) are the same. For $k_I > k_Q$, the quadrature component is transformed to generate a rotated pseudo-Gray mapped QAM constellation, required to map an odd number of bits per two dimensions.

When k_{QAM} is one the mapping is implemented as shown in figure 17. As it can be seen in this configuration the components S_I and S_Q take the same value.

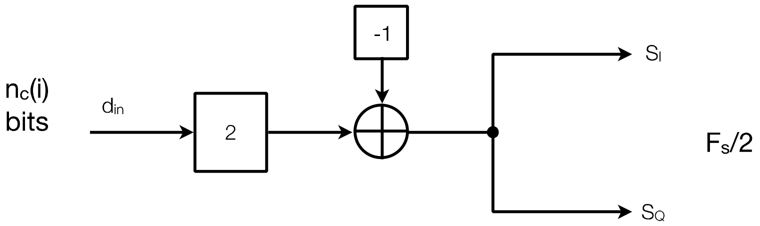

Figure 17: Gray mapper block diagram for kQAM = 1

5.2.3.7.5 First Lattice transformation $\Lambda_1^t(l)(x)$

The symbol S_I and the symbol S_Q are transformed by a lattice transformation to carry out, together with the next addition operation, the so-called cosset partitioning. For this purpose, I and Q components are considered as the real and imaginary parts of a complex number S.

Then at each level l the transformation $L(l)=\Lambda_1^t(l)\left(S(l)\right)$ is applied to S(l) to obtain L(l) as:

$$L(l)=\frac{1}{2}\times\left(S(l)+(1+j)\times(2^{\lceil n_b(l)\rceil}-1)\right)\times 2^{\sum_{i=1}^{l-1}\lceil n_b(i)\rceil}\times\left(\frac{1+j}{2}\right)^{rem(2\times n_b(l),2)}$$

Where $j=\sqrt{-1}$ and rem denotes remainder after integer division. In particular, in the above formula, rem is the remainder of division of the first operand (i.e. $2n_b(l)$) by the second operand (i.e. 2).

The entire transformation is composed of three sub-operations:

a) The lattice is translated to allow the constellation to be contained within the first two-dimensional quadrants.

b) The lattice is scaled to enable the cosset partitioning by vector addition with the constellation of the other levels.

c) The lattice is rotated by 45 degrees before the vector addition for constellations with an odd number of bits per two dimensions.

The translation, denoted here as $\Lambda_{1,1}^t(l)$, is defined for each $x \in \mathbb{C}$ (x is a complex number), wherein $j=\sqrt{-1}$ and l denotes level of the MLCC, as:

$$\Lambda_{1,1}^t(l)(x)=\frac{1}{2}\left(x+\left(1+j\right)\times\left(2^{\lceil n_b(l)\rceil}-1\right)\right).$$

Scaling and rotation are grouped into a single sub-operation denoted $\Lambda_{1,2}^t(l)$ and defined for each $x \in \mathbb{C}$ as:

$$\Lambda_{1,2}^t(l)(x)=x\times 2^{\sum_{i=1}^{l-1}\lceil n_b(l)\rceil}\times\left(\frac{1+j}{2}\right)^{rem(2\times n_b(l),2)},$$

where the operation rem denotes the remainder after an integer division.

The complete lattice transformation $\Lambda_1^t(l)$ including translation, scaling and rotation is defined as:

$$\Lambda_1^t(l)(x)=\Lambda_{1,2}^t(l)\left(\Lambda_{1,1}^t(l)(x)\right).$$

The lattice transformation for the first level does not include scaling and rotation since $n_b(1)$ =1 bit/dim. The corresponding lattice transformation architecture is shown in figure 18.

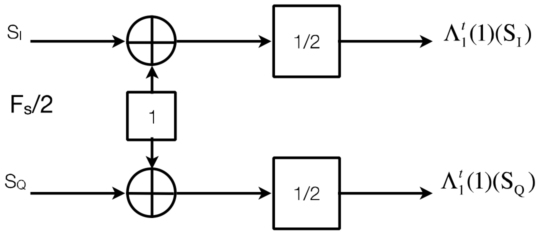

Figure 18: First Lattice transformation for the first MLCC level

The input and output signals for each component branch are considered integer numbers and arithmetic operations are defined with natural bus width increase. The output of the mapper, symbol S_I and symbol S_Q are the input to the lattice transformation.

For the second level, two different cases are distinguished. For $n_b(2)$ = 1 bit/dim, rotation is not performed. For $n_b(2)$ = 0,5 bit/dim rotation is required since the corresponding 2D constellation maps one bit per two dimensions (odd number). The second level lattice transformation architecture is illustrated in figure 19. As it can be seen from the figure 19, the value of $n_b(2)$ controls the multiplexers whether or not to perform the rotation.

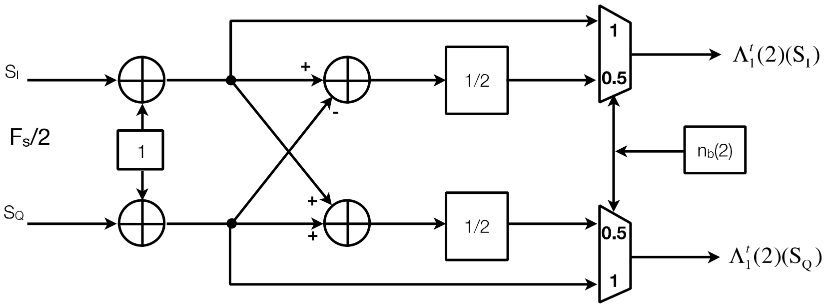

Figure 19: First Lattice transformation for the second MLCC level

The lattice transformation for the third level is shown in figure 20. Rotation is implemented for the following values of $n_b(3)$: 0,5 bits/dim, 1,5 bits/dim, 2,5 bits/dim and 3,5 bits/dim. For $n_b(3)$ = 1 bits/dim, 2 bits/dim, 3 bits/dim and 4 bits/dim the rotation is disabled.

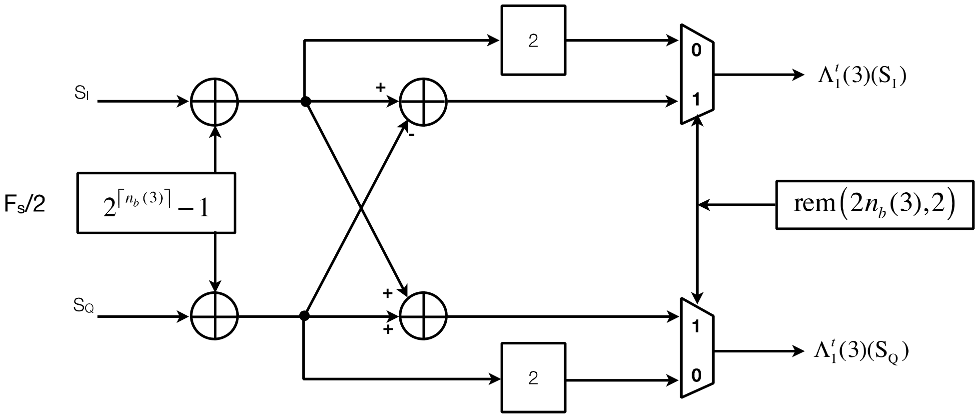

Figure 20: First Lattice transformation for the third MLCC level

5.2.3.7.6 Lattice addition

After performing the first lattice transformations for each active level, the lattice transformed symbols from each of the three levels are added, performing the cosset partitioning over lattice Z^2 and the final partitioning. In particular, the in-phase and the quadrature components from the three levels are added separately to generate a respective new in-phase component S_I^a and quadrature component S_Q^a as illustrated in figure 21.

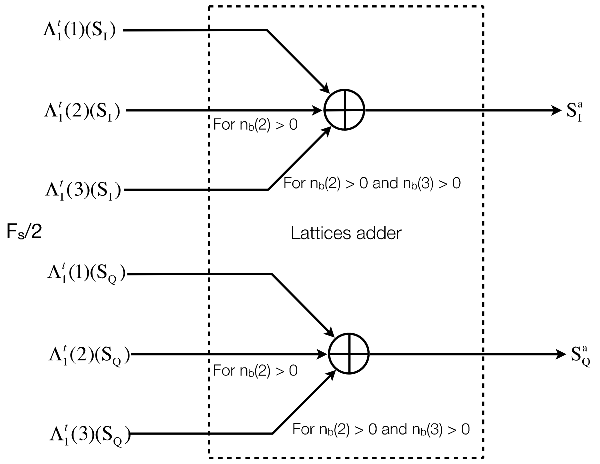

Figure 21: Lattice addition for cosset partitioning

The outputs of the lattice transformations for each level are finally added to obtain a complex number $S_I^a + j\cdot S_Q^a$.

5.2.3.7.7 Second Lattice transformation $\Lambda_2^t(x)$

The symbols with in-phase component S_I^a and quadrature component S_I^a output from the lattice adder are then further transformed in order to obtain the final zero-mean two-dimensional square constellation over Z^2 or RZ^2. The second step lattice transformation $\Lambda_2^t(x)$ includes the following three steps:

a) rotation by -45 degrees for ξ=1,5 bits, 2,5 bits, 3,5 bits, 4,5 bits and 5,5 bits per dimension (where $\xi = \sum_{i=1}^{3} n_b(i)$);

b) modulo operation which constraints the constellation symbols to a square region within the first 2D quadrant;

c) centring and scaling.

The transformation can be defined analytically as per the equation below where ξ is the total number of bits per dimension for PAM constellation generated by the MLCC encoder.

$$\Lambda_2^t(x) = 2\times\mathrm{mod}\left(x\times(1-j)^{\mathrm{rem}(2\xi,2)}, 2^{\lceil\xi\rceil}\right) + (1+j)\times\left(1-2^{\lceil\xi\rceil}\right)\ \forall\, x\in\mathbb{C},\ j=\sqrt{-1}$$

In particular, the modulo operation is defined as mod(x,z) = x - n × z, where $n = \lfloor x/z \rfloor$, and where z is an integer power of two, and x is real. Since $z = 2^{\lceil\xi\rceil}$, the modulo operation may be implemented by means of a logic "and" operation.

This lattice transformation is illustrated in figure 22. As it can be seen in figure 22, the first part implements the rotation by -45 degrees as a function of the value of ξ. The modulo operation is applied afterwards to constraint the symbols to a square constellation in the first 2D quadrant. Then the scaling and centring of the constellation is performed, resulting in the final zero-mean square or rotated QAM constellation with the minimum distance of 2 or $2\sqrt{2}$, respectively. The transformed symbol components $\Lambda_2^t(S_I^a)$ and $\Lambda_2^t(S_Q^a)$ take odd values.

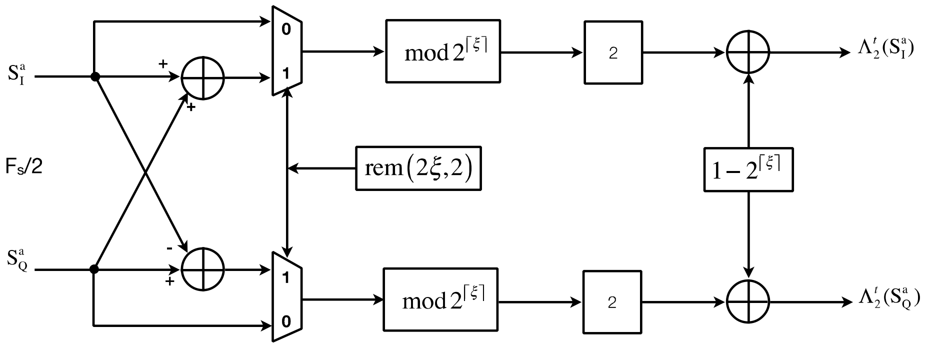

Figure 22: Second Lattice transformation

5.2.3.7.8 Mapping to PAM symbols

The in-phase and the quadrature components $\Lambda_2^t(S_I^a)$ and $\Lambda_2^t(S_Q^a)$ of the 2D symbols output from the second-step lattice transformation are then time domain multiplexed resulting in a sequence of 1D symbols belonging to a $2^{\lceil \xi \rceil}$-PAM constellation. The multiplexing operation is illustrated in figure 23. A free counter from 0 to 1 is clocked at the 1D symbol rate and controls the input of the multiplexer to take alternatively the in-phase and quadrature input symbols. The M-PAM Symbols belong to the set $\{-M+1,-M+3,\cdots,M-3,M-1\}$, where $M=2^{\lceil \xi \rceil}$.

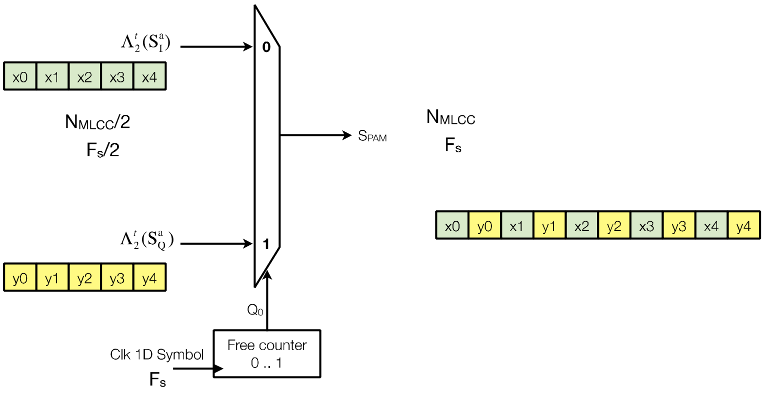

Figure 23: Multiplexer for mapping to PAM symbols from MLCC encoded QAM symbols

5.2.3.7.9 Symbol scrambler

The PAM symbols are then scrambled to ensure that nonlinear distortion affects all PAM levels equally. Jointly with non-linear compensation that may be implemented by receiver, the symbol scrambler will provide the same symbol error probability for all the constellation points.

The symbol scrambler is divided in two sub-blocks. The first one, illustrated in figure 24, is in charge of generating a pair of pseudo random signals (v and s) per PAM symbol from a binary MLS generator, with polynomial $1+x^{22}+x^{25}$. The second one, illustrated in figure 25, operates these two signals over the input PAM symbols to generate the scrambled PAM symbols.

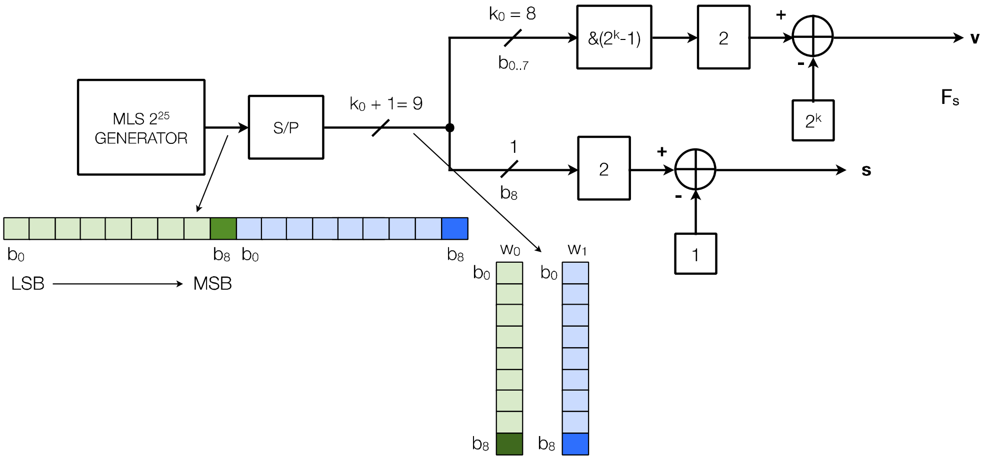

Figure 24: Symbol scrambler: v and s signals generation

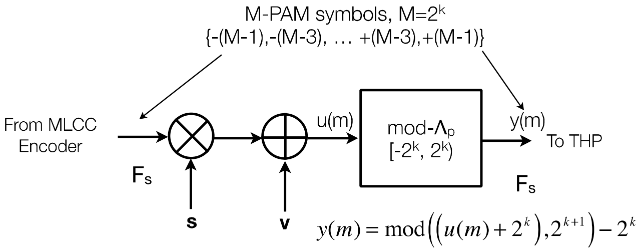

Figure 25: PAM symbols scrambling

The MLS generator is equal to that defined in figure 12 and is initialized to a known state at the beginning of the frame described in clause 5.2.1, with an initial state 0x0155_D559, where the left most digit corresponds to the initial value of register 0. The modulo operation reduces the scrambled symbols to the same Voronoi region of the Tomlinson-Harashima precoder defined in CMB transmit function (clause 5.2.7). As it can be seen in figures 24 and 25, the symbol scrambler is configured according to the MLCC encoder in terms of M-PAM. Therefore, $k = \lceil \xi \rceil$ in figure 24 and figure 25, as it was defined in clause 5.2.3.7.

