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DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

Multi-pair bonding using time-division inverse multiplexing

ITU-T Recommendation G.998.3



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ITU-T Recommendation G.998.3

Multi-pair bonding using time-division inverse multiplexing

Summary

This Recommendation describes a method for bonding of multiple digital subscriber lines (DSL) using Time-Division Inverse Multiplexing (TDIM). This Recommendation provides a specification of the TDIM protocol in sufficient detail, to allow development and testing of interoperable implementations for both transmitter and receiver. It includes a multi-pair synchronization frame format, Bonding Communication Channel (BCC), byte-oriented dispatching, hitless addition and removal of pairs, fast removal of pair upon pair failure, using IEEE 802.3ah handshake for pair discovery, parameter negotiation and setup, and an optional FEC and interleaver.

Source

ITU-T Recommendation G.998.3 was approved on 13 January 2005 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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ITU-T Recommendation G.998.3

Multi-pair bonding using time-division inverse multiplexing

1 Scope

This Recommendation defines the bonding function for the TDIM-based bonding method, the purpose of which is to provide inverse multiplexing of various service data streams (Ethernet, ATM, TDM) over multiple DSL physical links and to retrieve the original stream at the far-end from these physical links.

This Recommendation is a detailed specification of the TDIM protocol in sufficient detail to allow development and testing of interoperable implementations for both transmitter and receivers. It includes:

- 1) Multi-pair synchronization frame format.
- 2) Bonding Communication Channel (BCC).
- 3) Dispatching algorithm
- 4) Hitless addition and removal of pairs.
- 5) Fast removal of pair upon pair failure.
- 6) Using IEEE 802.3ah handshake for pair discovery, parameter negotiation and setup.

This Recommendation defines a new TPS-TC for DSL transceivers. Architecturally, this TPS-TC should be placed above the PMS-TC (at the alpha/beta-interface) of existing or future DSL transceivers. Practically, the exact same result can be obtained by stacking the new TPS-TC defined in this Recommendation on top of the Clear Channel or STM TPS-TC as defined in existing DSL Recommendations.

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 Recommendation G.704 (1998), *Synchronous frame structures used at 1544, 6312, 2048, 8488 and 44 736 kbit/s hierarchical levels*.
- [2] ITU-T Recommendation G.7041/Y.1303 (2003), *Generic framing procedure (GFP)*.
- [3] ITU-T Recommendation G.991.2 (2003), *Single-pair high-speed digital subscriber line (SHDSL) transceivers*.
- [4] ITU-T Recommendation G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers*.
- [5] ITU-T Recommendation G.992.3 (2005), *Asymmetric digital subscriber line (ADSL) transceivers 2 (ADSL2)*.
- [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] ITU-T Recommendation I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification: General characteristics*.
- [9] IEEE 802.3ah (2004), *Telecommunications and Information Exchange Between Systems – LAN/MAN – Specific Requirements – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specifications*, Amendment: *Media Access Control Parameters, Physical Layers, and Product Type*.

3 Definitions

There are no additional definitions required in this Recommendation.

4 Abbreviations, Acronyms, and Symbols

This Recommendation uses the following abbreviations:

ADSL	Asymmetric Digital Subscriber Line
ANSI	American National Standards Institute
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode
BCC	Bonding Communication Channel
bps	bits per second
BTU-C	Bonding Terminating Unit, CO side
BTU-R	Bonding Terminating Unit, RT (or CPE) side
BW	Bandwidth
Clk	Clock
CPE	Customer Premises Equipment
CO	Central Office
CRC	Cyclic Redundancy Check
DS1	Digital Signal 1, (1.544 Mbit/s)
DS3	Digital Signal 3, (44.736 Mbit/s)
DSL	Digital Subscriber Line
E1	Electrical interface signal, Level 1, (2.048 Mbit/s)
E3	Electrical interface signal, Level 3, (34.368 Mbit/s)
EFM	Ethernet in the First Mile
enum	Enumerated
EOC	Embedded Operations Channel
FCS	Frame Check Sequence
FE	Far End
FEC	Forward Error Correction
GF	Galois Field
GFP	Generic Framing Procedure
HEC	Header Error Check

HS	Handshake
IEEE	Institute of Electrical and Electronics Engineers
IL	Interleaver
IMA	Inverse Multiplexing for ATM
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
kbit/s	kilobits per second
LSB	Least Significant Bit/Byte
Mbit/s	megabits per second
MSB	Most Significant Bit/Byte
MUX	Multiplexer
NE	Near End
NS	Number of Services
PLI	Packet Length Identifier
PM	Performance Monitor
PMI	Physical Medium Independent
PSD	Power Spectral Density
RS	Reed Solomon
RT	Remote Terminal
rx	Receive/receiver
SDH	Synchronous Digital Hierarchy
SF	Super-Frame
SHDSL	Single-Pair High-Speed Digital Subscriber Line
STM	Synchronous Transfer Mode
TC	Transmission Convergence
TDIM	Time-Division Inverse Multiplexing
TDM	Time Division Multiplexing
TPS-TC	Transport Protocol Specific – Transmission Convergence
Tx	Transmit/transmitter
uint 8	Unsigned Integer 8 bits
uint 16	Unsigned Integer 16 bits
UTC	Unable To Comply
VDSL	Very high speed Digital Subscriber Line

5 Data flow

Figure 1 represents the data flow model which is defined in this proposed text. Data from a mix of services is encapsulated into a single data stream. The data stream can then optionally pass through forward error correction and interleaving, and then be dispatched (inverse multiplexed) over multi-pair modems.

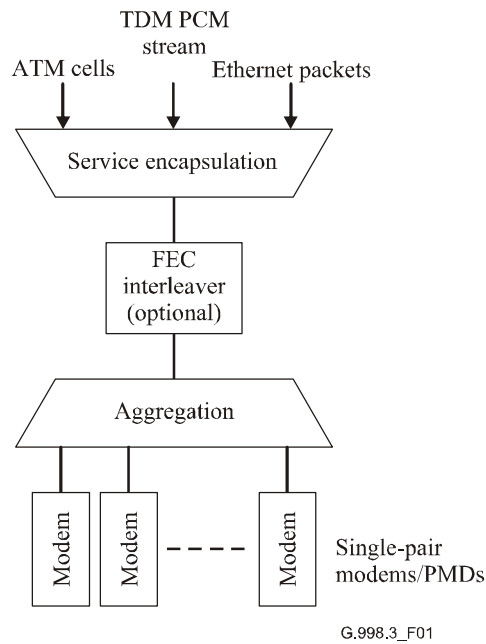


Figure 1/G.998.3 – Data flow model

The data flow model using modem rate matching is illustrated in Annex A.

