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Digital sections and digital line system – Access networks

Ethernet-based Multi-Pair Bonding

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ITU-T Recommendation G.998.2

ETHERNET-BASED MULTI-PAIR BONDING

Summary

This Recommendation describes a method for bonding of multiple digital subscriber lines (DSL) for Ethernet transport. This Recommendation can support SHDSL, VDSL and ADSL transport as well as future xDSL technologies as they emerge.

This Recommendation builds on the IEEE 802.3ah-2004 methods and extends Ethernet transport over other xDSL technologies, including ADSL. The Recommendation does not describe the details of the specific xDSL transport technology. Rather, it focuses on the aspects of the PCS layer modifications required for bonding.

1 Scope

This Recommendation specifies portions of Clause 61 of IEEE Standard 802.3ah-2004 Amendment to Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specification as a normative reference and identifies the requirements for multi-pair bonding in IEEE 802.3ah-2004 that are different in the United States. Further, this Recommendation specifies the requirements for extending the bonding methods in IEEE 802.3ah-2004 to xDSL technologies other than VDSL and SHDSL.

The following are the objectives this Recommendation:

a. To provide support for operation of xDSL technologies on multiple pairs of voice grade twisted pair cable.

b. To provide 100 Mb/s burst data rate at the Ethernet media independent interface using Rate Matching.

c. To provide full duplex operation.

d. To provide a communication channel with a mean BER at the α/β service interface of less than 10^{-7}.

2 References

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

[1] ITU-T Recommendation G.991.2 (2001), *Single-pair high-speed digital subscriber line (SHDSL) transceivers.*

[2] ITU-T Recommendation G.991.2 (2003), *Single-pair high-speed digital subscriber line (SHDSL) transceivers.*

[3] ITU-T Recommendation G.992.1 (1999), *Asymmetric Digital Subscriber Line (ADSL) Transceivers.*

[4] ITU-T Recommendation G.992.3 (2002), *Asymmetric Digital Subscriber Line (ADSL) Transceivers – 2 (ADSL2)*

[5] ITU-T Recommendation G.992.5 (2003), *Asymmetric Digital Subscriber Line (ADSL) Transceivers – Extended Bandwidth ADSL2 (ADSL2plus)*

[6] ITU-T Recommendation G.993.1 (2004), *Very-high-speed Digital Subscriber Line Transceivers*

[7] ITU-T Recommendation G.994.1 (2003), *Handshake procedures for Digital Subscriber Line (DSL) Transceivers.*

[8] IEEE 802.3 (2002), *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specification*

[9] IEEE 802.3ah (2004), *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specification -Amendment: Media Access Control Parameters, Physical Layers, and Management Parameters for Subscriber Access Networks*

[10] T1.424 (2004) - *Interface between Networks and Customer Installations - Very-high-bit-rate Digital Subscriber Lines (VDSL) Metallic Interface (DMT Based).*

3 Definitions

This Recommendation defines the following terms:

3.1 **10PASS-TS**:The IEEE 802.3 standard for delivering single and multi-pair Ethernet transport over G.993.1 (MCM) transceivers.

3.2 **2BASE-TL**:The IEEE 802.3 standard for delivering single and multi-pair Ethernet transport over G.991.2 transceivers.

3.3 **aggregation group:** A collection of lines that may be aggregated into a single Ethernet interface.

3.4 **carrier sense**: In a local area network, an ongoing activity of a data station to detect whether another station is transmitting. Note—The carrier sense signal indicates that one or more DTEs are currently transmitting.

3.5 **collision:** A condition that results from concurrent transmissions from multiple data terminal equipment (DTE) sources within a single collision domain.

3.6 **downstream**: Direction from central office to remote terminal.

3.7 **Media Independent Interface**: In IEEE 802.3, a transparent signal interface at the bottom of the Reconciliation sublayer.

3.8 **Physical Medium Attachment**: That portion of the Physical Layer that contains the functions for transmission, reception collision detection, clock recovery and skew alignment.

3.9 **Physical Medium Dependent**: That portion of the Physical Layer responsible for interfacing to the transmission medium. The PMD is located just above the Medium Dependent Interface (MDI).

3.10 **Physical Media Entity**: In IEEE 802.3ah-2004, a reference to an individual loop contained with an aggregate group.

