D4.1Top level specification of the PTSP, TC and MAC components

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Keywords	Packet Transport System Protocol, Transmission Convergence, Medium Access Control, PHY and TC OAM functionality.
Abstract (for dissemination)	The implementation of the Transmission Convergence layer of the GPON system is at the core of the mechanism responsible for the efficient installation, operation, maintenance and performance monitoring of the system. It reflects the ITU-T G.PON.gtc standard and is composed of 3 parts: the Packet Transport System Protocol (PTSP), the Transmission Convergence (TC) components and the Medium Access Control (MAC) component. The PTSP describes and implements a protocol responsible for the communication between the OLT and the ONUs. The TC and MAC components address the hardware requirements of the system to fulfill the specifications and functionalities of the GPON system

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ABBREVIATIONS

A/D	Analogue / Digital
AFE	Analogue Front End
APD	Avalanche Photodiode
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
BER-T	Bit Error Rate-Tester
BIP	Bit Interleaved parity
BW	Bandwidth
CMSB	Control and Mains Signalling Board
CDR	Clock and Data Recovery
CPA	Clock and Phase Alignment
CRC	Cyclic Redundancy Code
D/A	Digital / Analogue
DC	Direct Current
DCC	Data Communication Channel
DS	Downstream
DSC	Downstream Cell
E/O	Electrical/Optical
EDFA	Erbium Doped Fibre Amplifier
FEC	Forward Error Correction
FPGA	Field Programmable Gate Array
FSAN	Full Service Access Network
FSM	Finite State Machine
FPGA	Field Programmable Gate Array
GbE	Gigabit Ethernet
GBLD	Gigabit Burst Mode Laser Driver
GBRX	Gigabit Burst mode Receiver
GEM	GPON Encapsulation Method
GICI	General Internal Card Interface
GMII	Gigabit Medium Independent Interface
GOLT	Gigabit Optical Line Termination
GONT	Gigabit Optical Network Termination
GPON	Gigabit Passive Optical Network
GXT	Gigabit Line/Network Termination (ASIC)
GXTP	Gigabit Line/Network Termination Programmable (FPGA)
HW	Hardware
LCF	Laser Control Field
LD	Laser Diode/Driver
LOS	Loss of signal
LSb	Least Significant bit
LSB	Least Significant Byte
MAC	Medium Access Control
MBS	Multi Burst Slot
MII	Medium Independent Interface
MS	Management Station
MSb	Most Significant bit
MSB	Most significant Byte
NE	Network Element
OAM	Operation Administration and Maintenance
OBC	On Board Controller
ODN	Optical Distribution Network
O/E	Optical / Electrical
OLT	Optical Line Termination
OMCC/I	ONU Management & Control Channel / Interface
ONU/T	Optical Network Unit / Optical Network Termination
OTDR	Optical Time Division Reflectometry
PCB	Physical Control Block
PDU	Protocol Data Unit
PLI	Payload Length Indicator
PLO	Physical Layer Overhead
PLOAM	Physical Layer Operation Administration and Maintenance
PLS	Power levelling Sequence
PON	Passive Optical Network
PRBS	Pseudo Random Bit Sequence
PTSP	Packet Transport System Protocol
RW	Ranging Window
PWM	Pulse Width Modulator
RX	Receiver
RXCF	Receiver Control Field
SDU	Service Data Unit
SFF	Small Form Factor
SPI	Serial Peripheral Interface
SU	Service Unit
SW	Software
TC	Transmission Convergence
TDMA	Time Division Multiple Access
TX	Transmitter
US	Upstream
USC	Upstream Cell
VP	Virtual Path
VC	Virtual Channel
WDM	Wavelength Division Multiplexing

REFERENCES

[1] Quantum Bridge Communications, “Transmission Convergence Layer for Gigabit Passive Optical Networks”, FSAN working document G.GPON.GTC, Oct. 24, 2002, 95 Pages.