6 Multi-pair synchronization

6.1 Introduction

The multi-pair aggregation group synchronization is done in the aggregation layer, independently from the underlying physical layer. Time-Division Inverse Multiplexing (TDIM) bonding uses a super frame format for multi-pair synchronization, as described below.

6.2 Frame format

The multi-pair synchronization frame, called super-frame, is made of smaller entities. Figure 2 describes the frame format for the super-frame. Note that wherever applicable, Most Significant Bit/Byte (MSB) bits are always transmitted first in time and Least Significant Bit/Byte (LSB) bits are always transmitted last.

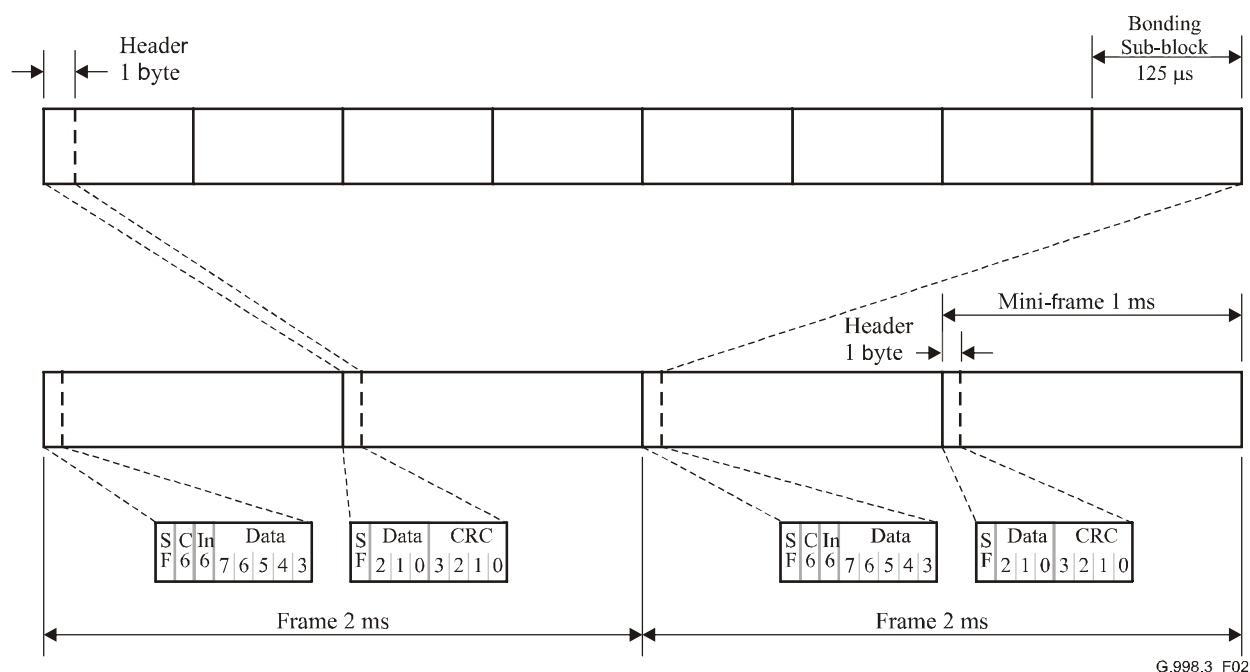


Figure 2/G.998.3 – Multi-pair synchronization – Frame format

6.2.1 Bonding sub-block and mini-frames

The bonding sub-block has a fixed time period of 125 μs. A sub-block duration of 125 μs yields a rate granularity of 8 kbit/s.

A mini-frame contains 8 bonding sub-blocks and has a period of 1 ms. The start of a mini-frame is synchronized to the start of a bonding sub-block. The first byte in each mini-frame (in each DSL pair) is taken for header. The mini-frame header is used to indicate the start of a super-frame and to transferring events and messages to the far end.

The amount of bits in each sub-block is a function of the sub-block location, the number of bonded pairs and on the total data rate of all the bonded pairs.

The amount of bonding payload bits carried by each of the last 7 bonding sub-blocks of every mini-frame is equal to $N(Rate) = Rate/8 \text{ kbit/s}$, while:

- $N(Rate)$ is the number of bits in each sub-block, depending on the accumulated link data rate.
- $Rate$ is the accumulated data rate of all the pairs measured in bits-per-second [bps].

The amount of bonding payload bits carried by the first bonding sub-block in each mini-frame is $N(Rate) - 8M$ where M is the number of individual pairs in the bonded system.

NOTE – If rate matching is used (see Annex A), then:

The amount of bits available for bonding payload in the first bonding sub-block of every mini-frame is $N(Rate) - 16M$.

The amount of bits available for bonding payload in the 8-th bonding sub-block of every mini-frame is $N(Rate) + 8\Delta$, where $\Delta = \sum_{i=1..M} \Delta_i$, and each Δ_i is dependent on the rate variation on pair i and can take the values $-1, 0, 1, 2$. Moreover, each Δ may take different values in each Mini-Frame (see Annex A for details).

6.2.2 Frame

A frame is built from 2 mini-frames and therefore has a period of 2 ms. There are 16 bits of header in each frame, one byte in each mini-frame. The format of the frame header is described in Figure 3.

Each frame header has 6 expected bits that are known in advance (Super Frame (SF) bits, Cyclic Redundancy Check (CRC) bits). Error in these bits is used to recognize a pair failure.

10 (ten) consecutive frames with CRC errors or wrong SF bits on a specific pair shall be used to declare this pair faulty.