3.11 **remote terminal**: A terminal located downstream from a central office switching system.

3.12 **upstream**: Direction from remote terminal to central office.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

α	the interface between the PMS-TC and TPS-TC layers at a CO
β	the interface between the PMS-TC and TPS-TC layers in CPE
γ	the interface between the TPS-TC layer and the PCS layer
ADSL	Asymmetric Digital Subscriber Line
ANSI	American National Standards Institute
ATIS	Alliance for Telecommunications Industry Solutions
BER	Bit Error Ratio
CL	Capabilities List
CLR	Capabilities List Request
CO	Central Office
CPE	Customer Premise Equipment
CRC	Cyclic Redundancy Check
CS	Carrier Sense
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DSL	Digital Subscriber Line
DTE	Data Terminal Equipment
EFM	Ethernet in the First Mile
FEC	Forward Error Correction
FIFO	First In, First Out
HDLC	High-level Data Link Control
IEEE	Institute of Electrical and Electronic Engineers
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
MAC	Media Access Control
MCM	Multi-Carrier Modulation

MII	Medium Independent Interface
MP	Mode Proposal Message
MSB	Most Significant Bit
MS	Mode Select Message
PAF	PMA Aggregation Function
PCS	Physical Coding Sublayer
PHY	Physical Layer Entity Sublayer
PMA	Physical Media Attachment
PMD	Physical Media Dependent
PME	Physical Media Entity
PMS-TC	Physical Media-Specific TC Layer
PTM	Packet Transfer Mode
SFD	Start Frame Delimiter
SHDSL	Single-Pair High-bit-rate DSL
TC	Transmission Convergence layer
TC-CRC	Transmission Convergence – Cyclic Redundancy Check
TPS-TC	Transmission Protocol-Specific TC Layer
VDSL	Very High-speed Digital Subscriber Line
xDSL	a collective term referring to any of the various types of DSL technologies

5 Technologies Addressed and Architecture

This clause addresses technology specific parameters for some bonded PHYs. The values presented here were derived from the rules set forth in Clause 61 of IEEE 802.3ah-2004. Other PHYs may be addressed by following these rules.

5.1 Technologies Nomenclature

Large portions of this Recommendation reference the IEEE 802.3ah-2004 specification. A cross-reference to the technology nomenclature, and a reference to the relevant Recommendations, are given in Table 1.

Table 1/G.bond – Technology Nomenclature

Reference in this Recommendation	IEEE 802.3ah-2004 Reference	Relevant Recommendation
VDSL	10PASS-TS	T1.424 [12]
SHDSL	2BASE-TL	G.991.2 [1]
ADSL	N/A	G.992.1 [2]

As shown in the table, the IEEE reference to 10PASS-TS is the IEEE 802.3 standard for transporting Ethernet using a MCM-VDSL-based PHY. Likewise, 2BASE-TL is the IEEE 802.3 standard for transporting Ethernet using a SHDSL-based PHY. There is no IEEE standard for transporting Ethernet over ADSL, though that operation is clarified in this Recommendation.

5.2 System Considerations

The Copper PHYs addressed by this Recommendation are only defined for full duplex operation as defined in the IEEE 802.3 specification.

5.3 Relationship between IEEE 802.3ah-2004 Terminology and Layering (informative)

The Physical Coding Sublayer (PCS) contains two functions: MAC-PHY rate matching and PME aggregation. The functional position of the PCS is shown in Figure 1.

The γ-interface and the α(β)-interface are generic interfaces used in various xDSL specifications such as the ones referenced in Clause 2. The α(β)-interface is a simple octet-synchronous date interface; the γ-interface add protocol-awareness.

Note that the bit rates in the shaded area labeled "PMD rate domain" are derived from the DSL bit rates. Data is transferred across the γ-interface at the rate imposed by the lower layers. The bit rates in the shaded area labeled "100 Mb/s rate domain" are synchronous to the MII rate. Data is transferred across the MII at the rate of one nibble per MII clock cycle. The MAC-PHY rate matching function adjusts the inter packet gap so that the net data rate across this interface matches the sum of rates across the γ-interface.[1]

In the transmit direction, frames are transferred from the MAC to the PCS across the MII when the MAC-PHY rate matching function allows this. In the PCS, preamble and SFD octets are removed. The data frame is fragmented by the PAF, and fragments are forwarded, optionally through a flexible cross-connect, towards each of the aggregated PME instances via the γ-interface. . The TC sublayer accepts data from the MAC-PHY rate matching function or the PAF, at the rate at which it can be processed by the TC sublayer, by asserting Tx-Enbl on the γ-interface.