5.2.4 Physical header encoding

5.2.4.1 Introduction to physical header encoding

The header bits carry control information for the CMB. Those bits are arranged in a block of 720 bits as described in clause 5.2.4.2. The block is then encoded using a BCH code to obtain a block of 896 bits that are mapped to 1 792 PAM symbols with two levels. Then the symbols are divided in 14 groups of 128 and 16 zero symbols are added at the beginning and end to obtain a sub-block of 160 symbols. The sub-blocks are transmitted at different points in the frame as specified in clause 5.2.2.

The transmission scheme for the physical header is designed to provide a robust communication channel such that control information can be exchanged between both link ends under worst channel conditions.

5.2.4.2 Physical header data (PHD)

The Physical header data is divided in fields that are defined in table 6.

The field PHD.TX.CODING.LEN specifies the code-word length of the MLCC, given in number of M-PAM symbols per MLCC code word. This configuration cannot change dynamically once the PHY has initiated the CMB transmission. This information shall be decoded by the remote PHY to configure accordingly the MLCC decoding in CMB receive function. Only the setting of 2 016 is permitted for this field, although several bits are reserved for future extensions.

The field PHD.TX.NEXT.CODING.SE specifies the MLCC configuration in terms of spectral efficiency that is used in the next frame. This enables a dynamic adaptation of the PHY rate to the channel conditions. In the same way PHD.RX.REQ.CODING.SE enables a receiver to request a particular MLCC configuration for the next frame. PHD.RX.REQ.CODING.SE = 0 indicates that no request is performed.

A number of fields in the header are used for THP pre-coding. PHD.TX.NEXT.THP.SETID > 0 enables the use of THP in the next frame. When THP is enabled, PHD.TX.NEXT.THP.SETID specifies the set of coefficients that is used for the transmission of the next frame. PHD.RX.REQ.THP.SETID specifies a set of THP coefficients that the receiver requests the transmitter to use. The values of the requested coefficients are specified in PHD.RX.REQ.THP.COEF[0..8]. The THP coefficients are transmitted in order from the least significant bit of PHD.RX.REQ.THP.COEF[0] to the most significant bit of PHD.RX.REQ.THP.COEF[8].

The PHD.RX.REQ.THP.COEF[0..8] coefficients are real numbers in signed fix-point format of 12 bits width. Of these 12 bits, the 2 most significant bits are used to represent the sign and integer part, and the 10 least significant bits represent the decimal part. The THP coefficients can take values in the interval [-2, 2) with a precision of $9{,}7656 \times 10^{-4}$.

THP pre-coding is done per frame so that it may be possible to change the coefficients in each frame to adapt to channel conditions.

PHD.TX.NEXT.PDB.OFFSET is a pointer to the first bit of the first PDB in the payload of the next frame. This information is intended to help the receiver in delimiting the PDBs in the frame payload.

PHD.TX.FRAMEID and PHD.RX.LASTFRAMEID are used to provide a sequence number of both TX and RX frames, for debugging tasks.

PHD.RX.STATUS indicates to the link partner the local CMB receive function is ready to provide reliable PAM symbols to the rest of the CMB receive function.

PHD.CAP fields inform about the capacity of the PHY to support optional features. PHD.CAP.LPI informs that PHY is able to receive frames implementing Low Power Idles, so that the remote PHY can turn off the optical power during the payload sub-blocks to reduce energy consumption. PHD.CAP.ABR informs about the capability to make adaptive bit rate, both making requests for coding configuration to remote PHY and accepting requests from the remote PHY.

PHD.DEVID fields are defined to identify the PHY. Identification procedure is undefined and unique identifiers have not been assigned. However, a number of bits for device identification are reserved for future extensions. PHD.DEVID.FLG indicates that the PHD carries device identification in the field PHD.DEVID.INFO. PHD.DEVID.INFO shall take value 0 when PHD.DEVID.FLG = 0.

PHD.VENDOR fields are reserved in PHD to provide a low bit rate auxiliary communication channel to implement proprietary control tasks and signalling of the CMB between both link partners. PHD.VENDOR.FLG signals if vendor proprietary information is included in PHD.VENDOR.INFO field. The field PHD.VENDOR.INFO shall take a value with all the bits equal to 0 for PHD.VENDOR.FLG = 0. Otherwise, the encoding PHD.VENDOR.INFO is left to the implementer as well as the methods to decode and reliably distinguish the encoded information of other possible implementations.

All the PHD fields are ordered from least to most significant bit and transmitted from top to bottom according to table 6. For PHD.CRC16 the bit ordering is specified in clause 5.2.4.3.

Table 6: Physical Header Data (PHD) definition

Symbol	Description	# of bits	Valid values
PHD.TX.FRAMEID	Current TX frame counter	8	0 to 255
PHD.TX.CODING.LEN	MLCC code-word length, given in M-PAM symbols.	3	0x00: 2 016 symbols / CW 0x01 to 0x07: reserved for future use
PHD.TX.NEXT.CODING.SE	Next frame MLCC spectral efficiency configuration (in number of coded bits per dimension)	4	0: reserved 1: 1,0 2: 1,5 3: 2,0 4: 2,5 5: 3,0 6: 3,5 7: 4,0 8: 4,5 9: 5,0

Symbol	Description	# of bits	Valid values
			10: 5,5 11: 6,0 12 to 15: reserved for future use
PHD.TX.NEXT.THP.SETID	THP coefficients set Id that will be used in the next frame	2	0: the next frame is not TH precoded: 1 to 3
PHD.TX.NEXT.PDB.OFFSET	Offset of the first PDB in Payload of the next frame	7	0x00 to 0x40
PHD.RX.LASTFRAMEID	Last frame counter received in return channel before current TX frame	8	0 to 255
PHD.RX.REQ.CODING.SE	Requested MLCC configuration (in number of coded bits per dimension) by RX based on quality measurements	4	0: request for changing the MLCC configuration is not performed 1: 1,0 2: 1,5 3: 2,0 4: 2,5 5: 3,0 6: 3,5 7: 4,0 8: 4,5 9: 5,0 10: 5,5 11: 6,0 12 to 15: reserved for future extensions
PHD.RX.REQ.THP.SETID	Requested THP coefficients set Id	2	0: no request for changing the THP coefficients is performed: 1 to 3
PHD.RX.REQ.THP.COEF[0..8]	Requested THP coefficients set when PHD.RX.REQ.THP.SETID is not equal to 0. 9 b(k) coefficients of 12 bits	108	Each b(k) is formatted (12, 2) Ordered from b(0) to b(8)
PHD.RX.STATUS	Indicates that local CMB receive function is able to make the reception of PAM symbols with reliability. This corresponds to the content of variable loc_rcvr_status. The CMB receive function shall use this PHD field to determine the rem_rcvr_status.	1	0: NOT_OK 1: OK
PHD.CAP.LPI	Signals the capacity of the PHY to support the reception of Low Power Idles during the payload sub-blocks	3	0: LPI is not supported 1: LPI is supported 2 to 7: reserved
PHD.CAP.ABR	Signals the capacity of PHY to implement Adaptive Bit Rate (ABR), so that the PHY is able to request and accept adaptive MLCC configuration	2	0: ABR is not supported 1: ABR is supported 2 to 3: reserved
PHD.DEVID.FLG	Indicates the PHD carries device identifier information encoded in PHD.DEVID.INFO	1	0 1: reserved for future extensions
PHD.DEVID.INFO	Device identifier The identification procedure is left undefined, and this field is reserved for future extensions	48	0 1 to 2^{48} - 1: reserved for future extensions
	Reserved bits for future extensions. These bits shall be set to 0.	128	0 1 to 2^{128} - 1: reserved for future extensions
PHD.VENDOR.FLG	Indicates the PHD carries vendor proprietary information encoded in PHD.VENDOR.INFO	1	0: no vendor information is included 1: PHD carries vendor proprietary information
PHD.VENDOR.INFO	Vendor proprietary information used for application specific implementations and extensions. In case of PHD.VENDOR.FLG = 0, this field shall take the value zero for all the bits.	374	0 to 2^{373} - 1
PHD.CRC16	Cyclic redundancy code of 16 bits. Specified in clause 5.2.4.3	16	0x0000 to 0xFFFF
Total (bits)		720	

5.2.4.3 Physical Header CRC16

The header is protected with a CRC16 cyclic redundancy parity check code. The CRC16 is described in figure 26. The 16 CRC bits are sent at the end of the 720 bits PHD block.

The CRC16 shall be generated using the following generator polynomial:

$$1+x^2+x^5+x^6+x^8+x^{10}+x^{11}+x^{12}+x^{13}+x^{16}.$$

The implementation shall produce the same result as that in figure 26. The first 704 PHD bits are used to compute the CRC16 with the switch connected (CRCgen setting). The 16 delay elements S0 to S15, shall be initialized to 0. After the 704 bits have been serially processed, the switch is disconnected (CRCout setting) and the 16 stored values (S0 to S15) are the CRC16. CRC16 is transmitted in order from S15 to S0.

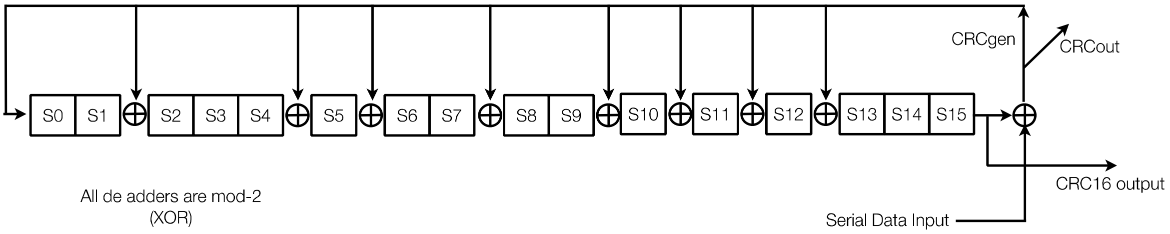

Figure 26: Physical Header CRC

5.2.4.4 Physical Header scrambler

The header block is scrambled prior to transmission. The original bits are XORed with a pseudorandom sequence; this sequence shall be generated using a LFSR with polynomial: $1+x^{22}+x^{25}$ (MLS generator). The LFSR is initialized to a value of 0x0068_D332 at the beginning of the frame, where the left most digit corresponds to the initial value of register 0. The header bits are then scrambled prior to transmission. The implementation of the scrambler shall produce the same results as that shown in figure 27.

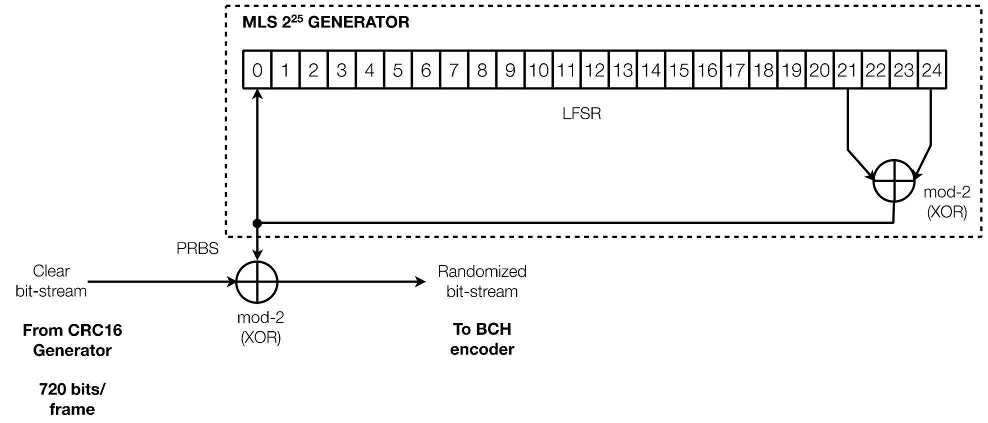

Figure 27: Physical Header scrambler reference block diagram

5.2.4.5 Physical Header BCH encoding

A (896,720) BCH code is used to encode the header. The code is described by the generator polynomial G(x):

0x0001_A3E8_171D_BCA4_EE1E_7CDC_A7DA_FB8D_8F39_8072_8516_6007,

being g(0) the rightmost bit.

To obtain the parity bits, 1 151 zero bits are prepended to the 720 bits prior to the BCH encoding. The BCH encoder shall produce the same result that the implementation of figure 15. All the elements S_x are initialized to zero before encoding. After the 1 871 bits block has been serially processed with switch connect to BCHgen, the S_x bits shall be transmitted from S_{p-1} to S_0 starting with S_{p-1}, with switch unconnected (BCHCout).

5.2.4.6 Physical Header mapping to PAM symbols

The incoming 896 bits are mapped into 1 792 2-PAM symbols. The mapping of BCH encoded bits in 2-PAM symbols based on a two-dimensional BPSK constellation is illustrated in figure 28.

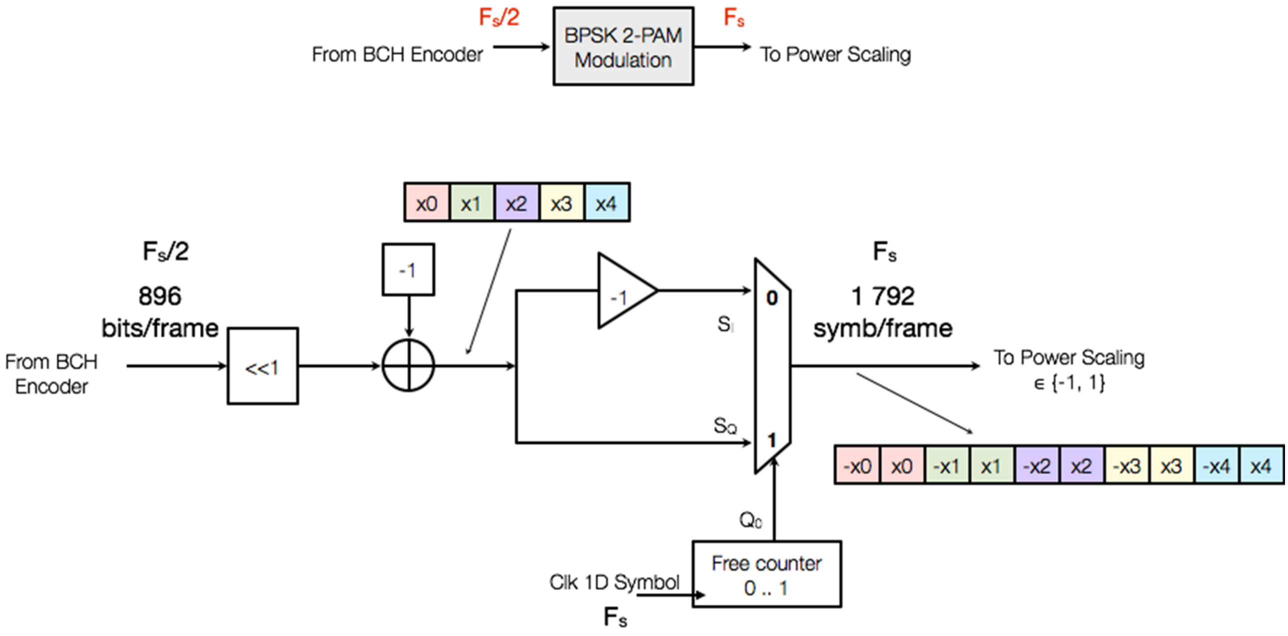

Figure 28: Physical Header PAM mapping

5.2.4.7 Physical Header Subframes (PHS)

The 1 792 symbols block is divided in 14 sub-blocks of 128 symbols each, denoted as Physical Header Subframe (PHS). Prior to transmission, 16 zero symbols are added at the beginning and the end of the PHS as it is illustrated in figure 29. Consecutive PHS blocks extended with zeroes are transmitted at the corresponding locations of the frame as defined in clause 5.2.2.