Figure 3 defines the content of the frame header fields:

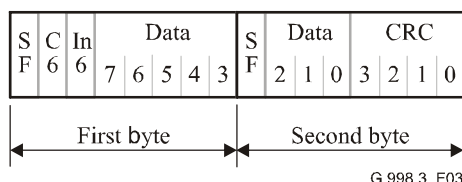


Figure 3/G.998.3 – Frame header format

- SF (Super-Frame indication) – Indicates the start of a super-frame. This bit is located in the start of each mini-frame. It shall be set to '1' at the first mini-frame in the super-frame and otherwise set to '0'.
- C6 (Cyclic Redundancy Check code) – The super-frame CRC-6 field is made up of six C6 bits C6[5:0] which are part of each frame. The CRC-6 field is calculated over all the multi-pair data that was transmitted during the previous super-frame (excluding the frame header overhead, and the modem rate matching overhead, if used), and is used to detect errors in the data in a specific super-frame. The encoding of the six bits is defined by the generating polynomial $G(x) = x^6 + x + 1$, (see ITU-T Rec. G.991.2, "Single-pair high speed digital subscriber line (SHDSL) transceivers"). Mathematically, the CRC value corresponding to a given super-frame is defined by the following procedure:
 - The first 6 bits of the super-frame are complemented.
 - The N bits of the super-frame are then considered to be the coefficients of a polynomial $M(x)$ of degree N–1. (The first bit of the super-frame corresponds to the $x^{(N-1)}$ term and the last bit of the super-frame corresponds to the x^0 term.)
 - $M(x)$ is multiplied by x^6 and divided by $G(x)$, producing a remainder $R(x)$ of degree 5.
 - The coefficients of $R(x)$ are considered to be a 6-bit sequence.
 - The bit sequence is complemented and the result is the CRC.
 - The 6 bits of the CRC value are placed in the "C6" bits in the following super-frame overhead so that the x^5 term (C6[5]) is located in the first frame of the super-frame, and the x^0 term (C6[0]) is located in the last frame of the super-frame. The bits of the CRC are thus transmitted in the order $x^5, x^4, \dots, x^1, x^0$.
- In6 – Six bits, one per frame, that make a SF field of six indication bits In6[5:0].
 - The indication bit In6[5] which is transmitted in the first frame of the SF is called M/E and is used for Message/Event indication. It indicates the meaning of the Data[7:0] bits. M/E = '0' indicates that the Data[7:0] bits are part of an event, M/E = '1' indicates that the Data[7:0] bits are part of a message.
 - The indication bit In6[4] has different meanings depending on whether it is transmitted by the bonding terminating unit, central office (CO) side (BTU-C) or the bonding terminating unit, remote terminal (RT) side (BTU-R):

- BTU-R: In6[4] = '1' indicates the BTU-R aggregation layer is capable of operating in the regular aggregation mode, without the use of the Modem Rate Matching mechanism.
- BTU-C: In6[4] = '1' orders the BTU-R to operate in the regular aggregation mode without the modem rate matching.
- The indication bit In6[3] has different meanings depending on whether it is transmitted by the BTU-C or the BTU-R:
 - BTU-R: In6[3] = '1' indicates the BTU-R aggregation layer is capable of operating with the use of the modem rate matching mechanism.
 - BTU-C: In6[3] = '1' orders the BTU-R to use the modem rate matching mechanism.
- The indication bits In6[2:0] are reserved for future use, and currently set to '1'.
- Data [7:0] – Byte of data that makes a part of an event or a message (see 12.3), according to the M/E bit.
- CRC [3:0] (Cyclic Redundancy Check code) – Four bits assigned to a CRC code. A CRC-4 (see 2.3.3.5/G.704) shall be generated for each frame header (not including the CRC-4 field) and transmitted on the CRC field. The encoding of the four bits is defined by the generating polynomial $G(x) = x^4 + x + 1$. Mathematically, the CRC-4 value corresponding to a given frame header is defined by the following procedure:
 - The first 4 bits of the frame header are complemented.
 - The 12 bits of the frame header are then considered to be the coefficients of a polynomial $M(x)$ of degree 11. The first bit of the frame header corresponds to the x^{11} term and the last bit of the frame header corresponds to the x^0 term.
 - $M(x)$ is multiplied by x^4 and divided by $G(x)$, producing a remainder $R(x)$ of degree 3.
 - The coefficients of $R(x)$ are considered to be a 4-bit sequence.
 - The bit sequence is complemented and the result is the CRC field.
 - The 4 bits of the CRC value are placed in the CRC field of the frame header so that the x^3 term is located in the left most bit of the CRC field, and the x^0 term is located in the right most bit of the CRC field. The bits of the CRC are thus transmitted in the order x^3, x^2, x^1, x^0 .

6.2.3 Super-Frame (SF)

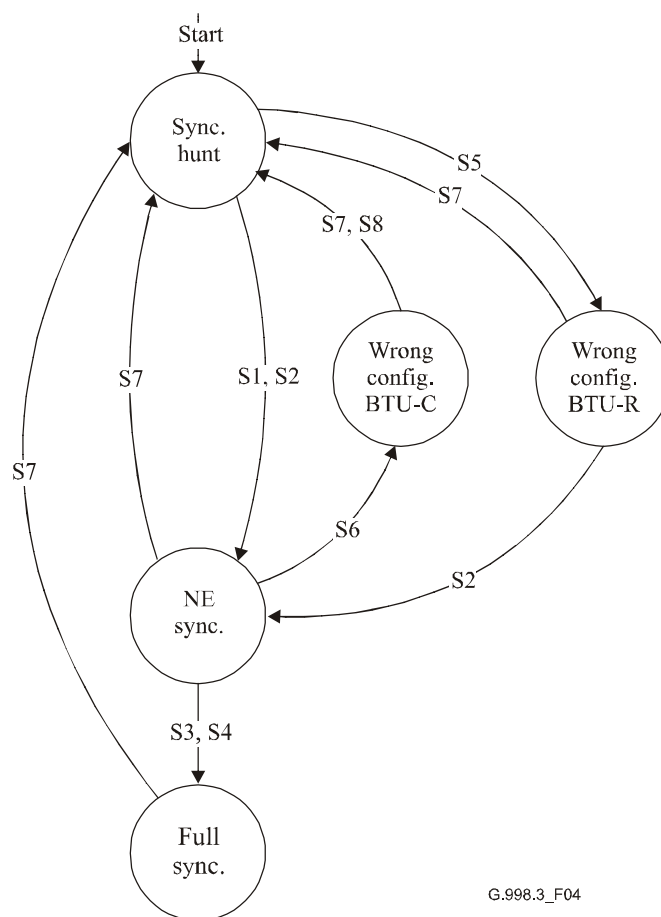
A super-frame is built from 6 frames and has a period of 12 ms.