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EXECUTIVE SUMMARY

The Transmission Convergence (TC) layer of the GPON system is at the core of the mechanism responsible for the efficient installation, operation, maintenance and performance monitoring of the system. The present document is divided into 4 parts, the first chapter gives an architectural overview of the TC layers, pointing out the responsibilities of each partners involved in this task. Chapter 2 deals with the Packet Transport System Protocol (PTSP), where the finite state client-server protocol carrying out the physical layer and the operation administration and maintenance (OAM) functionalities are described. Chapter 3 describes the challengers and gives a top-level description of the TC components necessary for the correct implementation on this layer. Finally, chapter 4 describes the medium access control (MAC) protocol, which is responsible for the correct and efficient arbitrating of the upstream data.

For the implementation purpose it is useful to view the system being constituted by the software and hardware related part, thus while the PTSP deals basically with the software implementation, the TC and MAC components concentrate on the hardware challenges of the GPON TC layer. Much of the task of the TC layer is determined by the ITU-T G.GPON.GTC standard, since up to this moment the standard has not being finalised and frozen, some of the implementations described here may still go through some modification.

The PTSP chapter is divided in 5 sections; the first section gives a brief overview of a PON system and describes the challenges and important issue to be addressed in such system, such as ranging and synchronisation. The state machine, messages definition and configuration parameters are depicted and described in the second section. The third section gives a dynamic overview of the protocol, defining the installation and activation methods, detailing the initial ranging procedure with all the steps for ranging, and describing the procedures during the normal operation. The fourth section lists and describes the response for the possible alarms and fault handling. Finally, a brief overview of the management interface is given in the last section.

The TC components chapter describes the TC frame structure as required by the standard and the structure of the hardware units to correctly process the data flow according to the protocol. The first section gives a detail overview of the frame structures for both the upstream and downstream link. Furthermore, the other two sections specifies the TC components for the Line Termination (NT) and the Network Termination (NT), which are both composed of a control, physical, TC and GEM units. Each of these units' functionalities is specified and described in this chapter.

The MAC components are responsible for the arbitration for the access in the upstream direction. This chapter is divided between the description and specification of the MAC controller on the LT and on the NT. On the LT the MAC is responsible for the construction of the BW map and the preparation of the halting pointers used on the ranging procedure. While on the NT it should handle the reception of the BW map, define the next transmission and prepare the DBA report message.

1 INTRODUCTION

1.1 Introduction

The top-level specification of the Transmission Convergence (TC) layer for the GPON system is described in the deliverable D3.1.

In the current document, we will present the functional specification of the components, which support the TC layer as defined in D3.1. More precisely, chapter 2 describes the functionality of the Packet Transport System Protocol (PTSP), which implements the Physical and TC OAM functions. Chapter 3 deals with the physical component, which supports the GPON TC layer. And chapter 4 deals with the physical component, which support the GPON MAC.

Next section gives an overview of the selected architecture for the GPON TC.

1.2 Architecture Overview

The GPON TC layer as defined in D3.1 can be organized in three main building blocks as depicted in Figure 1:

- The SW for the transport system, including PHY and TC OAM functions
- The GTC component, which includes all functions to allow mainly transmission and reception of GTC frames. There will be two versions: LT GTC and NT GTC to be used respectively on LT side and NT side of the network.
- The MAC component, which provides all functions related to dynamic bandwidth allocation. There will be two versions: LT MAC and NT MAC to be used respectively on LT side and NT side of the network.