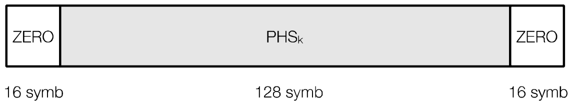

Figure 29: Physical Header Subframe (PHS) with zeroes insertion

5.2.5 Physical pilots encoding

5.2.5.1 Introduction to physical pilots

The pilot signals S1 and S2 carry information to aid the receiver initialization and continuous tracking. The S1 pilot signal is transmitted at the beginning of each frame as shown in figure 3 and is designed to facilitate frame and symbol synchronization. The S2 pilot signal is transmitted in sub-blocks that are distributed over the frame as shown in figure 3. The S2 pilot is designed to facilitate channel estimation and equalization by the receiver as well as continuous clock recovery.

5.2.5.2 S1 pilot symbols generation

The S1 pilot signal is composed of 128 two level PAM symbols that are transmitted at the beginning of each frame. These symbols are generated after mapping a 128 bits sequence generated using a Linear Feedback Shift Register (LFSR).

The generator polynomial is $1 + x^{22} + x^{25}$. The implementation shall produce the same result as the implementation illustrated in figure 12. The register shall be initialized with a value of 0x00AC_2B4B at the beginning of each frame, where the left most digit corresponds to the initial value of register 0. The bits generated by the LFSR are then mapped to 2 level PAM symbols using the scheme in figure 30. The output symbols belong to the set {-1, 1}.

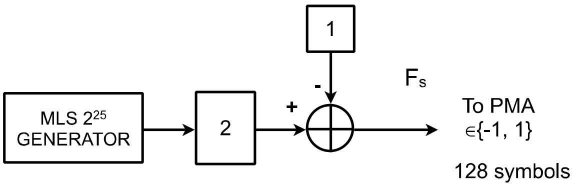

Figure 30: S1 pilot symbols generation

The S1 pilot starts and ends with a sequence of zero symbols as shown in figure 31. Each sequence of zero symbols is composed of 16 symbols.

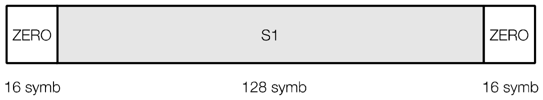

Figure 31: S1 pilot zeroes insertion

5.2.5.3 S2 pilot symbols generation

The S2 pilot signal is composed of 1 664 symbols that are transmitted in 13 sub-blocks of 128 symbols each. The bits are generated using a Linear Feedback Shift Register (LFSR) and mapped to PAM symbols with 256 levels. A sequence of zero symbols is inserted at the beginning and end of each S2 pilot sub-block.

The generator polynomial is $1 + x^{22} + x^{25}$. The implementation shall produce the same result as the implementation illustrated in figure 12. The register shall be initialized with a value of 0x00AC_2B4B at the beginning of each frame, where the left most digit corresponds to the initial value of the register 0.

The bits generated by the LFSR are then mapped to 256 level PAM symbols using the scheme in figure 32. After LFSR generation, the bits are converted from serial to parallel (S/P) to symbols with 8 bits. The right most bit is the most significant bit.

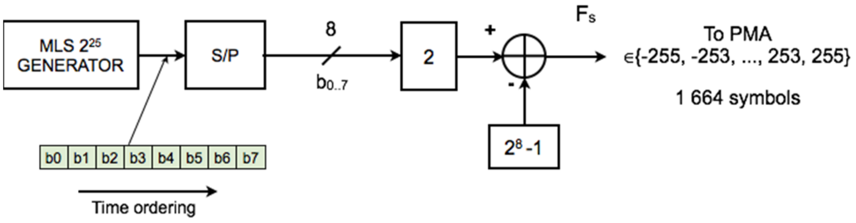

Figure 32: S2 pilot symbols generation

After PAM mapping, the S2 pilot is divided in 13 sub-blocks of 128 symbols each. Each S2 pilot sub-block starts and ends with a sequence of zero symbols as shown in figure 33. Each sequence of zero symbols is composed of 16 symbols.

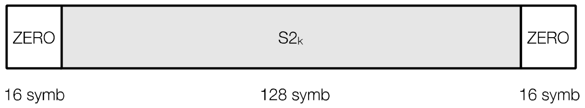

Figure 33: S2 pilot sub-blocks zeroes insertion

5.2.6 Power scaling

Prior to transmission, the signal is scaled to ensure that the OMA is approximately the same across the entire frame. Power scaling for payload PAM symbols is implemented as illustrated in figure 34.

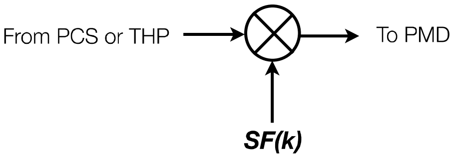

Figure 34: Power scaling for PAM payload symbols

The scaling factor SF(k) depends on the number of PAM levels used and on whether THP is active or not. The factors for different configurations of the payload data MLCC encoding are shown in table 7.

Table 7: Scaling factor configurations for payload PAM symbols

$\lceil \xi \rceil$	M-PAM	SF(k) THP enabled	SF(k) THP disabled
1	2	128	255
2	4	64	85
3	8	32	36
4	16	16	17
5	32	8	8
6	64	4	4

The scaling factor for Physical Header sub-blocks is $SF_H = 255$, since they are modulated with 2-PAM. For S1 pilot the scaling factor is $SFS_1 = 255$ as well. For S2 sub-blocks the scaling factor is $SFS_2 = 1$, since 256-PAM symbols are used.

5.2.7 Tomlinson-Harashima Precoding (THP)

The PAM symbols to be transmitted, corresponding to the payload data of a frame, are precoded using THP as shown in figure 35. The coefficients b(i) are transmitted from the remote device in the Physical Header Data (PHD) of a previous frame as described in clause 5.2.4. The coefficient b(i) used for precoding corresponds to PHD.RX.REQ.THP.COEF[i] transmitted by the remote PHY.

At the beginning of each payload sub-block (i.e. after either S1, S2 or PHS sub-blocks are transmitted) the state of feedback filter b(i) shall be reset (i.e. assuming all the previous symbols entering the TH precoder are zero).

The zero symbols at the beginning and at the end of each S1, S2 and PHS sub-block make possible the TH precoding of payload symbols without inter-symbol interference in reception.

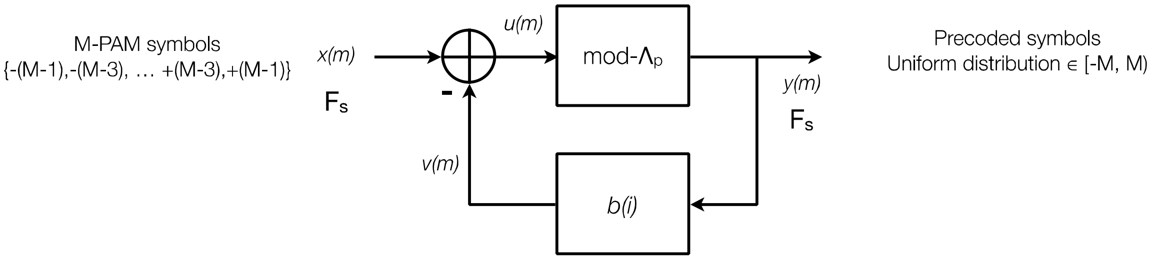

Figure 35: Tomlinson-Harashima precoding, functional block diagram

The precoder is defined by the following mathematical equations:

$$v(m) = \sum_{i=0}^{N_b-1} b(i) y(m-i-1),$$

$$u(m) = x(m) - v(m),$$

$$y(m) = \mathrm{mod}\big((u(m)+M), 2M\big) - M,$$

where $\mathrm{mod}(y,x) = y - x\left\lfloor \frac{y}{x} \right\rfloor$ and produces symbols that are distributed in the region [-M, M) and where $\lfloor \cdot \rfloor$ denotes the rounding down to an integer of a real number. $M = 2^{\lceil \xi \rceil}$, where ξ is defined in clause 5.2.3.7.

When the PHY powers on and while PHD.RX.REQ.THP request information is not received, all the coefficients b(i) shall be set to zero. The precoding is disabled when all b(i) are set to zero.

5.3 CMB receive function

The CMB receive function shall map incoming PAM symbols from the EO interface.

The CMB receive function shall indicate to the CMB the type of received PAM symbol by means of the CMB_DATATYPE.indication message.

For CMB_DATATYPE.indication(PAYLOAD), the CMB receive function shall perform the symbol level descrambling, the MLCC decoding to correct the errors that channel impairments may produce to the communication signal and the binary descrambling.

After this, the PDB.CTRL and PDB.DATA blocks shall be used to extract the frames from the received bits. Finally, the recovered data shall be de-encapsulated and sent out via the data interface.

A number of error situations can occur during the de-encapsulation. The CMB receive implementation shall check the CCRC for PDB.CTRL blocks and the DCRC field associated to data packets to detect errors. In case of error, the error can be signalled to the data interface. The implementation shall not send an erroneous data packet without signalling the error. As an example, the following error situations are discussed:

a) An error in a PDB.DATA affecting a bit other than PDB.TYPE.

b) An error in a PDB.DATA affecting PDB.TYPE.

c) An error in a PDB.CTRL affecting a bit other than PDB.TYPE.

d) An error in a PDB.CTRL affecting PDB.TYPE.

An error in a PDB.DATA that affects a bit other than PDB.TYPE is detected when checking the DCRC associated with the data packet. When the error affects the PDB.TYPE bit, the error is detected when checking the CCRC field as the block will be interpreted as a control block due to the error. When the error in a PDB.CTRL affects a bit other than PDB.TYPE it is detected when checking the CCRC. Finally, an error in the PDB.TYPE bit of a control frame causes it to be interpreted as a PDB.DATA block. The error is apparent to the CMB receive function if it occurs when no frame is being received as a data PDB shall be preceded by the corresponding PDB.CTRL. If it occurs in a PDB.CTRL block that is in the middle of back-to-back data packets (as illustrated in figure 12) then both data packets appear as one to the CMB receive function. The error is detected when checking the DCRC of the frame, also an error is detected if the frame length is checked by the CMB receive function. In any case a frame which data or associated control blocks are in error are considered erroneous.

On the other hand, for CMB_DATATYPE.indication(HEADER) the CMB receive function shall perform the physical header decoding enabling the transfer of CMB parameters between both link partners.

Finally, for CMB_DATATYPE.indication(PAYLOAD_OFF) message, the CMB receive function may disable the decoding circuits that are not used in order to reduce the energy consumption.

The CMB Receive function also comprises a receiver for pulse-amplitude modulated signals. It is able to both detect symbol sequences from the signal received from the EO. The signals received from the EO are described mathematically in clause 5.7.3.

When both link ends have signalled support for the LPI mode, the CMB receive function is also in charge of sensing the rx_signal from EO to determine the use of the Low Power Idle mode in payload sub-blocks, indicating to the CMB the proper data type by means of CMB_DATATYPE.indication(PAYLOAD_OFF) message. When this condition is detected, the CMB shall generate the EO_RXPWR.request message to the EO taking into account the implementation dependent delays of sleep and wake times of the EO receive implementation. The CMB may also disable the unused demodulation circuits to reduce the energy consumption.

After BCH decoding and block alignment at the CMB receive function, the quality of the PAM symbols already equalized shall allow a PDB block error rate (PDB-ER, which is measured for the PDB.CTRL blocks) of less than $6{,}5 \times 10^{-9}$ over a channel that meets the channel specifications and the EO receiver optical specifications provided in clause 7 and the respective annexes form annex A to D. The PDB-ER can be measured by checking the CCRC of the received PDB.CTRL blocks.

For a PHY providing a speed of 1 000 Mbit/s with a transmit symbol rate of 312,5 Msymb/s, the PDB-ER shall be less than $6{,}5 \times 10^{-9}$ if the CMB receive function collects less than 100 erroneous PDB.CTRL blocks during 17 minutes, assuming LPI mode is disabled and no PDB.DATA blocks are transmitted. In this scenario, all the PDB.CTRL blocks shall be PDB.IDLE (see clause 5.2.3.2).

For PDB.DATA blocks, the data packet Error Rate (FER) shall be less than $L \times 10^{-10}$ where L is the frame length in bits. The FER can be measured by checking the DCRC associated with the data packet. When frames of different lengths are transmitted, the average frame length can be used for the estimation of the FER.

To achieve the indicated performance, it is highly recommended that the CMB receive sub-clause includes the functions of signal equalization, both linear and non-linear (see clause 5.7.3 for signals received from EO).

5.4 PHY Control function

5.4.1 Introduction to PHY control function

PHY Control function is in charge to enable the PHY for reliable communication with the link partner. PHY Control shall comply with the state diagram described by figure 36.

PHY Control information is exchanged between link partners using bits contained in the physical headers of the frames. The format and use of those bits is defined in clause 5.2.4.2.

5.4.2 Start up sequence

The start up sequence shall comply with the state diagram description given in figure 36.

Upon power on, reset, or release from power down, the PHY shall carry out the clock recovery from the receive signal. The clock recovery is composed of two states. The first one is in charge of obtaining the symbol and frame synchronization by using the a priori known S1 pilot signal that is inserted by the transmitter at the beginning of the frame (see clause 5.2.2).

After frame synchronization is achieved, the CMB Clock Recovery function shall carry out the fine recovery to provide a stable clock that samples the receive signal with a suitable phase for reliable reception. Fine timing recovery may be implemented either based on the a priori known S1 and S2 pilot signals (i.e. data-aided algorithms) or based on blind algorithms that use payload sub-blocks and physical header sub-frames after equalization.

When clock is stable, the CMB Receive function shall be able to train the equalizers based on pilots S1 and S2 reception in order to compensate the inter-symbol interference caused by the communication channel. Blind tracking algorithms for timing recovery may be enabled after the equalizer training has finished.

After this, the CMB Receive function shall be able to receive the physical header data (PHD) from the link partner carrying information about the transmission parameters as well as optional capabilities like LPI and ABR. The CMB Phy Control function shall be able then to assign OK to the rcvr_hdr_lock state variable when CMB Receive function is able to provide reliable reception of PHD. The criteria to determine reliable PHD reception is left to the implementer and it may be based on the correctness of PHD.CRC16 field. The CMB Receive function shall implement continuous checking of reliable PHD reception, which should be assured for valid link operation.

As soon as the physical header data is reliable the CMB shall be able to carry out the THP initialization making the first coefficients adaptation between the link partners and, optionally, carry out the first ABR adaptation.