The super-frame is used in order to synchronize all the bonded pairs, and to frame bonding communications channel (BCC) events and messages.

The super-frame has a CRC-6 field which is made of the six C6 bits which are part of each frame. The CRC-6 field is calculated over all the multi-pair data that was transmitted during the previous super-frame, and is used to detect errors in the data in a specific super-frame. This information is used for performance monitoring of the bonded pairs.

6.3 Multi-pair synchronization state machine

Figure 4 describes the multi-pair synchronization state machine, with the states and the transitions between the states. The states and transition conditions are defined below.



G.998.3_F04

Figure 4/G.998.3 – Multi-pair synchronization state machine

6.3.1 States

Table 1/G.998.3 – Multi-pair synchronization state machine states definition

State	Definition	Receiver actions	Transmitter actions	Transitions
Sync hunt	The pair is synchronizing by searching for the aggregation group framing, decoding the evSync events, and compensating for delay difference to the other pairs in the aggregation group	Searching for frame headers, decoding evSync events	Sending evSync events with: - Value[0] – indicating no synchronization (0x00) - Value[1] – pair number in the BTU-C and 0xFF in the BTU-R - Value[2] – Aggregation group number in the BTU-C and 0xFF in the BTU-R	[S1], [S2] to "NE Sync" state [S5] to "Wrong Config BTU-R" state

Table 1/G.998.3 – Multi-pair synchronization state machine states definition

State	Definition	Receiver actions	Transmitter actions	Transitions
NE sync	The near end is synchronized to the aggregation group	BTU-C is waiting for the BTU-R to get to "NE sync" state (indicated by Value[0] = 0x01 in the received evSync event). BTU-R is waiting for the BTU-C to get to "Full Sync" state (indicated by receiving events other than evSync events)	Sending evSync events with: - Value[0] – indicating NE synchronization (0x01) - Value[1] – the pair number - Value[2] – the aggregation group number The BTU-R is taking the pair number and the aggregation group number from the events received from the BTU-C	[S3], [S4] to "Full Sync" state [S6] to "Wrong Config BTU-C" state [S7] to "Sync Hunt" state
Wrong config BTU-C	This state is for the BTU-C only. The BTU-R is not able to get the aggregation group number or the pair number	None	Sending evSync events with: - Value[0] – NE sync (0x01) - Value[1] – the pair number - Value[2] – the aggregation group number	[S7], [S8] to "Sync Hunt" state
Wrong config BTU-R	This state is for the BTU-R only. There is wrong configuration: The BTU-R is already connected to another Aggregation Group or the pair number assigned to this pair is already in use by the BTU-R	Waiting for evSync events with a different Aggregation Group number or pair number	Sending evSync events with: - Value[0] – Wrong Config (0x80 or 0x81) - Value[1] – the pair number - Value[2] – the Aggregation Group number The BTU-R is sending its own pair number and Aggregation Group number	[S2] to "NE Sync" state [S7] to "Sync Hunt" state
Full sync	The pair is synchronized to the Aggregation Group at both ends. It can be added to the Aggregation Group by using "Sync Change" procedure	Receiving same messages or events as the other pairs in the Aggregation Group	Sending same messages or events as the other pairs in the Aggregation Group	[S7] to "Sync Hunt" state

6.3.2 Transition conditions

- [S1] In the BTU-C: Consecutive three super-frames decoded with the same evSync event without errors.
- [S2] In the BTU-R: Consecutive three super-frames decoded with the same evSync event without errors, with legal aggregation group number (equal to the aggregation group number received by other synchronized pairs, if exist), and legal pair number (not used by another synchronized pair).
- [S3] In the BTU-C: Receiving evSync event with "NE Sync" indication (Value[0] = 0x01) from the BTU-R.
- [S4] In the BTU-R: Receiving valid super-frame that is not an evSync event.
- [S5] In the BTU-R: Consecutive three super-frames were decoded with the same evSync event without errors, but with an illegal aggregation group number (different from the aggregation group number already decoded by the BTU-R from previous synchronized pairs) or with an illegal pair number (i.e., already used by previously synchronized pair).
- [S6] In the BTU-C: Receiving evSync event with an indication from the BTU-R of "Wrong Config" (Value[0] = 0x80 or 0x81).
- [S7] 10 (ten) consecutive frames with errors (bad CRC-4 or wrong SF bits).
- [S8] In the BTU-C: A management decision to resynchronize this pair with a different aggregation group number and/or a different pair number.

7 Dispatching

7.1 Principles

The dispatcher maps the data stream bits coming from the encapsulation layer (or from the Forward Error Correction (FEC)/Interleaver), which is virtually divided into "bonding sub-blocks" (see Figure 2), to each of the pairs in the aggregation group.

7.2 Algorithm

The dispatching algorithm is recurring every bonding sub-block (125 μ s). The dispatching algorithm goes over all of the bits contained in a bonding sub-block, by order from the first to the last. The dispatching algorithm goes over all of the pairs by order of their logical number in the aggregation group, and assigns bits from the bonding sub-block to the pairs. Each pair is assigned n_i ($n_i = \text{Rate}_i / 8 \text{ kbit/s}$) bits, where the first bits in each mini-frame are used as header bits and not for data bits.

NOTE – For bonding systems implementing Annex A, a slight variation from n_i may occur at the 8-th.

Bonding sub-block of each mini-frame. For a detailed description see Annex A and the dispatching pseudo-code below.