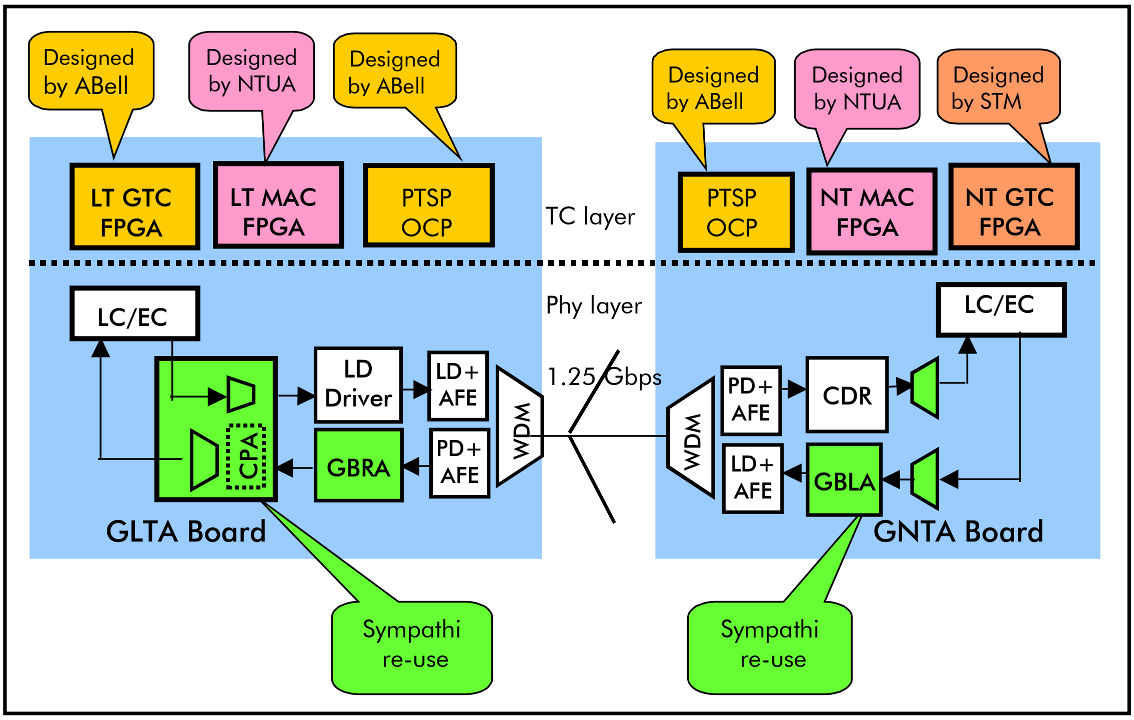

Figure 1: Functional building blocks

2 PACKET TRANSPORT SYSTEM PROTOCOL

2.1 Introduction

A Passive Optical Network (PON) is a bi-directional point-to-multipoint system, with share optical fiber as medium of communication. It consists of an Optical Line Termination (OLT) connected to several Optical Network Units (ONUs) by optical fiber, whereas the fiber arrives at each ONU by means of passive splitter. This implies that a successful GPON system must be able to cope with several different challengers and fulfil some basic requirement.

2.1.1 Notification

For a new ONU to be installed the OLT has to be able to uniquely identified each ONU, so that a proper distinction of the information flow to and from the ONUs is possible. Thus, each ONU has an 8 bytes serial number for unique worldwide identification.

2.1.2 Time ranging

The ONUs can be found at different distances from the OLT, thus different time delays are expected to happen between the moments the OLT requests a command and the time it receives the response from each ONUs. A mechanism to equalize these delays is necessary to avoid data collision and poor bandwidth utilization of the system. Basically, this mechanism adds an equalization delay, which is calculated for each ONU depending on the distance they are from the OLT and on the distance of the farthest ONU. As a result the OLT will receive the upstream data from all ONUs with an equal delay.

2.1.3 Amplitude ranging

The optical power output of the transmitter on the ONUs are projected to be the same. However, due to their distance from the OLT, different fiber configurations and due to the output power tolerances at the ONU, the received power on the OLT will vary accordingly. As a consequence, to ensure that the OLT will be able to receive the optical signal and convert it to a digital form, the receiver of the OLT will have a dynamic range capability to handle this variation.