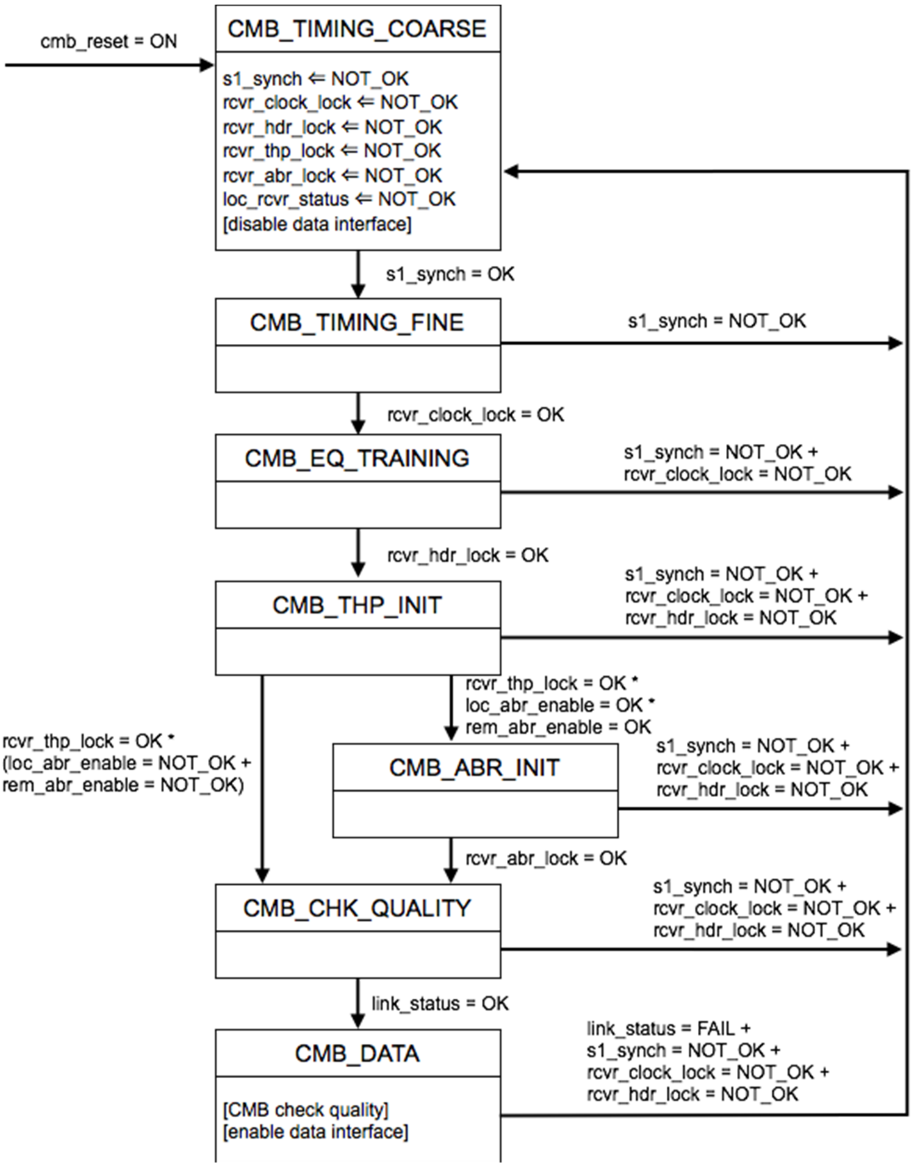

Figure 36: PHY Control state diagram

THP initialization is implemented in the same way the continuous tracking, according to the state diagrams defined in clause 5.4.3.2. CMB Phy Control function shall assign OK to rcvr_thp_lock indicating the THP is locked and the payload data is being received precoded with the first THP coefficients requested to the link partner.

When THP is locked and ABR is locally and remotely enabled, the CMB PHY Control function shall be able to make the first request of MLCC spectral efficiency adaptation to the link partner by using the PHD over the return channel. The ABR initialization is implemented in the same way the continuous tracking, according to the state diagrams defined in clause 5.4.3.3. Once ABR initialization has finished it is communicated via the variable rcvr_abr_lock.

Finally, the CMB Phy Control function shall assign OK to the loc_rcvr_status variable when CMB Receive function is able to provide a reliable reception of payload sub-blocks according with specifications in clause 5.3. The criteria to determine reliable reception of payload sub-blocks is left to the implementer and it may be based on SNR measured in data decoding. The loc_rcvr_status shall be signalled to the link partner by means of the field PHD.RX.STATUS. Further, the value of the rem_rcvr_status variable shall be supplied according to the value of PHD.RX.STATUS received from the remote PHY. The CMB Receive function shall implement tracking of the decoded signal to continuously determine the correct value of variable loc_rcvr_status.

A PHY that locally implements LPI mode in payload data sub-blocks, shall disable the LPI mode during the start-up sequence, until link_status = OK and PHD.CAP.LPI signalled by the remote PHY takes value 1.

All the variables used in the state diagram are defined in clause 6.6.

5.4.3 Continuous tracking sequences

5.4.3.1 Introduction to tracking functions

Upon the link_status being asserted OK, both PHY link partners are able for reliable transmission. Further, both link partners are able to properly use the PHD to carry out continuous adaptation of THP coefficients as well as to optionally implement continuous adaptive bit rate (ABR).

The state diagrams defined in the following clause 5.4.3.2 and clause 5.4.3.3, described in figure 37, figure 38, figure 39 and figure 40, for continuous tracking of THP and ABR are the same used during the start-up sequence to respectively initialize the THP and ABR.

5.4.3.2 THP coefficients adaptation sequence

Figure 37 provides the state diagram that shall be implemented by a PHY to adapt the THP coefficients of the CMB Transmit function in response to the requests performed by the link partner. A PHY shall always announce the THP set-id in the previous frame to the one in which the THP coefficients according with the set-id shall be applied.

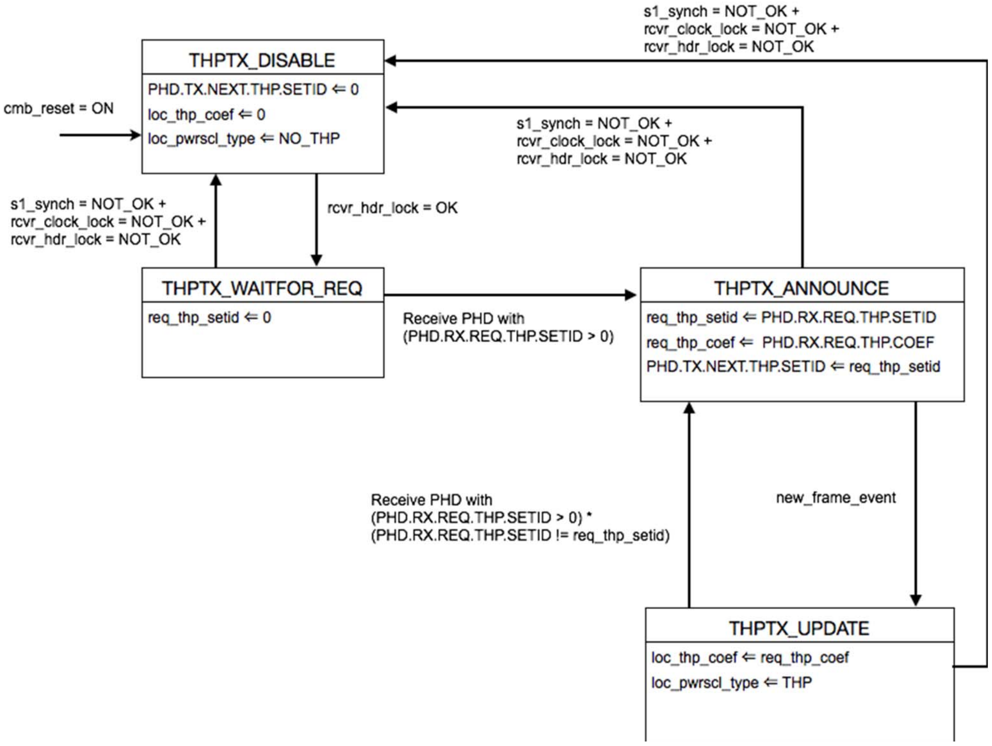

Figure 37: Transmitter THP coefficients adaptation state diagram

All the variables used in the state diagram are defined in clause 6.6.

The CMB receive function shall implement the algorithms to estimate the equalization coefficients suitable to compensate the inter-symbol interference by means of Tomlinson-Harashima precoding. The algorithms for coefficients estimation are left to the implementer. The state diagram to implement the THP configuration requests is defined in figure 38. The CMB PHY Control function shall use the local CMB Transmit function to encode the THP configuration request in the corresponding PHD bits (see clause 5.2.4.2). The PHD.RX.REQ.THP.SETID field shall be used to guarantee that the coefficients used in link partner CMB Transmit function match with the local state of the CMB Receive function.

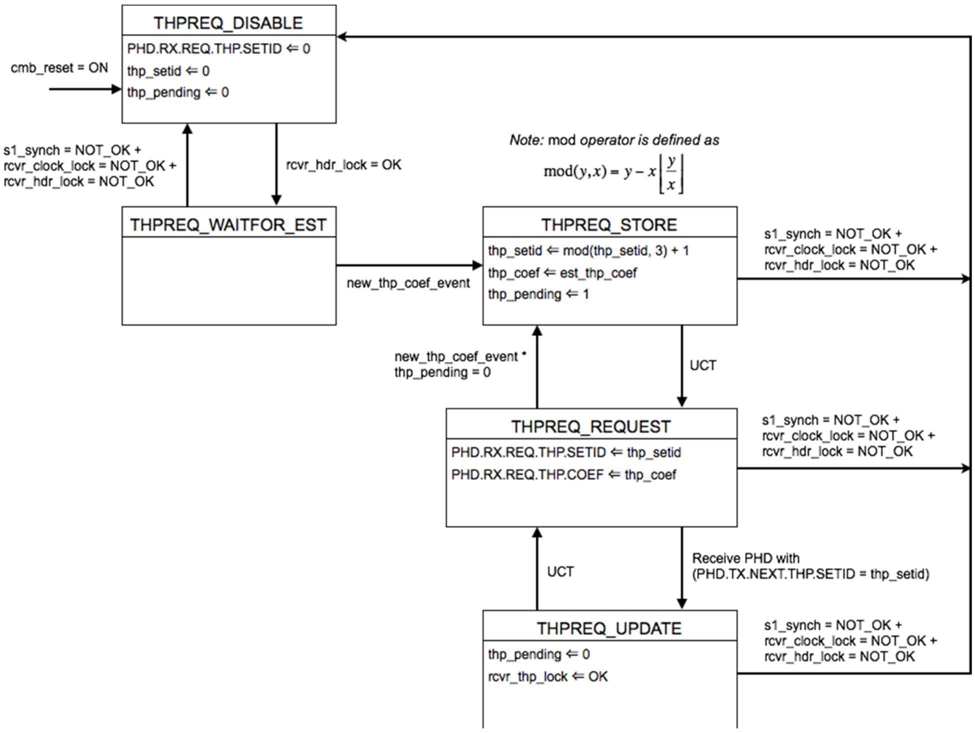

Figure 38: THP configuration request state diagram

5.4.3.3 Adaptive Bit Rate sequence

Figure 39 provides the state diagram that shall be implemented by a PHY supporting Adaptive Bit Rate (ABR) to adapt the CMB Transmit function according to the requests performed by the link partner to change the MLCC encoder spectral efficiency.

CMB Transmit function shall always announce the new MLCC spectral efficiency in the frame before the MLCC encoder is re-configured.

All the variables used in the state diagram are defined in clause 6.6.

When both link partners have signalled ABR support by means of PHD.CAP.ABR field, the CMB Transmit functions shall be configured to use the minimum MLCC spectral efficiency, to enable the CMB Receive function of the link partner to make the first channel quality measurement with good accuracy. After this, CMB PHY Control shall wait for the requests done by the link partner to accordingly adapt the MLCC configuration.

The CMB Receive function shall implement the algorithms to make the channel quality measurements that allow to dynamically adapt the MLCC rate. These algorithms are implementation dependent and shall always provide the block error rate (PDB-ER) indicated in clause 5.3 for any adaptive MLCC spectral efficiency.

Figure 40 provides the state diagram that shall be implemented by CMB PHY Control function to make the requests to the link partner to adapt the bit rate. The CMB PHY Control function shall use the local CMB Transmit function to encode the MLCC configuration request in the corresponding PHD bits (see clause 5.2.4.2). The matching between both link partners is assured because the MLCC spectral efficiency is always announced in the previous frame. The PHY shall be able to reconfigure the CMB Receive functions on a per frame basis, according to the last decoded PHD received from the remote PHY.

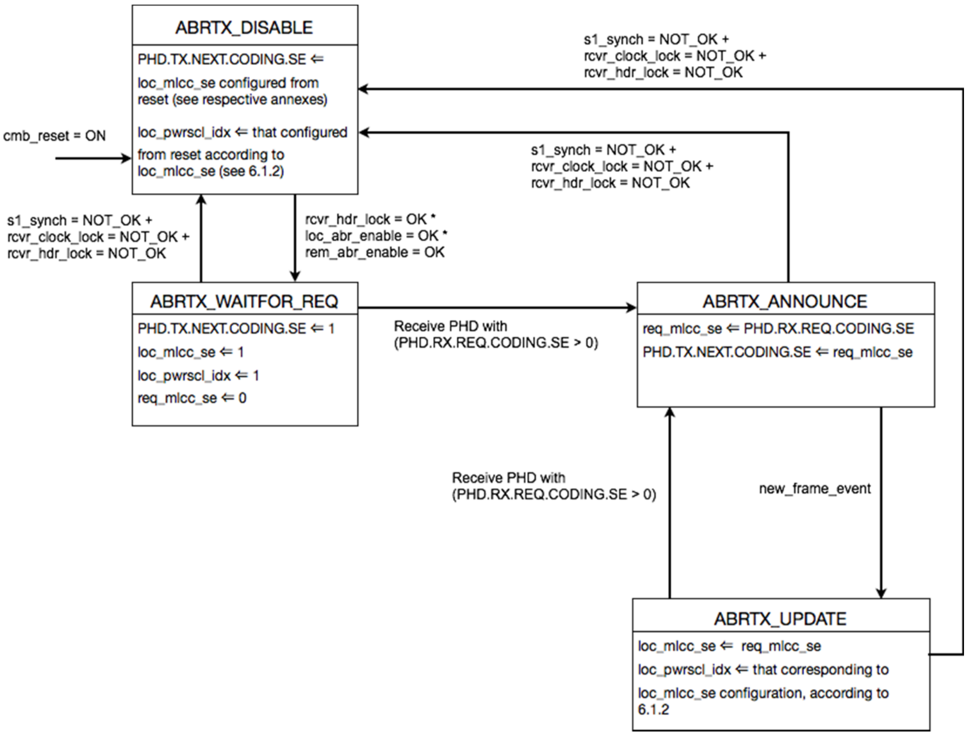

Figure 39: Transmit Adaptive Bit Rate state diagram

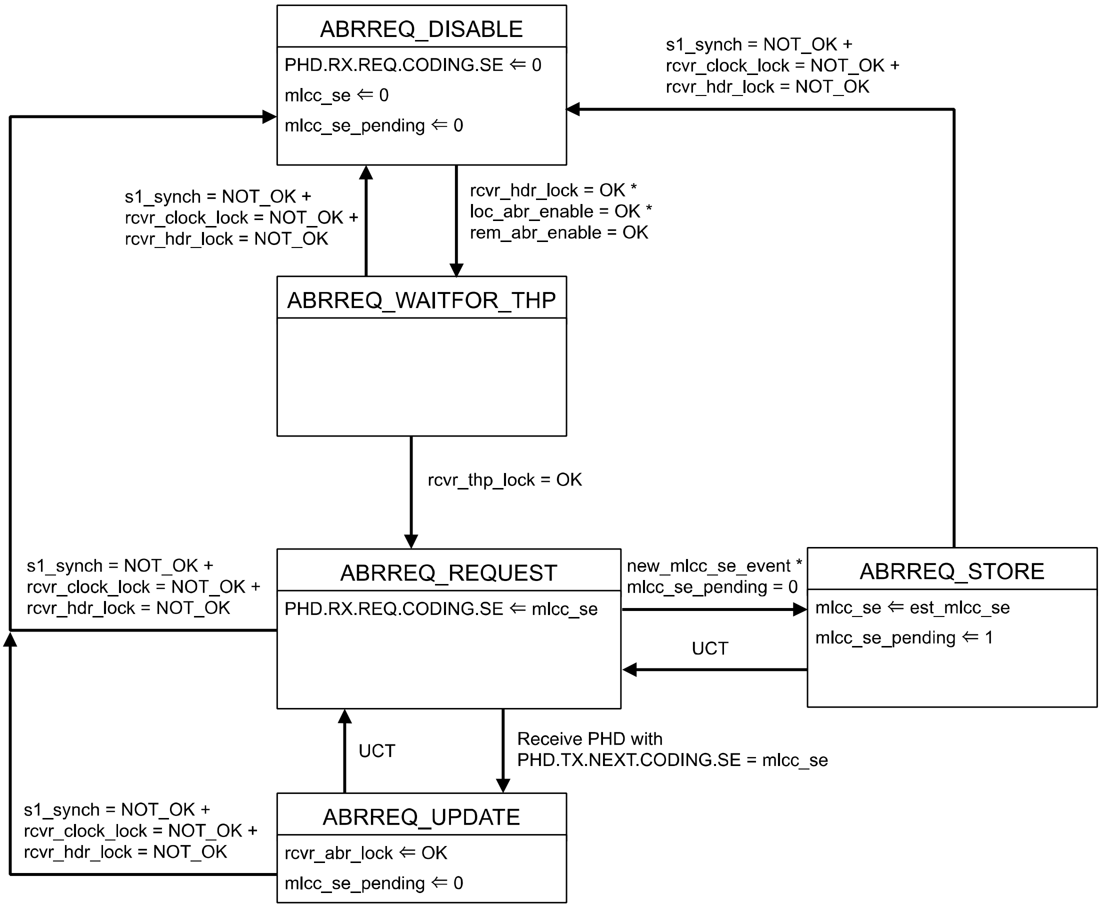

Figure 40: Adaptive Bit Rate configuration request state diagram

5.5 Link Monitor function

Link Monitor function uses the receive channel status of the local and remote PHYs to establish the status of the link and informs it via the link_status variable. When there is a failure of link the CMB stops normal operation.