7.3 Pseudo code

The following pseudo-code defines the dispatching algorithm:

```
Sub_Block_Counter = 1
Repeat every 125  $\mu$ s {
    Bonding_Sub_Block_Bit = 1
    For Pair_Number = 1: Number_of_Pairs {
        If (Bonding_Sub_Block_Bit==8 and Rate_Matching_Flag==2 ){
```

```

    Read  $\Delta_{Pair\_Number}$ 
}
else{
     $\Delta_{Pair\_Number}=0$ ;
}

    Bit_Counter = 1
    For Bit_Counter = 1:  $n_{Pair\_Number}+8*\Delta_{Pair\_Number}$  {
        If (Sub_Block_Counter==1 and Bit_Counter<=8*Rate_Matching_Flag) {
            Send_Header (Bit_Counter, Pair_Number)
        }
        else {
            Send_Data (Bonding_Sub_Block_Bit, Pair_Number)
            Bonding_Sub_Block_Bit++
        }
    }
    Sub_Block_Counter++
    If (Sub_Block_Counter > 8) {
        Sub_Block_Counter = 1
    }
}

```

where:

<i>Sub_Block_Counter</i>	The position of this sub-block in the mini-frame.
<i>Bonding_Sub_Block_Bit</i>	Index of the next bit from the bonding sub-block that shall be sent.
<i>Pair_Number</i>	Index of the current pair (its logical number in the aggregation group).
<i>Number_of_Pairs</i>	The amount of pairs currently delivering data in this aggregation group.
<i>Bit_Counter</i>	Counter of bits already sent on the current pair.
n_i	The (base) number of bits assigned to pair i .
Δ_i	The variation (in bytes) from n_i (non zero only for Annex A implementations).
<i>Rate_Matching_Flag</i>	1 if rate matching is not used, 2 if rate matching is used.
<i>Send_Header</i> (k, j)	A function that sends bit k of the mini-frame header to pair j .
<i>Send_Data</i> (k, j)	A function that sends bit k of the bonding sub-block to pair j .

8 Differential delay

The framing structure of the aggregation layer is capable of tolerating a differential delay of 6 ms between the fastest pair and the slowest pair; however, a TDIM bonding system is required to tolerate a differential delay of only 2 ms.

9 Clock synchronization

9.1 Scope

This clause defines the clock synchronization requirements between the BTU-C and the BTU-R, in the relevant layers and time domains: Service (TDM), aggregation and modems.

Figure 5 shows the time domains in the bonding system and the clocks that synchronize the time domains.

The directions BTU-C to BTU-R and BTU-R to BTU-C are independent, therefore there are 4 independent clocks:

- Each Time-Division Multiplexing (TDM) service clock is transmitted from the BTU-C to the BTU-R (1) over the aggregation time domain clock using stuffing. The TDM service clock is reconstructed at the BTU-R from the aggregation time domain clock by stuffing removal.
- The BTU-C Aggregation time domain clock (2) is transmitted over the modems in a plesiochronous manner. The BTU-R Aggregation time domain clock is reconstructed from the modems.
- The BTU-R Aggregation time domain clock (3) is transmitted over the modems in a plesiochronous manner. The BTU-C Aggregation time domain clock is reconstructed from the modems.
- Each TDM service clock is transmitted from the BTU-R to the BTU-C (4) over the Aggregation time domain clock using stuffing. The TDM service clock is reconstructed at the BTU-C from the Aggregation time domain clock by stuffing removal.

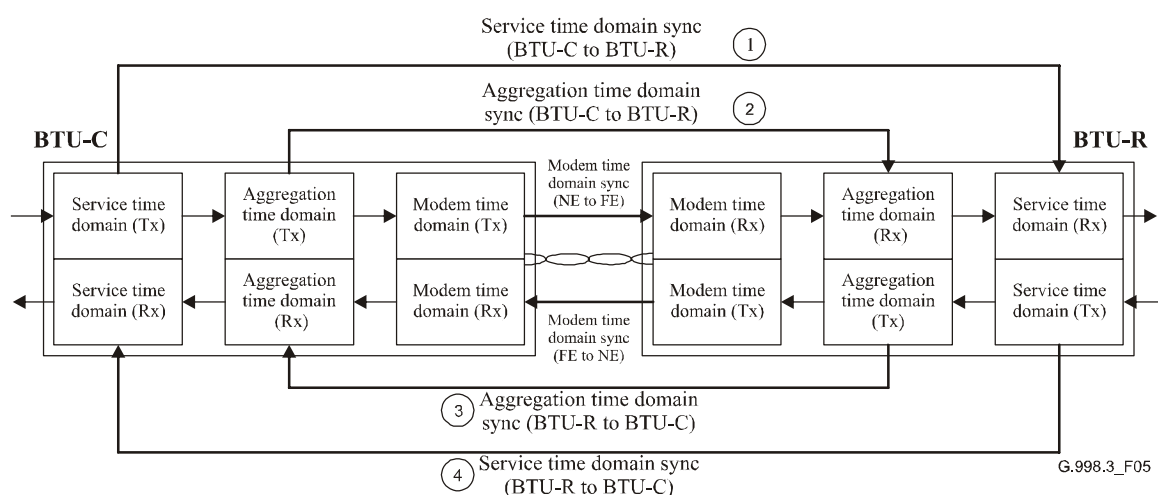


Figure 5/G.998.3 – Peer time domains and clock synchronization

Figure 6 shows a reference model for clock synchronization. It can be seen that the data/clock between the aggregation layer and the modems are synchronized to the aggregation time domain. However, each modem may use a different line clock (i.e., the modems time domain) and carry the

data and clock from the aggregation layer using stuffing (like in ITU-T Rec. G.991.2 and in Asymmetric Digital Subscriber Line (ADSL)).