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[1] Bit domains and physical clock domains don't necessarily coincide. The TC sublayer receives as clock signal from the PMA via the α(β)-interface, and a clock signal from the optional PAF or the MAC-PHY Rate Matching function via the γ-interface. The TC provides matching between the two clock domains.

The optional flexible cross-connect function may be present to provide access from a centralized bonding function (PAF) to TCs on lines distributed throughout a system. The method by which frames are transferred between the bonding function and the various TCs in the bonded group is outside the scope of this Recommendation.

In the receiver direction the TC sublayer pushed data to the PAF (if present) or the MAC-PHY rate matching function by asserting Rx_Enbl on the γ-interface. The PAF reassembles the received fragments into data frames. Preamble and SFD octets are generated and prepended to the data frame prior to passing it up to the MAC across the MII. The MAC-PHY Rate Matching function may delay the transfer of the frame to avoid simultaneous transfer of Transmit and Receive frames if required.

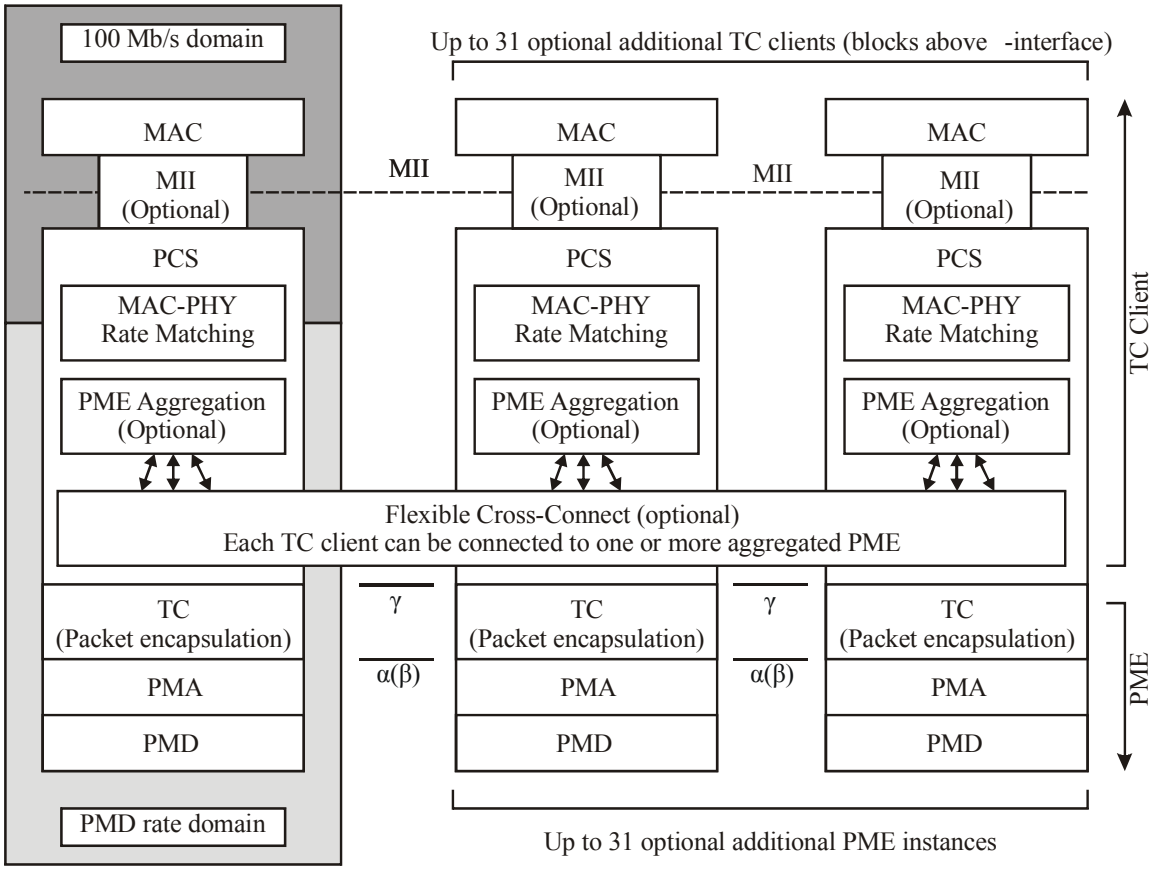

Figure 1/G.bond – Overview of PCS functions

Figure 2 compares the ITU layering with the IEEE layering by showing the relative positions of the γ and α(β) interfaces and the relevant architectural blocks. Some things to note include