The Link Monitor function shall comply with the state diagram of figure 41.

Upon power on, reset, or release from power down, the PHY shall perform the start-up sequence to supply the transmission link. As soon as reliable transmission is achieved in both link partners, the variable link_status = OK is asserted, upon which further PHY operations data packet communications can take place.

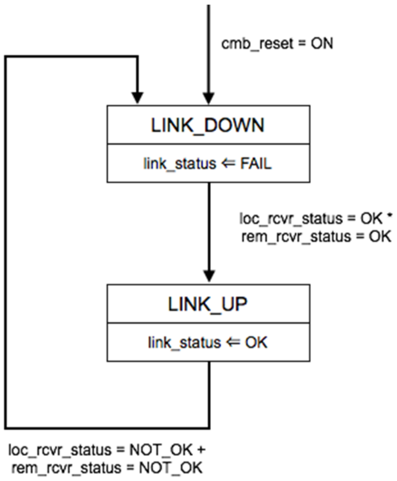

Figure 41: Link Monitor state diagram

5.6 Clock Recovery function

The Clock Recovery function shall provide a clock suitable for signal sampling on the receiver so that the block error rate (PDB-ER) indicated in clause 5.3 is achieved. The received clock signal should be stable and ready for use when equalizer training is performed during start-up sequence and when it has been completed (rcvr_clock_lock = OK).

The Clock Recovery function shall be able to recover a transmit symbol frequency with a deviation of ±100 ppm respect to the nominal symbol frequency. See annexes from A to D for detailed specification of the receiver frequency tolerance.

5.7 Interface to the EO

5.7.1 Introduction to the EO interface

The interface between the CMB and the EO is defined in terms of signals for which no specific implementation is described.

5.7.2 Signals transmitted to the EO interface

Depending on the CMB_DATATYPE.request message the signals transmitted to the EO transmit are different each symbol time. However, all of them can be expressed in a general form as follows:

$$x(n) = SF(n) \times \left(F_M\left(a(n) - \sum_{i=0}^{N_b} x(n-i-1) \times b(i)\right) \right) = SF(n) \times \left(a(n) + 2M \times m(n) - \sum_{i=0}^{N_b} x(n-i-1) \times b(i) \right)$$

Where, a(n) is the PAM modulation symbol from the $\{-M+1,-M+3,\cdots,M-3,M-1\}$ to be transmitted at time n × Ts, Ts is the transmit symbol period (always Ts = 1 / Fs), SF(n) is the power scaling factor specified in clause 5.2.6 for each frame data type, b(i) are the coefficients of TH precoding specified in clause 5.2.6, and the nonlinear operation $F_M(\alpha)=\operatorname{mod}(\alpha+M,2M)-M$ corresponds to changing the modulation symbol a(n) to an augmented modulation symbol $\tilde{a}(n)=a(n)+2M\times m(n)$ with the integer m(n) chosen such that the output lies in the interval $-M \le x(n) < M$.

When tx_type parameter takes values S1 or HEADER, M = 2 and for S2, M = 256. For ZERO a(n) takes the value 0. For PAYLOAD, the value of M depends on the MLCC encoding configuration, which can be fixed or adapted as a function of the channel condition. M can take values from 2 to 64. M remains constant at least during a complete frame for PAYLOAD type. Finally, the b(i) are 0 for all the values of tx_type except for PAYLOAD, which depends on the signalled coefficients PHD.RX.REQ.THP.COEF by the remote PHY.

5.7.3 Signals received from EO

Signals received from the EO can be expressed as pulse-amplitude modulated signals that have been filtered by a non-linear channel and corrupted by noise as follows:

$$y(n)=w_{o0}+\sum_{l_1=0}^{L}w_{o1}(l_1)x(n-l_1)+\sum_{l_1=0}^{L}\sum_{l_2=0}^{L}w_{o2}(l_1,l_2)x(n-l_1)x(n-l_2)+\dots$$

$$+\sum_{l_1=0}^{L}\sum_{l_2=0}^{L}\dots\sum_{l_p=0}^{L}w_{oP}(l_1,l_2,\dots l_P)x(n-l_1)x(n-l_2)\dots x(n-l_P)+N(n)$$

Where the received signal y(n) is considered sampled by CMB receive function with the recovered clock, at the optimum phase and with a frequency equal to the transmit symbol clock. x(n) is the transmitted signal to EO, N(n) the additive noise from optical to electrical conversion, and are the kernels of a truncated Volterra series that represents the non-linear response of the communication channel.

The received signal considers the electrical-to-electrical communication channel composed by all the elements from the CMB transmit function to CMB receive function, including the electrical-to-optical conversion carried out by EO transmit function, the fibre and the optical-to-electrical conversion carried out by EO receive function.

6 PHY service messages and interfaces

6.1 Introduction to service interfaces

PHY transfers data and control messages across the following three service interfaces:

a) Data Interface.

b) CMB Service Interface.

c) Connector Interface (Conn).

6.2 Data Interface

Data interface transmits and receives data to be transmitted and is being received. This interface is with external PHY components. The format and description of this interface is out of scope of the present document.

Data interface may be different depending of the type of data to be transmitted by the PHY.

6.3 Monitor Interface

6.3.1 Message description

The following service messages are used by the PHY to exchange control and status signals across the Monitor Interface.

6.3.2 CMB_LINK.indication

The CMB generates this message showing the link status of the lower levels. This message is used mainly by the CMB PHY Control function. The possible values of the message are: CMB_LINK.indication (link_status) = FAIL, or OK. FAIL: Failed to establish a reliable link.

- OK: A reliable link is established

The CMB generates this message when there is a change in link_status as described in clause 5.5.

6.4 CMB Service Interface

6.4.1 CMB service messages

PHY uses the following service messages to exchange symbols, status indications, and control signals across the service interfaces:

- CMB_UNITDATA.request(tx_symb)
- CMB_UNITDATA.indication(rx_symb)
- CMB_DATATYPE.request(tx_type)
- CMB_DATATYPE.indication(rx_type)
- CMB_RXSTATUS.indication(loc_rcvr_status)
- CMB_REMRXSTATUS.request(rem_rcvr_status)

6.4.2 CMB_UNITDATA.request

CMB uses this message to transfer data in the form of PAM symbols (tx_symb). The PAM symbols are obtained in the CMB Transmit function using the coding rules defined in clause 5.2 for each of the frame data types indicated by tx_type parameter. The meaning of the message is: CMB_UNITDATA.request(tx_symb).

During transmission, this message conveys to the CMB via the parameter tx_symb the value of PAM symbol to be sent over the optical link. The set of values that can take this parameter depends on the frame data type as well as the current configuration of the payload data encoding generated by the CMB transmit function.

The CMB transmit function generates CMB_UNITDATA.request(tx_symb) synchronously with every transmit symbol clock cycle. The frequency of this clock varies with the PHY speed, defined in the respective annexes. For example when the speed is 1 000 Mbit/s, the symbol rate is 312,5 MHz, which results in a symbol period of 3,2 ns.

Upon receipt of this message the CMB transmits to the EO the signals corresponding to the indicated symbols after processing with the THP, scale factor and frame building.

6.4.3 CMB_UNITDATA.indication

This message is used in the CMB Receive functions and defines the data to be transfer in the form of recovered PAM symbols to the CMB decoding blocks. The format of the message is: CMB_UNITDATA.indication(rx_symb).

During reception, this message conveys to the CMB via the parameter rx_symb the value of PAM symbol recovered from the optical link.

The CMB receive function generates CMB_UNITDATA.indication (rx_symb) messages synchronously with every data payload and physical header symbol recovered from the EO interface. The nominal rate of the CMB_UNITDATA.indication message varies with the PHY speed defined in the annexes from A to D and is governed by the recovered clock, internally generated by the CMB receive function. This clock shall be recovered from the signals received at the CMB to have the same frequency and constant phase as the transmit clock used by the remote PHY.

The effect of receipt of this message is unspecified.

6.4.4 CMB_DATATYPE.request

This message defines the type of data (tx_type) transferred in the form of PAM symbols from the CMB. The format of the message is: CMB_DATATYPE.request(tx_type).

During transmission, this message conveys to the CMB via the parameter tx_type the type of PAM symbol to be sent over the optical link. The set of values that this parameter can take is as follows:

- S1: the PAM symbol belongs to the pilot signal S1, which is designed to aid in frame synchronization and clock recovery tasks to be carried out by CMB receive function. The generation of S1 pilot is specified in clause 5.2.5.2.
- S2: the PAM symbol belongs to the pilot signal S2 designed to aid in clock recovery and equalization tasks to be carried out by CMB receive function. The generation of S2 pilot is specified in clause 5.2.5.3.
- HEADER: the PAM symbol belongs to the physical header designed to carry control information for CMB. The encoding and modulation of the physical header is specified in clause 5.2.4.
- ZERO: the PAM symbol belongs to the sequence of zeroes inserted at the beginning and the end of the S1, S2 and PHS sub-blocks. The insertions of ZERO symbols are defined in clause 5.2.4.7, clause 5.2.5.2 and clause 5.2.5.3.
- PAYLOAD: the PAM symbol conveys encoded encapsulated user information. The payload data encoding is specified in clause.
- PAYLOAD_OFF: the CMB transmit function is requested to power off the EO, when Low Power Idle mode has been negotiated to be used between both link partners.

The CMB transmit function generates CMB_DATATYPE.request(tx_type) synchronously with every CMB_UNITDATA.request(tx_symb).

Based on receipt of this message the CMB transmit function shall configure the THP processing and power scaling processing, as specified in clause 5.2.7 and clause 5.2.6.

6.4.5 CMB_DATATYPE.indication

This message defines the type of data (rx_type) transferred in the form of PAM symbols. The format of this message is: CMB_DATATYPE.indication(rx_type).

During reception, this message tells the CMB receive function the parameter rx_type the type of PAM symbol recovered from optical link. The set of values that this parameter can take is as follows:

- HEADER: the PAM symbol belongs to the physical header designed to carry control information. The encoding and modulation of the physical header is specified in clause 5.2.4.
- PAYLOAD: the PAM symbol conveys encoded encapsulated user information. The payload data encoding is specified in clause 5.2.3.
- PAYLOAD_OFF: the CMB receive function indicates that Low Power Idle was detected, so that no payload data are indicated to CMB receive function for the current payload sub-block. See clause 5.2.2 for frame structure when Low Power Idle is used.

The CMB receive function generates CMB_DATATYPE.indication(rx_type) synchronously with every CMB_UNITDATA.indication(rx_symb).

6.4.6 CMB_RXSTATUS.indication

CMB Receive generates this message when there is a change in the status of the receive link. The information indicated by this message is the loc_rcvr_status parameter, which is sent to the CMB Transmit and Receive, the CMB PHY Control function, and the Link Monitor indicating the status of the receive link. How the loc_rcvr_status parameter is set is up to the implementer. The remote PHY is informed of the loc_rvr_status parameters by the local PHY via the PHD as specified in clause 5.2.4.2.

The format of this message is CMB_RXSTATUS.indication(loc_rcvr_status). The possible values of loc_rcvr_status parameter are:

- OK: Set and remains valid while the reception link is reliable.
- NOT_OK: Set when the reception link is unreliable.

It is generated when the CMB Receive informs of a change in the reception link status. The effect of receipt of this message is specified by CMB PHY Control function in clause 5.4.

6.4.7 CMB_REMRXSTATUS.request

Local CMB Receive generates this message to indicate the remote PHY about the receive link status. The Local CMB Receive uses the loc_rcvr_status parameter to inform the remote PHY. When the loc_rcvr_status parameter is sent to the remote CMB, the parameter is redefined as rem_rcvr_status. The CMB PHY Control function receives the rem_rcvr_status parameter with the information of the receive link status of the remote PHY.

The parameter rem_rcvr_status is provided by the remote PHY communicating its loc_rcvr_status by using the physical header data (PHD) as specified in clause 5.2.4.2, and shall be available when CMB receive is able to provide reliable reception.

The format of the message is: CMB_REMRXSTATUS.request (rem_rcvr_status).

The possible values of rem_rcvr_status parameter are:

- OK: Set and remains valid while the remote reception link is reliable.
- NOT_OK: Set when the remote reception link is not detected as reliable.

The decoded PHD makes the CMB to generate a CMB_REMRXSTATUS.request message to indicate a change in rem_rcvr_status. The effect of receipt of this message is specified by CMB PHY Control function in clause 5.4.

6.5 EO service interface

6.5.1 EO service messages

PHY uses the following service messages to exchange communication and control signals across the EO service interfaces. EO interface is described in an abstract manner and does not imply any particular implementation.

The EO Service Interface supports the exchange of analogue electrical signals between CMB entities. The EO translates the electrical analogue signals to and from optical signals suitable for the specified medium.

The following messages are defined:

- EO_UNITDATA.request
- EO_UNITDATA.indication
- EO_TXPWR.request
- EO_RXPWR.request

The electrical specifications of the EO service interface are not system compliant points, because these are not readily testable in a system implementation.

6.5.2 EO_UNITDATA.request

This message defines the transfer of data in the form of analogue signal from the CMB to the EO interface.

The format of the message is EO_UNITDATA.request(tx_signal).

During transmission, this message conveys to the EO via the parameter tx_signal the value of the discrete time analogue electrical signal to be converted by EO and sent over the optical link, at the nominal symbol frequency, which is dependent on the PHY, defined in annexes from A to D.

The tx_signal value is obtained by digital-to-analogue conversion from the THP and power scaling processed PAM symbols in CMB Transmit function.

When the Low Power Idle mode is used, the analogue signal is undetermined during payload sub-blocks as described in clause 5.2.2.

The CMB transmit function generates EO_UNITDATA.request(tx_signal) synchronously with every transmit symbol clock cycle. The frequency of this clock varies with the PHY speed, defined in annexes from A to D.

Upon receipt of this message the EO converts the electrical analogue signal from the CMB into the appropriate optical signals on the optical connector. Optical levels are specified by the EO interface in clause 8.2.1 and in the annexes from A to D. Electrical levels are unspecified by the EO.

6.5.3 EO_UNITDATA.indication

This message defines the transfer of data in the form of continuous analogue electrical signal from the EO to the CMB.

The format of the message is EO_UNITDATA.indication(rx_signal).

During reception, this message conveys to the CMB via the parameter rx_signal the value of received signal converted by EO interface from optical signal received through the optical connector. Electrical levels are unspecified by the EO interface. The EO interface in clause 8.2.2 and the annexes from A to D specifies the optical levels at optical connector.

When the Low Power Idle mode is used, the analogue signal shall take a value less than an upper bound during the payload sub-bocks as described in clause 5.2.2. The upper bound is implementation dependent and will correspond to the state of no light received from the fibre, caused by no light being injected to the fibre from the EO transmit function of the remote PHY.

The EO_UNITDATA.indication(rx_signal) is continuously generated by the EO in the form of an electrical analogue signal from opto-electrical conversion. This rx_signal shall be properly sampled by the CMB receive function in order to recover the clock and the PAM symbols. The frequency and phase of the sampling clock implemented by the CMB receive function as well as the clock recovery algorithms are unspecified. The effect of receipt of this message is unspecified.

6.5.4 EO_TXPWR.request

This message is generated by the CMB transmit function to indicate to the EO interface transmit function to turn off or turn on the injection of optical power in the fibre, when Low Power Idle mode is used. The implementation of this message is optional, and the ability of PHY to use LPI shall be announced by the CMB in the physical header, as it is specified in clause 5.2.4.2.

The format of the message is EO_TXPWR.request(tx_pwr).

The tx_pwr parameter can take one of the two values: ON or OFF:

- ON: The EO Transmit function requests to turn on the optical power injection.
- OFF: The EO Transmit function requests to turn off the optical power injection.