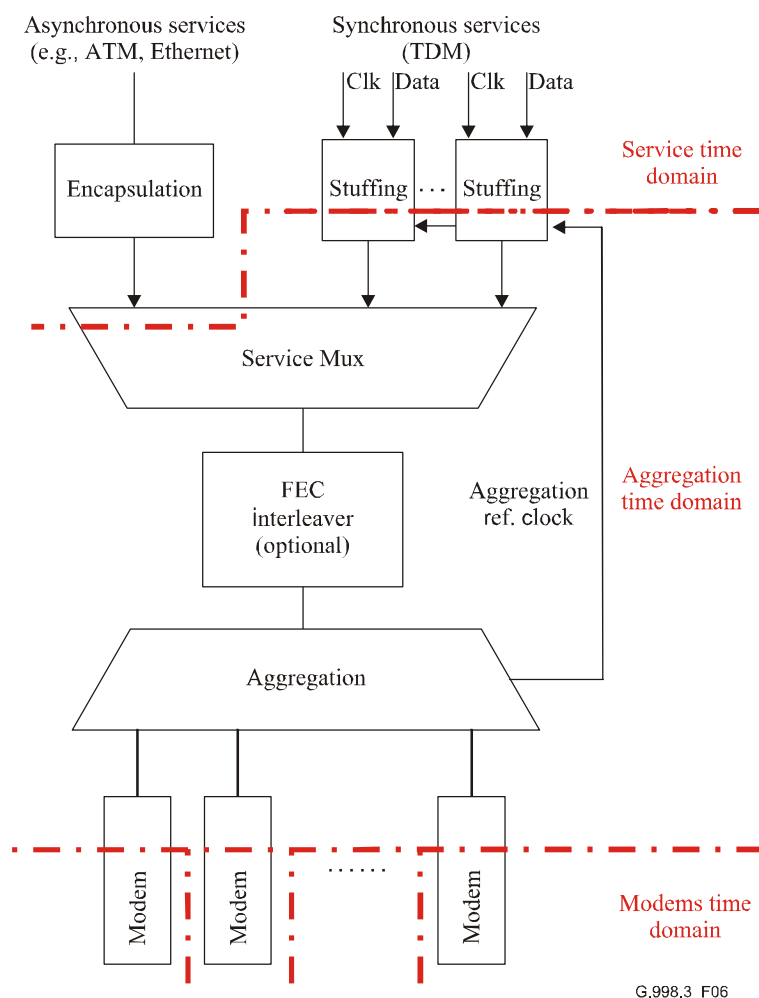


Figure 6/G.998.3 – Clock synchronization reference model

Clock synchronization under the use of the modem rate matching mechanism is described in Annex A.

9.2 TDM service synchronization and clock transfer

Each TDM service (e.g., Digital Signal 1, (1.544 Mbit/s) (DS1), Electrical interface signal, Level 1, (2.048 Mbit/s) (E1)) data and clock are transferred from the Near End (NE) to the Far End (FE). Plesiochronous services are transferred from the NE to the FE by adding stuffing at the NE and using stuffing removal at the FE. The stuffing is done relatively to the aggregation reference clock, which synchronizes the aggregation layers of BTU-C and the BTU-R. For more details see 10.4.

9.3 Aggregation layer synchronization

The aggregation layer at the BTU-R receiver is locked and synchronized to the aggregation layer at the BTU-C transmitter. The aggregation layer at the BTU-C receiver is locked and synchronized to the aggregation layer at the BTU-R transmitter.

The aggregation layer issues the aggregation reference clock which is the reference clock to the Aggregation time domain.

It is required that:

- The aggregation layer shall be synchronized to the FE as long as at least 1 (one) pair remains in the aggregation group.
- In case of losing synchronization or lock, recovery shall be done in a way that a service is not dropped for more than 50 ms.

It is an objective that:

- The aggregation layer should not lose synchronization to the FE even in cases of pair failure as long as at least 1 (one) pair remains in the aggregation group.

9.4 Pair synchronization

All the pairs participating in an aggregation group shall have the same data clock, coming from the aggregation layer.

Pair clocking under modem rate matching is described in Annex A.

This Recommendation does not define how the pairs achieve synchronization.

It is required that:

- In the case where a pair loses synchronization, other pairs in the aggregation group shall not lose synchronization.

10 Service encapsulation

10.1 Reference model

The encapsulation layer performs the following functions:

- Adding stuffing information to each TDM service in order to enable accurate clock transfer for each TDM service.
- Encapsulating the frame-based service payload (e.g., Ethernet frame in case of an Ethernet service) so the receiver can determine the start and finish of the payload (only to services where applicable, e.g., Ethernet).
- Allocating the service data streams into the N bits of the 125 μ s bonding sub-blocks (see 6.2.1).

Figure 7 illustrates the flow of the various services (Ethernet, ATM, TDM and Generic Framing Procedure (GFP)) through the encapsulation layer towards the aggregation layer.

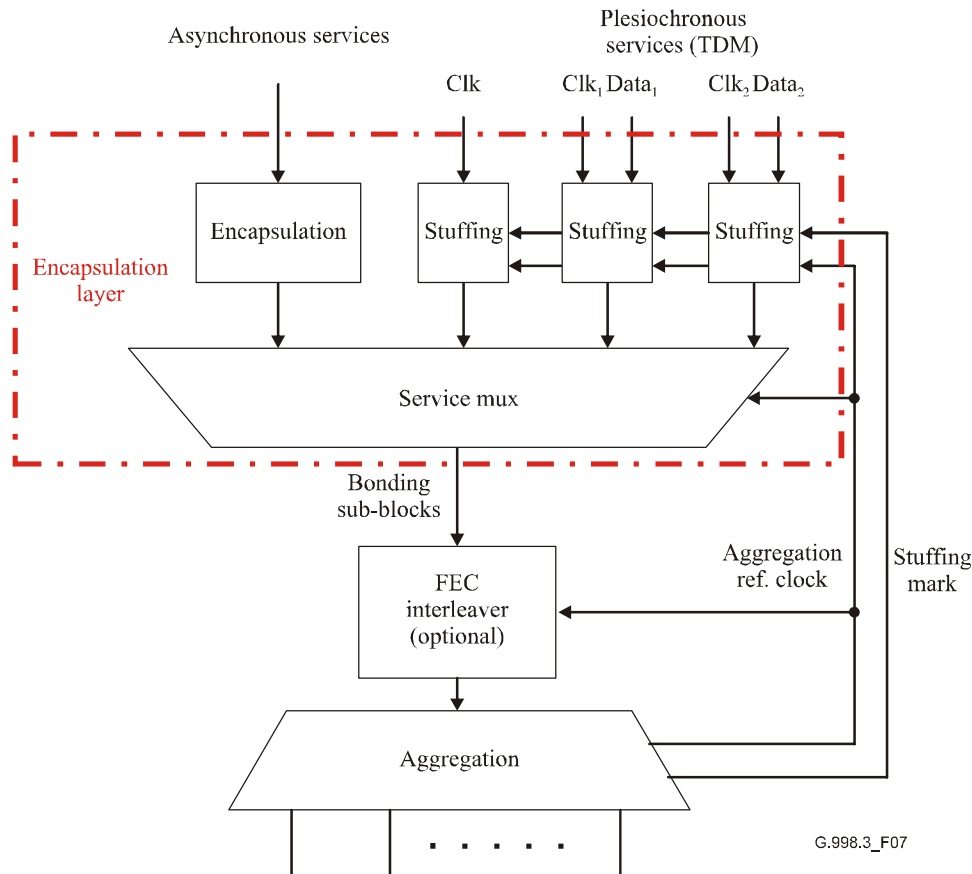


Figure 7/G.998.3 – Service encapsulation reference model

10.2 Service mux

The service data streams are allocated into the N bits of the 125 μ s bonding sub-blocks (see 6.2.1).