1) In IEEE 802.3ah-2004, the entire function of a bonded group (taking in/out frames, fragmenting/reassembly across multiple lines, encapsulating fragments on a line, etc.) is referred to as the PCS function. In Figure 2, shows two lines being aggregated intothe leftmost PAF function in both protocol stacks.

2) Since IEEE 802.3ah-2004 has only a single TPS-TC (it defines only 64/65-octet encapsulation as the TPS-TC), the TPS-TC function is abbreviated TC.

3) IEEE 802.3ah-2004 requires a rate matching function to provide an interface between the well-defined 100 Mbps Ethernet MAC and the variable rate aggregation function. The ITU protocol stack does not require the use of the standard Ethernet MAC, and thus no rate matching function is required.

As can be seen from the diagram, the protocol stacks are very similar, but have terminology and architectural differences related to the historical terminology and architecture of the individual standards organization.

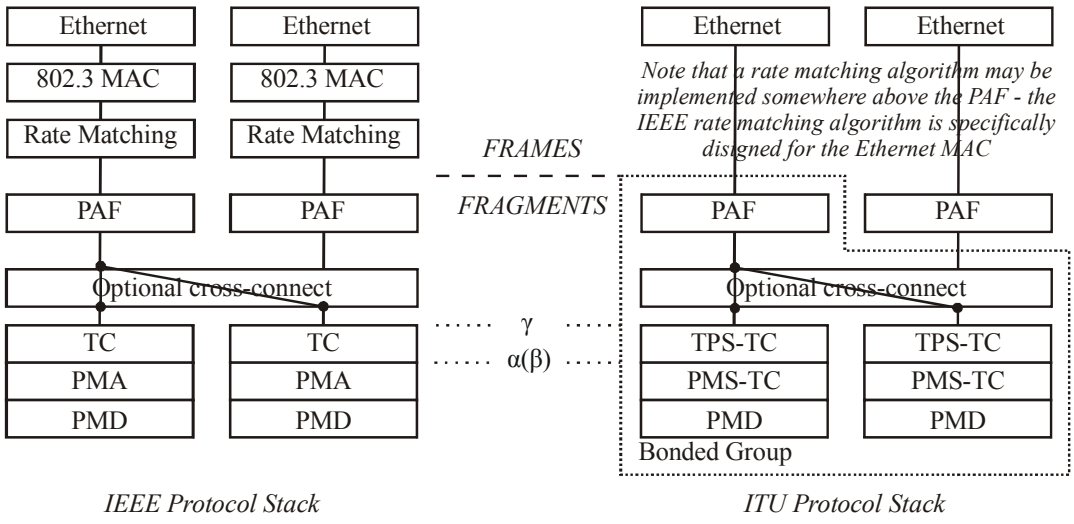

Figure 2/G.bond – Comparison of IEEE and ITU protocol stacks

5.4 Multiple Bearers

For physical layers that support multiple bearers, the methods of this Recommendation can be applied on one or multiple of those bearers independently. As each bearer can independently carry individual fragments, multiple bearers can be aggregated across multiple lines. Multiple bearers on the same line should not be aggregated.

6 Exceptions to IEEE 802.3ah-2004, Clause 61

xDSL systems bonding Ethernet TPS-TCs in accordance with this Recommendation shall comply with Clause 61 of IEEE 802.3ah-2004, except as specifically detailed in the remainder of the Clause.