The EO_TXPWR.request(tx_pwr) is generated by the EO transmit function taking tx_pwr the value OFF at the event of CMB generates the first CMB_DATATYPE.request with value PAYLOAD_OFF after ZERO. The EO_TXPWR.request(tx_pwr) shall be generated by CMB transmit function taking into account the delays of power scaling and frame building algorithms such that the optical power is powered off after the last ZERO symbol has been transmitted and synchronously with the transmit symbol clock. The frequency of transmit symbol clock is defined for each PHY at annexes from A to D.

The EO_TXPWR.request(tx_pwr) is generated by the CMB transmit function taking tx_pwr the value ON at the event of CMB generates the first CMB_DATATYPE.request with value ZERO after PAYLOAD_OFF. The EO_TXPWR.request(tx_pwr) shall be generated by CMB transmit function taking into account the delays of power scaling and frame building algorithms and the required time to wake up the EO transmit function. The wake up time is implementation dependent. EO_TXPWR.request(ON) shall be generated such that the optical power is powered on before the first ZERO symbol is received and synchronously with the transmit symbol clock.

- EO_TXPWR.request(OFF) shall produce the EO transmit function to power off the light injected to the fibre.

- EO_TXPWR.request(ON) shall produce the EO transmit function to power on the light injected to the fibre.

6.5.5 EO_RXPWR.request

This message is generated by the EO receive function to indicate to the EO receive function to turn off or turn on the optical to electrical conversion, when Low Power Idle mode is used. The implementation of this message is optional, and the ability of PHY to use LPI shall be announced by the CMB in the physical header, as specified in clause 5.2.4.2.

The format of the message is: EO_RXPWR.request(rx_pwr).

The rx_pwr parameter can take one of the two values: ON or OFF:

- ON: The EO Receive function requests to turn on the optical to electrical conversion carried out in the EO interface.
- OFF: The EO Receive function requests to turn off the optical to electrical conversion carried out in the EO interface.

The generation of this message by CMB receive function is unspecified. The CMB receive function may implement a signal processing algorithm in order to determine the lack of optical power during the payload sub-block periods in order to indicate to the CMB receive function the rx_type with value PAYLOAD_OFF and turn off the EO Receive. The effect of receipt of this message is unspecified.

6.6 Connector interface

This interface is between the EO with the plastic optical fibre. Several options are proposed in clause 8.

Data transmitted in the connector is optical information coming from the EO interface.

Received optical information in the connector is distorted by the optical fibre. Optical information is provided to the EO interface.

7 EO interface specifications

7.1 Introduction to EO interface

The present clause specifies the PHY Electro Optical interface and baseband medium for Plastic Optical Fibre (POF). The present clause also specifies the common parts to be fulfilled by all the PHYs defined in the annexes from A to D.

In addition the definition of optical parameters and the corresponding measurement procedures are specified. The values of these parameters are specified in the annexes from A to D of each PHY.

7.2 EO interface functional specification

7.2.1 Introduction to EO interface

The EO performs the Transmit and Receive functions that convey data between the EO service interface and the fibre connector.

7.2.2 EO interface block diagram

For purpose of system conformance, the EO interface is defined at the following points, depicted in figure 42. The optical transmit signal is defined at the output end of a patch cord (TP2), of 1 meter in length, of Plastic Optical Fibre consistent with the link type connected to the fibre connector, specified in clause 8. All the transmitter measurements and tests shall be made at TP2. The optical receive signal is defined at the output of the fibre optic cabling (TP3) connected to the receiver connector defined in clause 8. All the receiver measurements and specifications are made at TP3.

TP1 and TP4 are defined reference points as a reference for implementers. They might be used to certify component conformance. Electrical specifications are not defined for these points, as they might not be testable in a system implementation.

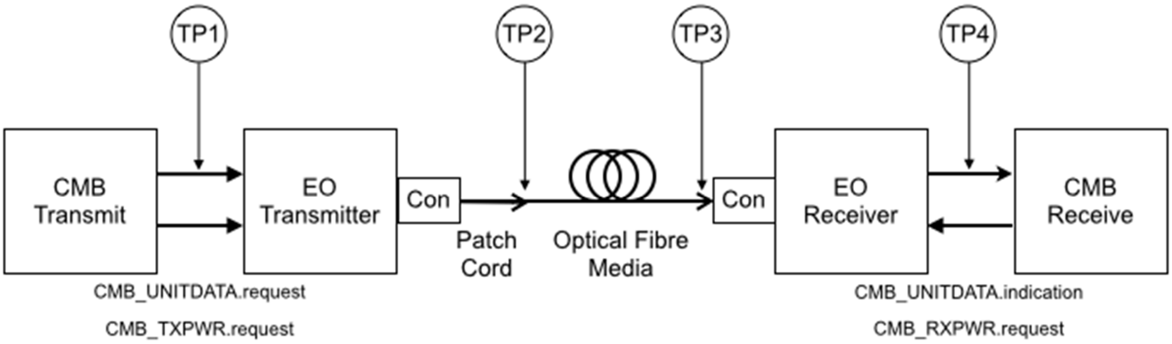

Figure 42: EO interface block diagram

7.2.3 Optical transmit function

The optical transmit function makes the electrical-to-optical conversion from the communication data in form of discrete time analogue electrical signal generated by the CMB transmit function to the fibre connector. Electrical levels at the EO interface are unspecified. The signal at the fibre connector shall meet the optical specifications defined in clause 7.3.2 and the annexes from A to D.

Maximum positive value of transmit signal (see clause 5.7.2) from CMB Transmit function shall correspond with higher optical power in TP2. Minimum negative value of transmit signal from CMB Transmit function shall correspond with lower optical power in TP2.

Optionally, the optical transmit function can also be able to sleep and wake up the optical power injected to fibre during a period of time. This functionality enables to use Low Power Idles during the data payload sub-blocks, so reducing the energy consumption of the PHY, as specified in clause 5.2.2. The EO interface shall be controlled from the CMB by means of the CMB_TXPWR.request message, as specified in clause 6.5.4.

7.2.4 Optical receive function

The optical receive function performs the optical-to-electrical conversion from the optical signal received from fibre connector to the continuous analogue electrical signal used by the CMB receive function to recover the communication PAM symbols. Electrical levels at the EO interface are unspecified. The signal at the fibre connector shall meet the optical specifications defined in clause 7.3.3 and the annexes from A to D.

Optionally, when the Low Power Idle mode is used by the remote PHY, the analogue signal shall take a value less than an upper bound during the payload sub-bocks as described in clause 5.2.2. The upper bound is implementation dependent and corresponds to the state of no light received from the fibre, caused by no light being injected to the fibre from the EO transmit function of the remote PHY.

Optionally, the Low Power Idle is detected by the CMB receive function, as specified in clause 5.3, which may power off the optical receive function to reduce the energy consumption by means of the message EO_RXPWR.request (see clause 6.5.5). The ability to support LPI during the payload sub-blocks shall be signalled by the local PHY in the physical header information as it is specified in clause 5.2.4.2.

7.3 Optical to fibre connector optical specification

7.3.1 Introduction to the optical to fibre connector optical specification

The operating range for EO interface is defined for each PHY in annexes from A to D. The annexes from A to D specify the parameters of CMB as well as the EO interface optical specifications for each specific PHY. In the present clause the transmitter and receiver optical parameters are described and the values for these parameters are specified for each PHY in annexes from A to D.

7.3.2 Transmitter optical specifications

Any transmitter shall meet the specifications at TP2 defined in table 8 per measurements techniques defined in clause 7.4.

Table 8: PHY transmit optical characteristics

Description	Value	Units
Transmitter type	Defined in annexes from A to D	-
Wavelength range (λ)	Defined in annexes from A to D	nm
RMS spectral width (max)	Defined in annexes from A to D	nm
Extinction ratio (min)	Defined in annexes from A to D	dB
Average Optical Power (max) $\mathrm{AOP}_{\max@TP2}$	Defined in annexes from A to D	dBm
Average Optical Power (min) $\mathrm{AOP}_{\min@TP2}$	Defined in annexes from A to D	dBm
T_{rise} / T_{fall} (max; 20 % to 80 %)	Defined in annexes from A to D	ns
EVM for 2-PAM (max)	Defined in annexes from A to D	%
EVM for 4-PAM (max)	Defined in annexes from A to D	%
EVM for 8-PAM (max)	Defined in annexes from A to D	%
Transmitter timing jitter (max)	Defined in annexes from A to D	ps RMS

All the parameters in table 8 are defined in clause 7.4.

7.3.3 Receiver optical specifications

Any receiver shall meet the specifications at TP3 defined in table 9. All the parameters in table 9 are defined in clause 7.4.

Table 9: PHY receive optical characteristics

Description	Value	Units
Wavelength range (λ)	Defined in annexes from A to D	nm
Average Optical Power (max) $\mathrm{AOP}_{\max@TP3}$	Defined in annexes from A to D	dBm
Average Optical Power Sensitivity (min) $\mathrm{AOP}_{\min@TP3}$	Defined in annexes from A to D	dBm

The optical analogue signals arriving to the fibre connector, coming from a remote PHY within the specifications of clause 7.3.2, and have passed through an optical medium specified in clause 7.5, are translated to CMB by means of EO_UNITDATA.indication message, such that, after clock recovery and equalization in CMB receive function and MLCC BCH decoding and block alignment in CMB receive function, the quality of the received data shall meet, for PDB.CTRL blocks, a PDB block error rate (PDB-ER) of less than $6{,}5 \times 10^{-9}$, as specified in clause 5.3. This shall be fulfilled in all the average optical power (AOP) range between the minimum and maximum defined in table 9 and annexes from A to D. The sensitivity is defined as the minimum AOP in TP3 that fits with table 9 requirements.

7.3.4 Worst-case link budget and system margin

The worst-case link budget and system margin for the PHY are defined in table 10, based on the transmitter and the receiver optical specifications provided in clause 8.2.1 and clause 8.2.2, respectively. The link budget chain is depicted in figure 43, as reference for the parameters defined in table 10. See clause 8.1.1 for the TP2 and TP3 definitions.

Table 10: PHY link budget and system margin definition

Description	Value	Units
Fibre Insertion Loss (IL1 in figure 43)	Defined in annexes from A to D	dBo
Worst-case System Margin - IL2 in figure 43 (see note)	Defined in annexes from A to D	dBo
Worst-case Link budget - difference between the minimum AOP at TP2 and the sensitivity (min AOP) at TP3	Defined in annexes from A to D	dBo
NOTE: Minimums of transmit AOP and transmit ER are assumed at TP2.		

The different insertion loss contributions, depicted in figure 43, are defined as follow:

a) IL1 - Fibre Insertion Loss: operating distances are used to calculate the insertion loss.

b) IL2 - Worst-case System Margin: every excess loss that is not considered in IL1, e.g. bends, repair, intermediate in-line connectors. The worst-case System Margin is defined as:

$$\mathrm{SM} = \mathrm{IL2} = \mathrm{AOP}_{\min@TP2} - \mathrm{IL1} - \mathrm{AOP}_{\min@TP3}$$

Minimum transmit Extinction Ratio at TP2 is also considered for definition.

c) Link Budget: the available attenuation between transmitter and receiver. This is defined as:

$$\mathrm{LB} = \mathrm{AOP}_{\min@TP2} - \mathrm{AOP}_{\min@TP3}$$

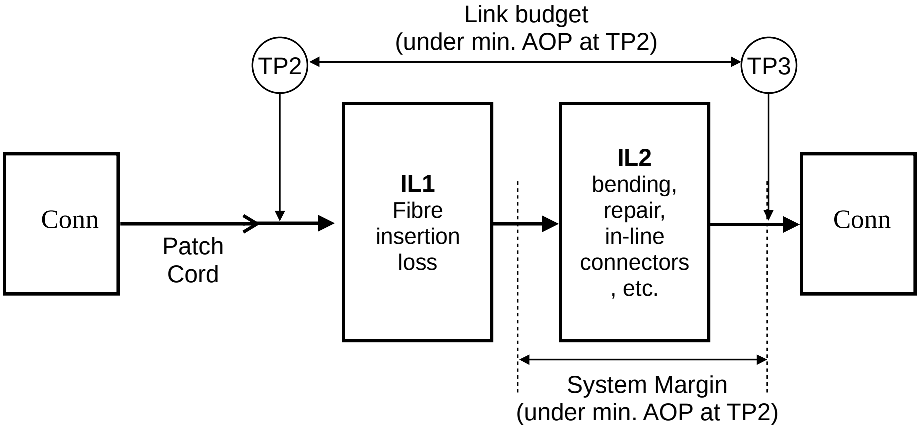

Figure 43: PHY reference diagram for link budget and system margin definition

7.3.5 Test modes

7.3.5.1 Introduction to test modes

Following test modes are defined to instruct the PHY to generate special signal patterns that are suitable for optical measurements defined in clause 7.3.

7.3.5.2 Test mode 1

The signal pattern generated by CMB in Test mode 1 shall consist on a square bipolar signal of FS / 20 MHz, which takes the extreme values corresponding to a 2-PAM modulation. The scale factor defined in clause 5.2.6 shall be configured to 255 in this test mode and both CMB and THP shall be bypassed.

FS is the transmit symbol rate that is defined for each PHY in annexes from A to D.

7.3.5.3 Test mode 2

The CMB shall be instructed to generate pseudo-random M-PAM sequences, using the full range of CMB transmit output. THP shall be bypassed and the Scale Factors defined in column 4 of table 7 shall be used for each M-PAM configuration in CMB transmit function.

CMB transmit function shall be configured as follows to generate the signal pattern:

- The data encapsulator shall be disconnected from binary scrambler.
- The frame building functionality shall be disabled, so header and pilot sections shall not be generated.
- The binary scrambler defined in clause 5.2.3.6 shall be fed with a zeroes binary stream, initialized at the beginning of test as it is defined in clause 5.2.3.6 and free running.
- The pseudo-random binary stream shall feed a mapper as defined in clause 5.2.3.7.4, being the mapper configured according to M-PAM, being $kI = kQ = \log_2(M) < 16$, and $kI = 4$, $kQ = 3$ for $M = 16$. This mapper shall generate two-dimensional symbols at half of the symbol rate.
- The output of mapper shall be connected to the multiplexer defined in clause 5.2.3.7.8, to generate the M-PAM symbols at symbol rate.
- The symbol rate is specified for each PHY in the respective annexes.
- LPI functionality shall be disabled.

- M shall be configured setting the bits with the desired bit density through Data Packet Interface.

7.3.5.4 Test mode 3

The signal pattern generated by CMB shall consist on a square bipolar signal, which takes the extreme values corresponding to a 2-PAM modulation. The scale factor defined in clause 5.2.6 shall be configured to 255 in this test mode and most of the CMB shall be bypassed.

The CMB transmit function shall generate the transmitted symbols using a symbol frequency FS clock, therefore providing a square signal of FS / 2 MHz.

FS is specified for each PHY in annexes from A to D.

7.3.5.5 Test mode 4

The CMB shall be instructed to generate pseudo-random M-PAM signal, as in the Test mode 2, but with a symbol rate of FS / 10 MHz. FS is defined for each PHY in annexes from A to D.

7.4 Optical measurement requirements

7.4.1 Introduction to optical measures

All the optical measurements shall be made through a short patch cord cable, as defined in clause 7.2.2, at TP2. The optical measurements in the receiver shall be done at TP3.

The transmitter testing methodology is such that the EO is not tested in isolation, but is always considered as part of the complete physical layer, i.e. TP1 is not used as a stimulus point, rather the complete physical layer is instructed to generate signals which are in turn measured at TP2.

The main reason for this approach is to allow vendors the freedom to partition the contributions to noise and other non-ideal aspects across the physical layer instead of the present document imposing any such partitioning.

7.4.2 Central wavelength measurement

The central wavelength shall be measured using an optical spectrum analyser per EIA/TIA standard FOTP-127/61.1 [2], 1991. This shall be measured under normal conditions using a valid PHY signal as specified in clause 5.2, and LPI will not be used to make this measurement. The symbol rate of the modulated signal is defined for each PHY in annexes from A to D.

The central wavelength is defined as:

$$\lambda_C = \frac{\sum_{i=1}^{N} P_i \lambda_i}{\sum_{i=1}^{N} P_i}$$

where the power spectral density is measured in N points, taking the PSD Pi (in watts/nm) for each λ_i (in nm).