The allocation of bits in each bonding sub-block is different, since one in every eight bonding sub-blocks contains a mini-frame header, and since a TDM service may require an amount of bytes in 1 ms which is not divisible by 8, resulting in an uneven distribution of bits in the bonding sub-blocks. The allocation of bits in the bonding sub-blocks repeats itself every 1 ms (every 8 bonding sub-blocks). In the following text j designates the index of the bonding sub-block in the 1 ms mini-frame cycle, $j = 1:8$.

Since TDM services require a constant amount of Bandwidth (BW), they are allocated into a fixed number of bits in the mini-frame. TDM _{i} service is allocated into $N_{i,j}$ bytes in bonding sub-block j . In every bonding sub-block j asynchronous services are allocated into the remaining bits $N_{async,j}$. For $j = 1$, which is the bonding sub-block that contains the mini-frame headers, $N_{async,1} = N - \sum_i N_{i,1} - 8 \times l \times M$, where M is the number of pairs in the aggregation group.

$l = 2$ if the modem rate matching mechanism is used, otherwise $l = 1$.

For $j = 2$ to 8, $N_{async,j} = N - \sum_i N_{i,j}$.

Table 2 defines the values of $N_{i,j}$ for the various TDM service types, including the stuffing information (see 10.4.2). $N_{i,j}$ is the amount of service data bytes (and the associated stuffing) in the j th bonding sub-block in a mini-frame.

Note that fractional digital signal 3, (44.736 Mbit/s) (DS3) and fractional electrical interface signal, Level 3, (34.368 Mbit/s) (E3) are carried as multiple clear channel DS1's, or E1's, respectively.

The service-type notation is used in the "service mapping" and "service configuration" messages to specify the $N_{i,j}$ allocation of each service i .

Table 2/G.998.3 – Service mapping constants

Service type notation	Service type	$N_{i,1}/8$ [byte]	$N_{i,2}/8$ [byte]	$N_{i,3}/8$ [byte]	$N_{i,4}/8$ [byte]	$N_{i,5}/8$ [byte]	$N_{i,6}/8$ [byte]	$N_{i,7}/8$ [byte]	$N_{i,8}/8$ [byte]
1	Clear channel DS1	24	24	24	24	24	24	25	25
2	Clear channel E1	32	32	32	32	32	32	32	33
3	Fractional DS1 (including P x DS0 channels)	P	P	P	P	P	P	P	P+1
4	Fractional E1 (including P channels)	P	P	P	P	P	P	P	P+1
5	DS3	699	699	699	699	699	699	699	700
6	E3	537	537	537	537	537	537	537	538
7	Clock transfer	1	1	1	1	1	1	1	1

10.2.1 Service mapping

Figure 8 describes the service mapping in the time and pairs space, including the mini-frames repeating every 1 ms. It can be seen that every 1 ms, where $j = 1$, N_{async} is reduced by $8 \times l \times M$ Bits, where M is the number of pairs in the aggregation group, and $l = 2$ if the modem rate matching is used, and $l = 1$ otherwise. Note that the dispatching into pairs is shown here for clarity only, and shall be done according to clause 7 (Dispatching).

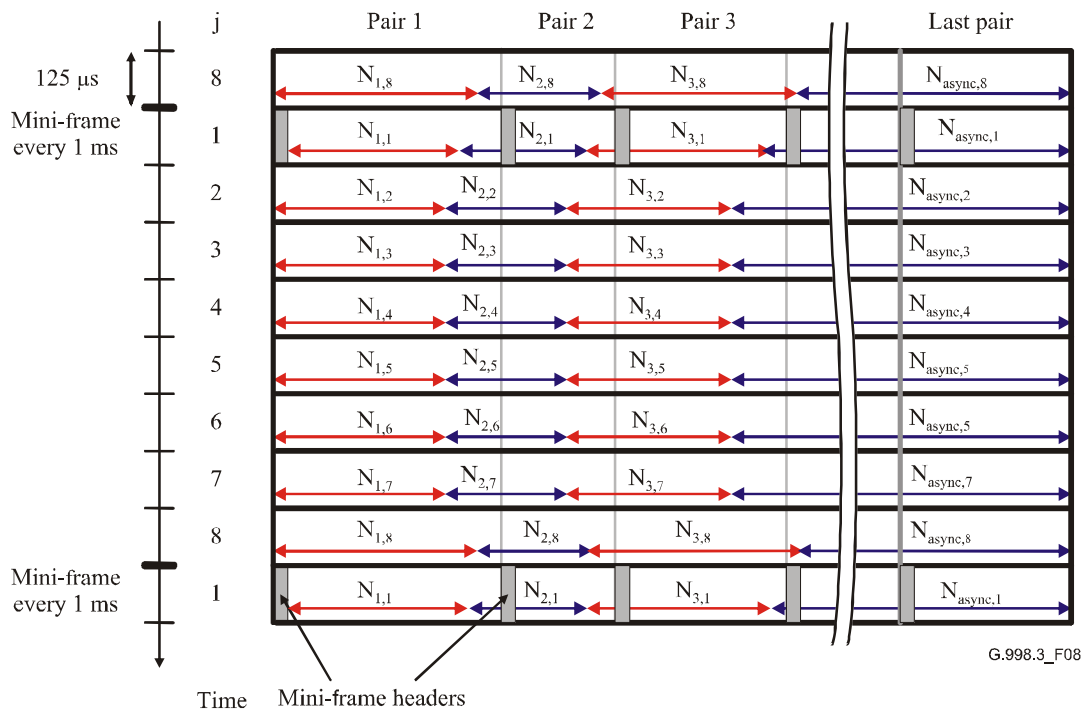


Figure 8/G.998.3 – Service mapping in time (and pairs) space

10.2.2 Clock transfer

Clocks (without data) can be transferred from the NE to the FE.