This clause details the exceptions to IEEE 802.3ah-2004, Clause 61.1 and 61.2, for generalizing the Ethernet bonding function, known as the PMA aggregation function (PAF) in IEEE 802.3ah-2004 [9], to xDSL technologies beyond SHDSL (G.991.2, 2BASE-TL) and VDSL (G.993.1, 10PASS-TS).

This Recommendation does not specify the TC used for bonding. Clause 61.2 of IEEE 802.3ah-2004 [9] defines a TC based on 64/65-octet encapsulation. However, other packet transfer mode TCs are also supported by this Recommendation.

Clauses 61.5 thru 61.10 are not applicable to this Recommendation.

6.1 Exceptions to 802.3ah-2004, Clause 61.1

Clause 61.1 provides an introduction and overview of the rest of Clause 61. There is a general exception throughout Clause 61.1 in that this Recommendation expands the scope of Clause 61 beyond 10PASS-TS (VDSL) and 2BASE-TL (SHDSL). Throughout the descriptive text in Clause 61.1, it should be noted that the specific references to 10PASS-TS and 2BASE-TL can be replaced with more generic references to multi-pair and physical layer systems as defined in this Recommendation.

6.1.1 Exceptions to Clause 61.1.1

Clause 61.1 applies with the previously noted generalization.

6.1.2 Exceptions to Clause 61.1.2

Clause 61.1.2 lists the objectives of Ethernet bonding as defined by IEEE 802.3ah-2004. This Recommendation includes the following added objective.

g) Operation of Ethernet multi-pair aggregation over xDSL technologies including ADSL, and future xDSL technologies.

6.1.3 Exceptions to Clause 61.1.3

Clause 61.1.3 compares the IEEE 802.3 architecture to the traditional xDSL architecture and applies as is.

6.1.4 Exceptions to Clause 61.1.4

Clause 61.1.4 overviews the entirety of Clause 61. Only those clauses relevant to multi-pair operation are relevant to this Recommendation. The relevant clauses are 61.1.4.1.1 and 61.1.4.1.3. The other clauses of 61.1.4 are not relevant to this Recommendation.

6.1.5 Exceptions to Clause 61.1.5

Clause 61.1.5 provides examples of multi-pair Ethernet configurations. Although the examples use hardware registers specific to IEEE 802.3ah-2004, the multi-pair bonding examples and possibilities are general to this Recommendation as well.

6.2 Exceptions to 802.3ah-2004, Clause 61.2

This clause details the exceptions to IEEE 802.3ah-2004, Clause 61.2.

6.2.1 Exceptions to Clause 61.2.1

Clause 61.2.1 defines rate-matching procedures Ethernet-over-xDSL technologies when utilizing an existing Ethernet MAC (media access control). This clause is unchanged and is applicable whenever the system is using an IEEE 802.3-compliant MAC over an Ethernet bonding and/or TPS-TC technology as defined in this Recommendation.

6.2.2 Exceptions to Clause 61.2.2

Clause 61.2.2 describes the PME aggregation function (PAF) which performs the multi-pair aggregation function for Ethernet-over-xDSL technologies. The PAF is responsible for segmenting a frame as received from the higher layer into multiple fragments, and transmitting them to the TPS-TCs on the individual loops. It is likewise responsible for reassembling fragments, as received from the TPS-TCs on the individual loops, into frames and handing them to the higher layer.

The PAF is an optional layer in IEEE 802.3. When not implemented, or when the PAF function is disabled, there can be at most one pair in an aggregate, and the frames pass between the higher layer and the TPS-TC pass directly.

The primary exceptions to Clause 61.2.2 when generalizing the Ethernet transport methods of IEEE 802.3ah-2004 are in the control mechanisms for provisioning and discovering which pairs are in the same aggregate group.

Clause 61.2.2.8.3 describes a set of registers for controlling the pairs in an aggregate group. These registers are

1) Capability register. Used so that a management or control entity may read from the physical layer whether multi-pair operation is supported, and if it is, whether it is enabled.
2) PMI_Available_register. Used to indicate what loops could be placed in an aggregate group.
3) PMI_Aggregate_register. Used to indicate what loops are in what aggregate groups.
4) Remote_discovery_register. Used to automatically discovery what loops are connected to the same remote device.
5) Aggregation_link_state_register. Used to indicate link state to the aggregation and management layer.