7.4.3 Spectral width measurement

The spectral width (RMS) shall be measured using an optical spectrum analyser per EIA/TIA standard FOTP-127/61.3 [2], 1991. This shall be measured under normal conditions using a valid PHY signal as specified in clause 5.2, and LPI will not be used to make this measurement. The symbol rate of the modulated signal is defined for each PHY in annexes from A to D.

The spectral width is defined as:

$$\lambda_W = \left(\left(\frac{\sum_{i=1}^{N} P_i \lambda_i^2}{\sum_{i=1}^{N} P_i} \right) - \lambda_C^2 \right)^{\frac{1}{2}}$$

where the power spectral density is measured in N points, taking the PSD Pi (in watts/nm) for each λ_i (in nm).

7.4.4 Extinction Ratio (ER) measurement

The Extinction Ratio (ER) shall be measured in time domain through the measurement of maximum optical power (P1) and minimum optical power (P0). It is defined as (in dBm):

$$ER = 10 \times \log_{10}(P_1 / P_0)$$

being P1 and P0 measured in mW, as the integration of all the optical PSD along the complete spectrum. To make negligible the effects in transmit signals of band limitation and possible AC coupling implementation of EO transmitter, a specific signal pattern shall be generated by the CMB. The signal pattern shall be generated configuring the PHY in Test mode 1.

7.4.5 Average Optical Power (AOP) measurement

The AOP shall be measured at TP2 and TP3 by means of a large area photo-detector able to couple all the output optical power from the fibre.

In order to make properly the AOP measurement, and considering the non-linear effects of the electrical-to-optical conversion of EO transmitter, the PHY shall be configured in Test mode 2 with M = 16 levels.

7.4.5 Transmit rise/fall time characteristics

The transmit rise and fall times measurement shall be done using an electrical oscilloscope after optical to electrical conversion or an optical oscilloscope. The minimum required bandwidth of the optical-to-electrical converter and oscilloscope shall be 5 / 2 times the symbol rate FS defined for each PHY in the respective annexes. Excess bandwidth could be used to not degrade the measurement.

Rise time shall be measured as the time to pass the optical signal from 20 % to 80 % of maximum amplitude. In a similar way, the fall time shall be measured as the time to pass the optical signal from 80 % to 20 % of maximum amplitude.

The PHY shall be configured in Test mode 1 to make these measurements.

7.4.6 Error Vector Magnitude (EVM) measurement

7.4.6.1 Introduction to EVM

EVM measurements are used to define conformance specifications at TP2 including other non-linear effects of the optical transmitter that cannot be measured by the measurement procedures defined in clause 7.3.

7.4.6.2 Reference receiver

Rather than analysing the optical signal from a transmitter directly, an idealized reference receiver is assumed, that demodulates and samples the signal prior to any EVM specification parameter computation. The reference receiver is illustrated in figure 44.

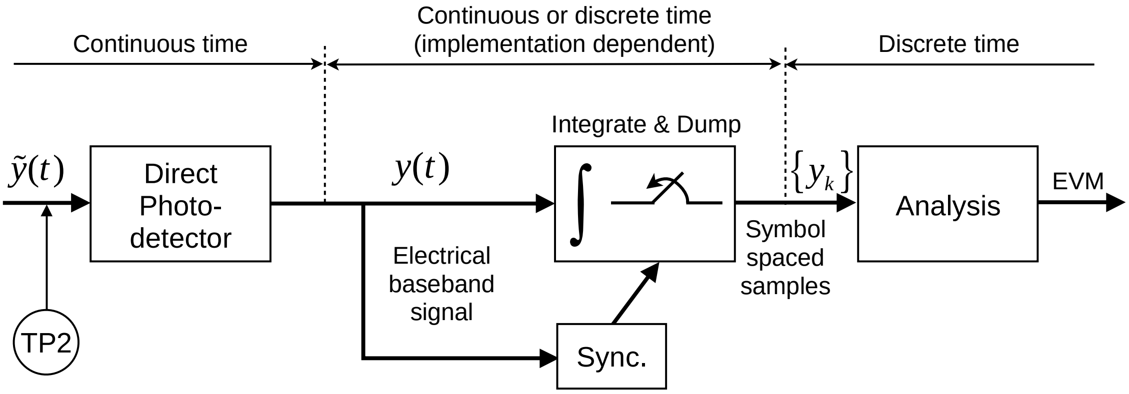

Figure 44: Reference receiver for EVM specification

The integrate & dump circuit gathers energy from whole symbol periods and, in effect, performs an average; this is equivalent to a matched filter receiver if the transmitter uses a rectangular pulse shaping filter (e.g. a zero order hold digital to analogue converter exhibits such a characteristic).

The purpose of the block labelled "Sync" is to direct the timing of the "Integrate & dump" operation so that symbol spaced samples are taken at the end of each symbol period.

7.4.6.3 Definitions

Throughout the EVM measurement description the following notation will be used:

- Define $\tilde{y}(t)$ as the continuous time domain optical signal present at TP2.
- Define $y(t)$ as the corresponding electrical signal after an ideal / reference power photo-detector.
- Define $\{y_k\}$ as the set of correctly synchronized baud-rate samples of $y(t)$.
- Define $\{x_k\}$ as the set of corresponding M-PAM levels transmitted, which are assumed known to the test environment.

7.4.6.4 Error Vector Magnitude (EVM)

The Error Vector Magnitude (EVM) is a measure of the deviation between the actual signals at TP2 compared to the ideal.

Measurement is performed assuming an ideal / reference receiver composing a direct photo-detector and a correctly synchronized baud rate sampling device.

The formal definition of EVM is:

$$EVM = 100 \times \sqrt{\frac{\frac{1}{N}\sum_{k=1}^{N}\left(y_k - x_k\right)^2}{E\left[x_k^2\right]}} \quad [\%],$$

where $E\left[x_k^2\right]$ is the expected value of x_k^2 used to normalize the EVM. Note that $E\left[x_k^2\right]$ is known (and fixed) for a particular PAM modulation format, and so it does not need to be computed at run-time.

Also note that under good signal to noise and small distortion conditions (which could be the case for transmitter measurements), it is not necessary for the test equipment to have exact knowledge of the transmit sequence $\{x_k\}$, rather it can approximate $\{x_k\}$ by $\{\hat{y}_k\}$, a collection of hard decisions based on the noisy observations $\{y_k\}$. For an accurate EVM measurement it is suggested to use exact knowledge of sequence $\{x_k\}$.

7.4.6.5 Signal pattern for EVM measurement

The CMB shall be instructed to generate the reference signal $\{x_k\}$ as pseudo-random M-PAM sequences, configuring the PHY in Test mode 2 (see clause 7.3.5.3). The number of M-PAM levels shall be configured through the Data Packet Interface, to make the EVM measurements as specified in clause 7.2.2.

7.4.7 Transmitter timing jitter measurement

The transmitter timing jitter measurement shall be done using an internal or external optical to electrical converter and a general-purpose oscilloscope or jitter meter.

The PHY shall be configured in Test mode 3 to generate the signal pattern for the transmitter timing jitter measurement.

The RMS jitter of the crossing events of the EO transmit signal with the average optical power, measured at TP2, relative to the corresponding edges of an unjittered clock reference with a frequency of FS / 2 shall be measured.

In order to guarantee null frequency deviation between the transmitter and the unjittered clock reference, the test instrument and testing device may share a low frequency clock reference if it can be proven this does not affect measurement accuracy.

7.5 Characteristics of the Plastic Optical Fibre cabling (channel)

7.5.1 Duplex cable

The EO specified in the present clause is for a plastic optical fibre cable with a multimode optical fibre IEC 60793-2-40 [1] types A4a.2. The cable may be duplex or simplex.

The construction of the duplex cable is illustrated in figure 45 and it may meet, but not limited to, the specifications given in table 11 or table 12. Jacket material specification is out of scope of the present document.

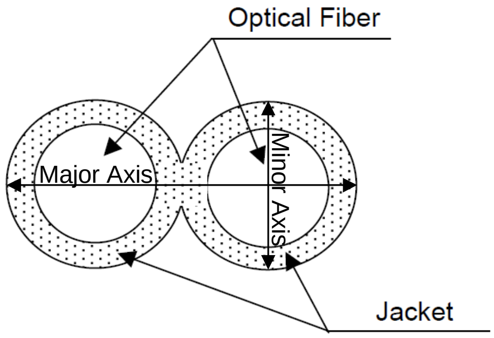

Figure 45: Plastic Optical Fibre duplex cable

Table 11: Plastic Optical Fibre duplex cable specification for 2,2 mm diameter

		Units	Min	Nominal	Max
Jacket Dimensions	Minor Axis	mm	2,13	2,20	2,27
	Major Axis	mm	4,30	4,40	4,50

Table 12: Plastic Optical Fibre duplex cable specification for 1,5 mm diameter

		Units	Min	Nominal	Max
Jacket Dimensions	Minor Axis	mm	1,43	1,49	1,55
	Major Axis	mm	2,85	3,00	3,15

8 Fibre connector specifications (Conn)

8.1 Introduction to the fibre connector

The EO is coupled to the fibre optic cabling at the fibre connector. The fibre connector is the interface between the EO interface and the fibre optical cabling as specified in clause 7.5. The fibre connector shall be either:

a) connectorized duplex receptacle of type LC, or

b) connector-less duplex receptacle that accepts a bare duplex cable termination.

8.2 Connectorized duplex fibre connector

The EO interface is coupled to the fibre optic cabling through a connector plug into the fibre connector optical receptacle. The fibre connector optical receptacle is the duplex LC, meeting the following requirements:

a) Meet the dimension and interface specifications of IEC 61754-20 [3] Ed.2.0.

b) Meet the performance specifications as specified in IEC 61754-20 [3] Ed.2.0.

c) Ensure that polarity is maintained.

d) The transmit side of the receptacle is located on the left when viewed looking into the transceiver optical ports with the keys on the bottom surface.

A sample drawing of a duplex LC connector is provided in figure 46.

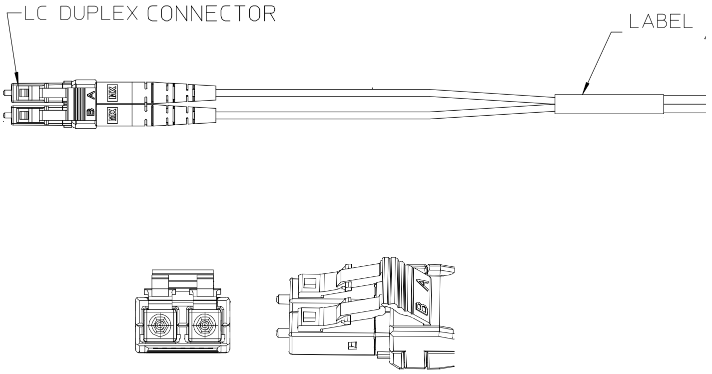

Figure 46: Duplex LC connector (informative)

8.3 Connector-less duplex fibre connector

The EO interface is coupled to the fibre optic cabling by means of connector-less duplex receptacle that accepts a bare duplex cable termination, where the receive side of the receptacle is located on the right when viewed looking into the transceiver.

The connector-less fibre connector requires no connector plug to be mounted on the plastic optical fibre cable. The terminated fibre cable (which could be cut with a simple cutting tool) is located and retained in the receptacle using a mechanism that relies on securing the cable by means of its jacket only.

An example of a connector-less fibre connector is shown for information in figure 47.

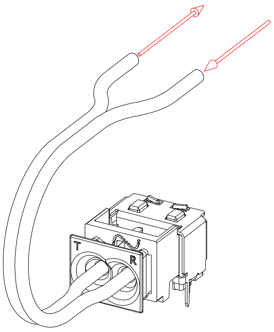

Figure 47: Connector-less duplex fibre connector (informative)

Annex A (normative): Specification for 1 000 Mbit/s over Plastic Optical Fibre

A.1 Parameters specification for CMB

1 000 Mbit/s operation defines a set of parameters and requirements for a sub-class of PHYs.

The specific parameters of the CMB that shall be met by a 1 000 Mbit/s PHY are the following:

a) The transmit symbol frequency shall be within the range 312,5 MHz ± 100 ppm.

b) The receive feature shall properly receive incoming data with a symbol rate within the range 312,5 MHz ± 100 ppm.

c) The MLCC will be configured to 3,3145 bits per symbol corresponding to: 1 bit for the first two levels and 1,5 bits for the third level as illustrated in table 5. Therefore, the modulation format outgoing the CMB transmit function during the payload sub-blocks shall be 16-PAM.

d) No ABR support shall be signalled by the PHY by means of the physical header PHD.

e) Low Power Idle mode implementation is optional, and its support shall be signalled by means of the PHD.

A.2 Delay constraints

The sum of the transmit and receive data delays for an implementation of a 1 000 Mbits/s PHY shall not exceed 25 µs, regardless of the data packet length.

A.3 EO specifications

A.3.1 Transmitter optical specifications for POF link of 25 metres

Any 1 000 Mbit/s transmitter shall meet the specifications defined in table A.1, as specified in clause 7.3.2, per measurements techniques defined in clause 7.4.

Table A.1: 1 000 Mbit/s transmit optical characteristics at TP2 for 25 m of POF

Description	Value	Units
Transmitter type	LED, Laser, VCSEL	n/a
Wavelength range (λ)	640 to 670	nm
RMS spectral width (max)	30	nm
Extinction ratio (min)	8	dB
Average Optical Power (max)	-1,5	dBm
Average Optical Power (min)	-8,0	dBm
T_{rise} / T_{fall} (max; 20 % to 80 %)	2,0	ns
EVM for 2-PAM (max)	28	%
EVM for 4-PAM (max)	29	%
EVM for 8-PAM (max)	29	%
Transmitter timing jitter (max)	8	ps RMS

A.3.2 Receiver optical specifications for POF link of 25 metres

Any 1 000 Mbit/s receiver shall meet the specifications defined in table A.2 as specified in clause 7.3.3, per measurement techniques defined in clause 7.4.

Table A.2: 1 000 Mbit/s receiver optical characteristics at TP3 for 25 m of POF

Description	Value	Units
Wavelength range (λ)	640 to 670	nm
Average Optical Power (max)	-1,5	dBm
Average Optical Power Sensitivity (min) (see note)	-19	dBm
NOTE: For minimum transmit ER.		

A.3.3 Worst-case link budget and system margin for POF of 25 metres

Table A.3 contains information about the link power budget for 1 000 Mbit/s, congruent with the transmitter and receiver optical specifications given in clause A.3.1 and clause A.3.2.

Table A.3: 1 000 Mbit/s worst-case link budget and system margin for 25 m of POF

Description	Value	Units
Fibre Insertion Loss	6,0	dBo
Worst-case System Margin	5,0	dBo
Worst-case Link Budget	11,0	dBo

A.3.4 Transmitter optical specifications for POF link of 50 metres

Any 1 000 Mbit/s transmitter shall meet the specifications defined in table A.4, as specified in clause 7.3.2, per measurements techniques defined in clause 7.4.

Table A.4: 1 000 Mbit/s transmit optical characteristics at TP2 for 50 m of POF

Description	Value	Units
Transmitter type	LED, Laser, VCSEL	n/a
Wavelength range (λ)	640 to 670	nm
RMS spectral width (max)	30	nm
Extinction ratio (min)	8	dB
Average Optical Power (max)	-1,5	dBm
Average Optical Power (min)	-7,0	dBm
T_{rise} / T_{fall} (max; 20 % to 80 %)	2,0	ns
EVM for 2-PAM (max)	28	%
EVM for 4-PAM (max)	29	%
EVM for 8-PAM (max)	29	%
Transmitter timing jitter (max)	8	ps RMS

A.3.5 Receiver optical specifications for POF link of 50 metres

Any 1 000 Mbit/s receiver shall meet the specifications defined in table A.5 as specified in clause 7.3.3, per measurement techniques defined in clause 7.4.

Table A.5: 1 000 Mbit/s receiver optical characteristics at TP3 for 50 m POF

Description	Value	Units
Wavelength range (λ)	640 to 670	nm
Average Optical Power (max)	-1,5	dBm
Average Optical Power Sensitivity (min) (see note)	-19,0	dBm
NOTE: For minimum transmit ER.		

A.3.6 Worst-case link budget and system margin for POF of 50 metres

Table A.6 contains information about the link power budget for 1 000 Mbit/s, congruent with the transmitter and receiver optical specifications given in clauses A.3.1 and A.3.4.