This is done by allocating 1 byte per bonding sub-block for each transferred clock. The first bit (MSB) in each such byte is used to construct a stuffing byte (see Figure 12) per mini-frame.

The functionality of the stuffing mechanism is described in 10.4.2, with the exception that the receiver functionality is the following:

- If the sum of SC[5:0] equals 0 or 1, then add two clock ticks.
- If the sum of SC[5:0] equals 5 or 6, then subtract two clock ticks.
- If the sum of SC[5:0] equals 2 or 3 or 4, then do nothing.

10.2.3 Service prioritization

TDM services have higher priority than asynchronous services. The order of priority from highest to lowest is TDM₁, TDM₂, ..., TDM_{last}, asynchronous service allocation₁, asynchronous service allocation₂, asynchronous service allocation_{last}.

Note that there can be more than a single allocation of BW for asynchronous services. In which case, the description in 10.2 should be changed accordingly.

When the BW of the aggregation group decreases (e.g., due to a pair failure), N decreases accordingly. As a result N_{async} decreases. According to the amount of the BW degradation it could happen that TDM services shall start dropping.

Figure 9 demonstrates this behaviour with the BW changes in time marked 1-3:

- 1) BW decreases. As a result the BW allocated for asynchronous services decreases while the BW allocated for TDM services remains intact.
- 2) BW decreases to a point where there is not enough BW for TDM₃ so TDM₃ drops. The available BW beyond TDM₁ and TDM₂ is allocated for asynchronous services.
- 3) BW increases. As a result TDM₃ recovers and the remaining BW is allocated for asynchronous services.

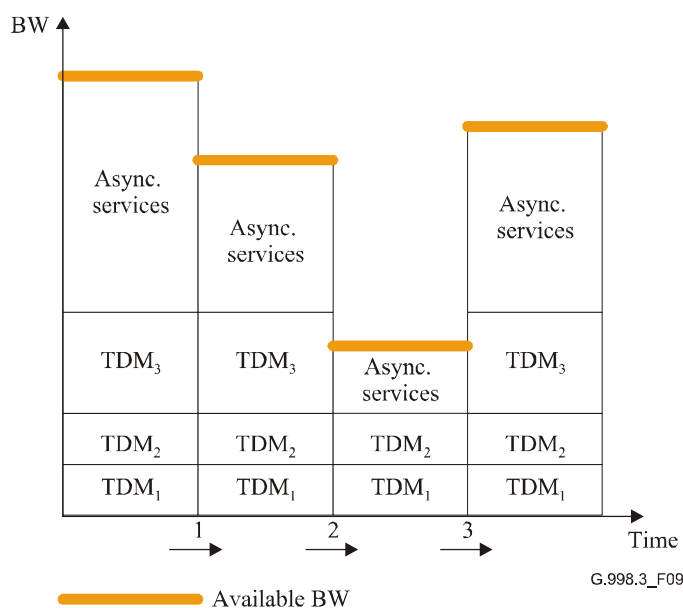


Figure 9/G.998.3 – Service prioritization in an available BW

10.3 Asynchronous services

Asynchronous services need to be encapsulated in a manner that enables the receiver to determine the start and finish of the service payload (e.g., Ethernet frame in case of an Ethernet service).

When a few (more than one) asynchronous services are transmitted in the same Bonding system, each asynchronous service shall be allocated with a distinct N_{async_i} bits, and shall be encapsulated separately.

The GFP protocol adds a header information to the incoming service data to identify the type of the encapsulated service, start (and end) of a data unit, and optionally adds some protection.

10.3.1 GFP format

Standard GFP adds a 4-byte core header to each data packet. This header consists of 2-byte long Packet Length Identifier (PLI) and 2 bytes of Header Error Check (HEC). Encapsulated frames are sent one after another as a continuous byte stream. The receiver at the FE locks onto the header, using HEC for frame delineation. In addition to the core header, a 4-byte payload header is pre-pended to the original payload, containing payload type and HEC. Additional extension headers may be added as well for the benefit of applications (up to 60 bytes). GFP also specifies an optional CRC-32 Payload Frame Check Sequence (FCS).

Figure 10 illustrates GFP frame format:

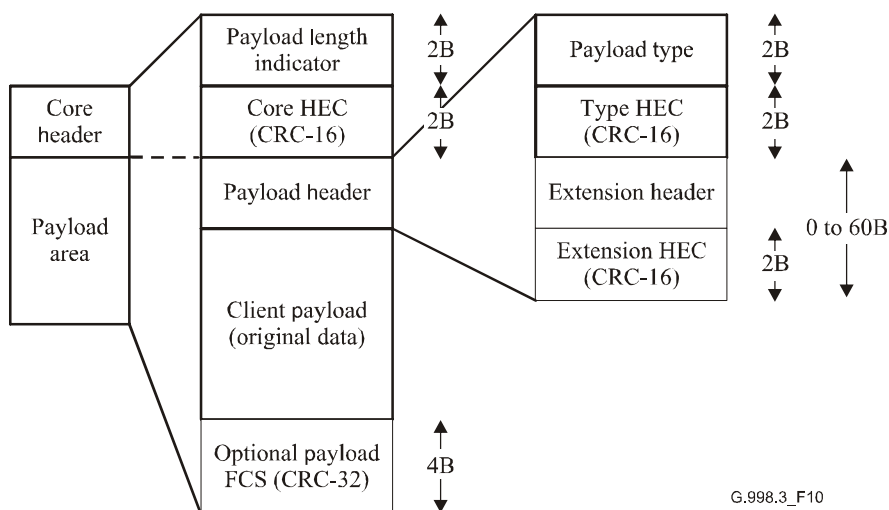


Figure 10/G.998.3 – GFP frame format

The payload area is scrambled to improve the robustness of the GFP frame delineation procedure and to provide a sufficient number of 0-1 and 1-0 transitions during idle transmission periods.

In order to compensate for BW differences and achieve a continuous byte stream at a constant rate even when the service BW decreases, idle frames are inserted into the byte stream when service data is not available. GFP idle frames are 4 bytes long with PLI = 0.

10.3.2 Ethernet

10.3.2.1 Inter-frame gap and preamble deletion and restoring

In Ethernet service transmission inter-frame gaps and preambles are discarded before the encapsulation, and are regenerated after de-capsulation at the receiver end.