Note that the underlying support for these registers is provided by G.994.1 handshaking messages. The mapping of these register settings to G.994.1 handshaking mechanisms is explained within IEEE 802.3ah-2004 in Clause 61.4, specifically for VDSL-based and SHDSL-based PHYs. Both this Recommendation and the IEEE 802.3ah-2004 standard utilize handshake codepoints defined in G.994.1. Clause 8 of this Recommendation supplies more information on using handshake to determine aggregation groups.

6.3 Exceptions to Clause 61. 3

IEEE 802.3ah-2004 defines 64/65-octet encapsulation in Clause 61.3, which is the required TPS-TC for Ethernet bonding as defined in 802.3ah-2004. However, this Recommendation does not define a specific TPS-TC required for the Ethernet bonding function. Therefore, Clause 61.3 is not required for this Recommendation.

The operation of Ethernet bonding over two possible packet TPS-TCs is given in separate annexes - Annex A for 64/65-octet encapsulation, and Annex B for HDLC encapsulation. 64/65-octet encapsulation is the preferred packet TPS-TC for Ethernet bonding.

Although the TPS-TC for Ethernet bonding is not specified in this Recommendation, there are requirements on whatever packet TPS-TC is used for this bonding Recommendation. Multi-pair operation requires a bound on the differential latency experienced between pairs in an aggregated

group. The encapsulation method chosen for a specific implementation shall result in traffic over the γ-interface meeting the restrictions of clauses 61.2.2.5 and 61.2.2.6.

The functional model of packet data transport is presented in Figure 3. In the transmit direction, the PTM entity obtains data packets to be transported from the application interface. The PTM entity processes each packet and applies it in a byte format to the γ-interface. The TPS-TC (PTM-TC) receives the packet from the γ-interface, encapsulates it into a special frame (PTM-TC frame) and maps into the PMS-TC frame (transmission frame) for transmission over the physical connection.

In the receive direction, the PTM-TC frame extracted from the received PMS-TC frame is directed into the PTM-TC. The PTM-TC recovers the transported packet and delivers it to the PTM entity via the γ - interface.

The PTM path-related OAM data, including information on errored packets, shall be presented to the TPS-TC management entity providing all necessary OAM functions to support the PTM-TC.

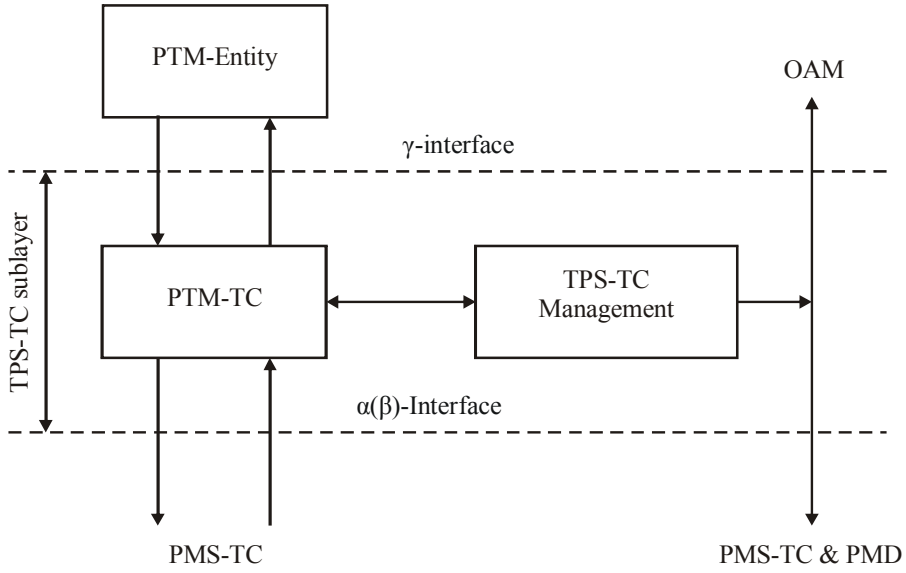

Figure 3/G.bond – Functional model of PTM transport

In the Transmit direction the TPS-TC sublayer accepts data from the PTM Entity at the rate at which it can be processed by the TPS-TC sublayer, by asserting Tx-Enbl on the γ-interface. In the receiver direction the TC sublayer pushes data to the PTM Entity by asserting Rx_Enbl on the γ-interface.