Table A.6: 1 000 Mbit/s worst-case link budget and system margin for 50 m POF

Description	Value	Units
Fibre Insertion Loss	10,0	dBo
Worst-case System margin	2,0	dBo
Worst-case Link Budget	12,0	dBo

Annex B (normative): Specification for 100 Mbit/s over Plastic Optical Fibre

B.1 Parameters specification for CMB

100 Mbit/s defines a set of parameters and requirements for a sub-class of PHYs.

The specific parameters of the CMB that shall be met by a 100 Mbit/s PHY are the following:

a) The transmit symbol frequency shall be within the range 62,5 MHz ± 100 ppm.

b) The receive feature shall properly receive incoming data with a symbol rate within the rage 62,5 MHz ± 100 ppm.

c) The MLCC will be configured to 1,8145 bits per symbol corresponding to: 1 bit for the first two levels and no bits for the third level as illustrated in table 5. Therefore, the modulation format outgoing the CMB transmit function during the payload sub-blocks shall be 4-PAM.

d) No ABR support shall be signalled by the PHY by means of the physical header PHD.

e) Low Power Idle mode implementation is optional, and its support shall be signalled by means of the PHD.

B.2 Delay constraints

The sum of the transmit and receive data delays for an implementation of a 100 Mbit/s PHY shall not exceed 90 µs, regardless of the data packet length.

B.3 EO interface specifications

B.3.1 Transmitter optical specifications

Any 100 Mbit/s transmitter shall meet the specifications defined in table B.1, as specified in clause 7.3.2 per measurements techniques defined in clause 7.4.

Table B.1: 100 Mbit/s transmit optical characteristics at TP2

Description	Value	Units
Transmitter type	LED, Laser, VCSEL	n/a
Wavelength range (λ)	640 to 670	nm
RMS spectral width (max)	30	nm
Extinction ratio (min)	8	dB
Average Optical Power (max)	-1,5	dBm
Average Optical Power (min)	-8,0	dBm
T_{rise} / T_{fall} (max; 20 % to 80 %)	7	ns
EVM for 2-PAM (max)	19	%
EVM for 4-PAM (max)	21	%
EVM for 8-PAM (max)	21	%
Transmitter timing jitter (max)	43	ps RMS

B.3.2 Receiver optical specifications for POF link of 100 metres

Any 100 Mbit/s receiver shall meet the specifications defined in table B.2 as specified in clause 7.3.3, per measurement techniques defined in clause 7.4.

Table B.2: 100 Mbit/s receiver optical characteristics at TP3 for 100 m POF

Description	Value	Units
Wavelength range (λ)	640 to 670	nm
Average Optical Power (max)	-1,5	dBm
Average Optical Power Sensitivity (min) (see note)	-33,0	dBm
NOTE: For minimum transmit ER.		

B.3.3 Worst-case link budget and system margin for POF of 100 metres

Table B.3 contains information about the link power budget for 100 Mbit/s, congruent with the transmitter and receiver optical specifications given in clauses B.3.1 and B.3.2.

Table B.3: 100 Mbit/s worst-case link budget and system margin for 100 m POF

Description	Value	Units
Fibre Insertion loss	18,0	dBo
Worst-case System Margin	7,0	dBo
Worst-case Link Budget	25,0	dBo

Annex C (normative): Specification for Gigabit Adaptive Bit Rate over Plastic Optical Fibre

C.1 Parameters specification for CMB

The gigabit adaptive bit rate defines a set of parameters and requirements for a sub-class of PHYs.

The specific parameters of the CMB sublayers that shall be met by a gigabit adaptive bit rate PHY are the following:

a) The transmit symbol frequency shall be within the range 312,5 MHz ± 100 ppm.

b) The receive feature shall properly receive incoming data with a symbol rate within the range 312,5 MHz ± 100 ppm.

c) The MLCC shall be configured according to the channel capacity. The receiver shall estimate the most suitable configuration and request its use to the transmitter using the relevant PHD fields. The receiver may implement the bit rate decision based on the reception quality of the pilot signals and/or the data payload sub-blocks.

d) Low Power Idle mode implementation is optional, and its support shall be signalled by means of the PHD.

The field PHD.TX.NEXT.CODING.SE specifies the MLCC configuration that shall be used by the transmitter in the next frame. The receiver shall configure the CMB to ensure that the specified MLCC configuration is used in the next frame.

The PHD.RX.REQ.CODING.SE specifies the MLCC configuration that the receiver requests the transmitter to use in the next frame. The transmitter, when possible, should use that configuration in the next frame.

A gigabit adaptive bit rate PHY shall be able to work at data-rates less than 1 000 Mbit/s. An implementation of a 1 Gbit/s data interface is recommended, to reduce both complexity and data delay. For systems integrating gigabit adaptive bit rate with no exposed data interfaces, there are no constraints on the possible MLCC configurations that can be used.

C.2 MLCC bit rate configurations

Table C.1 provides the bit-rate for the different configurations of MLCC encoding implementing adaptive bit rate. The bit-rate is provided at the input of the encapsulation procedure carried out by the CMB transmit function, taking into account the overheads produced by the transmission of the pilot signals and physical header as well as the overhead produced by the encapsulation of user data in PDB blocks.

Table C.1: MLCC bit rate configurations for gigabit adaptive bit rate

η (bits/s/ Hz/D)	M-PAM	nb(1) (bits/dim)	nb(2) (bits/dim)	nb(3) (bits/dim)	PHY bit rate (Mbit/s)
0,825 4	2	1	0	0	249
1,314 5	4	1	0,5	0	396
1,814 5	4	1	1	0	547
2,314 5	8	1	1	0,5	698
2,814 5	8	1	1	1,0	849
3,314 5	16	1	1	1,5	1 000

C.3 Delay constraints

The sum of the transmit and receive data delays for an implementation of a gigabit adaptive bit rate PHY shall not exceed the values provided in table C.2 in microseconds. These delay values are provided for data packets of 1 518 octets.

Table C.2: Delay constraints as function of MLCC configuration for a gigabit adaptive bit rate PHY Data packet of 1 518 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Delay max (µs)
0,825 4	2	249	64
1,314 5	4	396	51
1,814 5	4	547	42
2,314 5	8	698	44
2,814 5	8	849	40
3,314 5	16	1 000	25

For data delays provided in table C.2 it is assumed that a 1 Gbit/s data interface is used as data interface for PHY rates equal to or less than 1 000 Mbit/s.

For data packets with minimum length of 64 octets, the delay constraints can be reduced. The sum of the transmit and receive data delays for an implementation of an gigabit adaptive bit rate PHY shall not exceed the values provided in table C.3 in microseconds, for data packets of 64 octets.

Table C.3: Delay constraints as function of MLCC configuration for gigabit adaptive bit rate PHY Data packets of 64 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Delay max (µs)
0,825 4	2	249	13
1,314 5	4	396	19
1,814 5	4	547	18
2,314 5	8	698	25
2,814 5	8	849	25
3,314 5	16	1 000	25

As specified in clause 5.2.3.5.1, when the data packet length is known, the encapsulation procedure shall include this information in the PDB.CTRL preceding the data packet. For this kind of data packets, the delay can be reduced when PHY bit rate is less than the 1 Gbit/s data interface, since the buffering of CMB de-encapsulation does not require storing the complete data packet before starting the transfer to the reception data interface. Delays for this kind of data packets are provided only as information in table C.4 and table C.5.

Table C.4: Delay constraints as function of MLCC configuration for gigabit adaptive bit rate PHY, in case of data packets with signalled Length data packet of 1 518 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Delay max (µs)
0,825 4	2	249	51
1,314 5	4	396	38
1,814 5	4	547	29
2,314 5	8	698	30
2,814 5	8	849	27
3,314 5	16	1 000	25

Table C.5: Delay constraints as function of MLCC configuration for gigabit adaptive bit rate, in case of data packets with signalled Length data packet of 64 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Delay max (µs)
0,825 4	2	249	12
1,314 5	4	396	18
1,814 5	4	547	18
2,314 5	8	698	25
2,814 5	8	849	25
3,314 5	16	1 000	25

C.4 EO specifications

C.4.1 Transmitter optical specifications

Any gigabit adaptive bit rate transmitter shall meet the same specifications as the 1 Gbit/s bit rate transmitter. They are defined in table A.1, per measurement techniques defined in clause 7.4.

C.4.2 Receiver optical specifications

Any gigabit adaptive bit rate receiver shall meet the specifications defined in table A.2 for a POF link of 25 metres length when the provided PHY rate is 1 000 Mbit/s, per measurement techniques defined in clause 7.3.

C.4.3 Adaptive Bit Rate performance

Table C.6 provides, only for information, the performance that may be provided by a gigabit adaptive bit rate PHY that fits with the optical specifications defined in clause C.4.1 and clause C.4.2, as a function of the POF link length as well as the transmit average optical power. For the data reported in table C.6, the transmit AOP variation can be considered either produced by temperature dependency of the light emitter or produced by coupling, bending, or connectors losses in the fibre and/or the receiver.

Table C.6: Gigabit Adaptive Bit Rate performance

Transmit AOP (dBm)	PHY rate (Mbit/s) 10 m POF IL = 3 dBo	PHY rate (Mbit/s) 25 m POF IL = 6 dBo	PHY rate (Mbit/s) 50 m POF IL = 10 dBo	PHY rate (Mbit/s) 80 m POF IL = 14,7 dBo	PHY rate (Mbit/s) 100 m POF IL = 18 dBo
-1,5	1 754	1 754	1 452	1 000	547
-3,0	1 754	1 603	1 301	849	396
-6,0	1 603	1 452	1 150	698	249
-8,0	1 603	1 301	1 000	547	NO LINK

Annex D (normative): Specification for hundred adaptive bit rate over Plastic Optical Fibre

D.1 Parameters specification for CMB

The hundred adaptive bit rate defines a set of parameters and requirements for a sub-class of PHYs.

The specific parameters of the CMB sublayers that shall be met by a hundred adaptive bit rate PHY are the following:

a) The transmit symbol frequency shall be within the range 62,5 MHz ± 100 ppm.

b) The receive feature shall properly receive incoming data with a symbol rate within the range 62,5 MHz ± 100 ppm.

c) The MLCC shall be configured according to the channel capacity. The receiver shall estimate the most suitable configuration and request its use to the transmitter using the relevant PHD fields. The receiver may implement the bit rate decision based on the reception quality of the pilot signals and/or the data payload sub-blocks.

d) Low Power Idle mode implementation is optional, and its support shall be signalled by means of the PHD.

The field PHD.TX.NEXT.CODING.SE specifies the MLCC configuration that is used by the transmitter in the next frame. The receiver shall configure the CMB to ensure that the specified MLCC configuration is used in the next frame. The PHD.RX.REQ.CODING.SE specifies the MLCC configuration that the receiver requests the transmitter to use in the next frame. The transmitter when possible should use that configuration in the next frame.

A hundred adaptive bit rate PHY shall be able to work at data-rates greater than and less than 100 Mbit/s. If the data interface services interface is exposed in form of 100 Mbit/s or 1 000 Gbit/s interface, the PHY shall implement 1 000 Mbit/s data interface to be able to carry information at bit-rates greater than 100 Mbit/s. In case only MLCC rates of approximately 100 Mbit/s or less are supported, implementation of a 100 Mbit/s data interface is recommended to reduce the total delay (transmit plus receive), see table D.1.

For systems integrating hundred adaptive bit rate with no exposed data interfaces, there are no constraints on the possible MLCC configurations that can be used.

D.2 MLCC bit rate configurations

Table D.1 provides the bit-rate for the different configurations of MLCC encoding implementing adaptive bit rate. The bit-rate is provided at the input of the encapsulation carried out by the CMB transmit function, taking into account the overheads produced by the transmission of the pilot signals and physical header as well as the overhead produced by the encapsulation of user data in PDB blocks.

Table D.1: MLCC bit rate configurations for hundred adaptive bit rate PHY

η (bits/s/Hz/D)	M-PAM	nb(1) (bits/dim)	nb(2) (bits/dim)	nb(3) (bits/dim)	PHY bit rate (Mb/s)	Data interface
0,825 4	2	1	0	0	49	100 Mbit/s
1,314 5	4	1	0,5	0	79	100 Mbit/s
1,814 5	4	1	1	0	109	100 Mbit/s

D.3 Delay constraints

The sum of the transmit and receive data delays for an implementation of an hundred adaptive bit rate PHY shall not exceed the values provided in table D.2 in microseconds. These delay values are provided for data packets of 1 518 octets.

Table D.2: Delay constraints as function of MLCC configuration for hundred adaptive bit rate PHY, data packets of 1 518 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Data interface	Delay max (μs)
0,825 4	2	49	100 Mbit/s	324
1,314 5	4	79	100 Mbit/s	258
1,814 5	4	109	100 Mbit/s	90

For data delays provided in table D.2 it is assumed that 100 Mbit/s data interface is used for PHY rates equal to or less than 109 Mbit/s, and 1 000 Mbit/s is used for greater PHY rates. The delay constraints are valid for any data packet transmitted from 100 Mbit/s and 1 000 Mbit/s, independently of whether the length information is provided.

For data packets with minimum length of 64 octets, the delay constraints can be reduced. The sum of the transmit and receive data delays for an implementation of a hundred adaptive bit rate PHY shall not exceed the values provided in table D.3 in microseconds, for data packets of 64 octets.

Table D.3: Delay constraints as function of MLCC configuration for hundred adaptive bit rate PHY, data packet of 64 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Data interface	Delay max (μs)
0,825 4	2	49	100 Mbit/s	64
1,314 5	4	79	100 Mbit/s	95
1,814 5	4	109	100 Mbit/s	90

As specified in clause 5.2.3.5.1, when the data packet length information is provided, the encapsulation procedure shall include this information in the PDB.CTRL preceding the data frame. For this kind of data packets, the delay can be reduced when PHY bit rate is less than the 1 000 Mbit/s and 100 Mbit/s rate, since the buffering of CMB de-encapsulation does not require storing the complete data packet before starting the data interface transfer. Delays for this kind of data packets are provided only as information in table D.4 and table D.5.

Table D.4: Delay constraints as function of MLCC configuration for hundred adaptive bit rate PHY, in case of data packets with provided length information, data packet of 1 518 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Data interface	Delay max (μs)
0,825 4	2	49	100 Mbit/s	189
1,314 5	4	79	100 Mbit/s	123
1,814 5	4	109	100 Mbit/s	90

Table D.5: Delay constraints as function of MLCC configuration for hundred adaptive bit rate PHY, in case of data packets with signalled length data packet of 64 octets

η (bits/s/ Hz/D)	M-PAM	PHY bit rate (Mbit/s)	Data interface	Delay max (μs)
0,825 4	2	49	100 Mbit/s	59
1,314 5	4	79	100 Mbit/s	89
1,814 5	4	109	100 Mbit/s	90

D.4 EO specifications

D.4.1 Transmitter optical specifications

Any hundred adaptive bit rate PHY transmitter shall meet the same specifications that hundred adaptive bit rate PHY. They are defined in table B.1, per measurements techniques defined in clause 7.4.

D.4.2 Receiver optical specifications

Any hundred adaptive bit rate PHY receiver shall meet the specifications defined in table B.2 for a POF link of 100 metres length when the provided PHY rate is 100 Mbit/s, per measurement techniques defined in clause 7.3.

D.4.3 Adaptive Bit Rate performance

Table D.6 provides, only for information, the performance that may be provided by a hundred adaptive bit rate PHY that fits with the optical specifications defined in clause D.4.1 and clause D.4.2, as a function of the POF link length as well as the transmit average optical power. For the data reported in table D.6, the transmit AOP variation can be considered either produced by temperature dependency of the light emitter or produced by coupling, bending, or connectors losses in the fibre and/or the receiver.

Table D.6: Adaptive Bit Rate performance

Transmit AOP (dBm)	PHY rate (Mbit/s) 25 m POF IL = 6 dBo	PHY rate (Mbit/s) 50 m POF IL = 10 dBo	PHY rate (Mbit/s) 100 m POF IL = 18 dBo	PHY rate (Mbit/s) 150 m POF IL = 25 dBo	PHY rate (Mbit/s) 200 m POF IL = 32 dBo
-1,5	109	109	109	109	79
-3,0	109	109	109	109	49
-6,0	109	109	109	109	NO LINK
-8,0	109	109	109	109	NO LINK

History

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