For Ethernet bonding, the PTM entity is the PAF (PME aggregation function).

7 Management

Management is an optional layer in IEEE 802.3 Ethernet, and is therefore an optional layer in Ethernet bonding. However, when a management layer is present, the following attributes are recommended for each bonded Ethernet port.

- Local Aggregation Capacity. The number of lines that may be aggregated by the bonding layer.
- Local Lines Available. The set of lines that may be put into this aggregate. Note that a line may appear be potentially available to more than one aggregate port.

- Local Lines Aggregated. The set of lines that are currently in this aggregate. A line may be in at most one aggregate at a time.
- Local Aggregate Bandwidth. The current bandwidth of the aggregate Ethernet port (sum of the transmit data rates of the individual lines in the aggregate).

The following attributes are additionally recommended for the STU-C, and reflect (at the STU-C) the above attributes of the STU-R.

- Remote Aggregation Capacity. The number of lines that may be aggregated by the bonding layer at peer port the STU-R.
- Remote Lines Available. The set of lines that may be put into this aggregate at the peer port of the STU-R. Note that a line may appear be potentially available to more than one aggregate port.
- Remote Lines Aggregated. The set of lines that are currently in this aggregate at the peer port of the STU-R. A line may be in at most one aggregate at a time.
- Remote Aggregate Bandwidth. The current bandwidth of the aggregate Ethernet port (sum of the transmit data rates of the individual lines in the aggregate) at the peer port of the STU-R. This is equivalent to the sum of the receive data rates at the STU-C.

These management parameters echo those defined for the aggregation entity of IEEE 802.3ah-2004 (See Clause 30.11 of [9]).

8 Handshake

Clause 61.4 of IEEE 802.3ah-2004 defines the handshake operation for the IEEE standards 2BASE-TL and 10PASS-TS. That section defines handshake procedures for discovering which pairs are provisioned in which aggregate groups using the PME Aggregation and PME Aggregation Discovery codepoints of the IEEE handshake tree.

The procedures of that section are followed in this Ethernet bonding Recommendation with the following exceptions.

- There is no "PAF Enable" parameter as described in 61.4 of IEEE 802.3ah-2004 [9]. That parameter is used to define whether bonding is performed. As this Recommendation references bonded operation only, that parameter is not required.

Unlike the handshake operations of IEEE 802.3ah-2004 [9], this Recommendation defines the bonding layer to operate independently of the TPS-TC. Each line may select its TPS-TC independently of the others, as long as the maximum differential latency of the pairs is maintained as specified in this Recommendation.

NOTE: This Ethernet bonding Recommendation uses the PME Aggregation and PME Aggregation Discovery codepoints in G.994.1. The definition of these of these variables is in Clause 45.2.3.20 (PME aggregation) and 45.2.6.8 (PME aggregation discovery) of IEEE 802.3ah-2004. The transactions used to exchange these codepoints (e.g. "Get," "Set if Clear," "Clear if Same") are defined in Clause 61.4 of IEEE 802.3ah-2004. Note that an example of the aggregation discovery procedure is contained in Annex 61A of IEEE 802.3ah-2004.

Annex A

Ethernet Bonding with 64/65-octet Encapsulation

Clause 61.3.3 of 802.3ah-2004 specifies 64/65-octet encapsulation. The G.bond Recommendation shall be used in combination with the 64/65-octet encapsulation PTM-TC as defined in the individual ITU-T DSL transceiver Recommendations Series G.99x. The normative references to IEEE 802.3ah-2004 Clause 61.3.3 are made in the applicable ITU-T Recommendation.

NOTE - Clause 61.3.3.3 defines the 64/65-octet TC CRC size. This may be either 16-bit or 32-bit depending on the error correcting capabilities of the underlying technology. The CRC requirements are defined in the PTM-TC section of the applicable ITU-T Recommendation.

Annex B

Ethernet Bonding with HDLC Encapsulation

The specific normative requirements for HDLC encapsulation are contained in the applicable ITU Recommendation for the underlying transport technology.