2.1.4 Clock and phase alignment

Due to the finite precision of the ranging procedure, a guard time will be left between consecutive bursts. As a result, the first bit of each burst will lie anywhere in between this ± 2-bit guard time, requiring the receiver at the OLT to recover quickly the right clock of each burst coming from different ONU. For the clock phase alignment a pattern is inserted in the overhead of each upstream burst data with a guard time, a preamble and delimiter information, which are used for the correct recover of the clock and phase of the signal.

2.1.5 Ranging during normal operation

During normal operation the time delay and the received power at the OLT can change due to several reasons. These changes are taken into account by the PTSP protocol and dealt in a concurrent mechanism as the time and amplitude ranging.

2.1.5.1 Timing changes

The fiber between the OLT and the ONU can be subject to temperature changes, which will introduce time delay changes. To counter this, the OLT keeps track of the phase of the received signal for every ONU and notifies the ONU if this phase tends to deviate too much. The ONU then takes the action to adjust its equalization delay to the appropriate value.

2.1.5.2 Amplitude changes

The amplitude can change due to different effects, such as the usage of a clip on power meter and the aging of the laser, connectors, and fibers. The usage of a clip on power meter (on a primary coated fiber) introduces a fast, but limited change in the attenuation of the fiber. The aging of the optical devices is a slow process, which causes small amplitude changes. Amplitude changes will be handled at the OLT as long as the amplitude changes stay in the dynamic range of the receiver.

2.1.6 Encryption

The point-to-multipoint nature of the PON implies that the downstream data from the OLT is broadcasted to all ONUs. Since, this data stream can be seem by all the ONUs a security mechanism is necessary to ensure that each users are just able to access the data intended for them, and that no malicious eavesdropping threat is probable. A point-to-point encryption mechanism based on the Advanced Encryption Standard (AES) is used to protect the payload of the data. Furthermore, a precise mechanism for key exchange and switchover is performed by the PTSP protocol.

2.2 State, Messages, and Configuration

2.2.1 States Definition

The functional behaviour of the OLT and ONU are greatly determine by the definition and transition of the their states. A state is a condition or situation of the PTSP protocol in which it satisfies some condition, performs some activity, or waits for some event. In a broad perspective, a state is one of the elements of the state machine. The state machine is a graph of states and transitions that specifies the sequence of states that the system goes through in response to events, together with its responsive actions.

2.2.1.1 States of the OLT

Due to the point-to-multipoint architecture of the GPON a single OLT manages several ONUs, as a consequence the functional states for the activation and operational procedure of the OLT are divided into the Common-part and the Individual-ONU-dealing-part(n), where n corresponds to each ONU. The Common-part deals with the common function pertaining to the system as a whole, thus the behaviour of the OLT upon all ONUs. In contrast, the Individual-ONU-dealing-part(n) treats the functions related to a specific ONU, since each ONU is an individual unit with some unique characteristics and behaviours. See Figure 2 for a diagram of the OLT states.

2.2.1.1.1 Common part

This part deals with the acquisition of a new ONUs serial number, and the discovery of ONUs that return to service following a lost of window. The state diagram of this part is composed of 3 states and 9 events, which either trigger a state transition or initiate an action on the OLT.

The states are defined as:

1) *Serial number acquisition standby state (OLT-COM1)*
2) *Serial number acquisition state (OLT-COM2)*
3) *RTD measurement standby state (OLT-COM3)*

The events are defined as follows:

1) *'New' ONU search request from Ops system (EVT-COM1).*
2) *'Missing' ONUs (Loss-of-Window - LOW state) alarm (EVT-COM2).*
3) *Periodic Serial number acquisition cycle time-out (EVT-COM3).*
4) *Received valid Serial_Number window for 'new' ONU (EVT-COM4).*
5) *Received valid Serial_Number window for 'missing' ONU (EVT-COM5).*
6) *Received Unexpected Serial_Number window (EVT-COM6).*
7) *No valid Serial_Number window is received (EVT-COM7).*
8) *Serial number acquisition cycle limit is reached (EVT-COM8).*
9) *Delay measurement complete (EVT-COM9).*

2.2.1.1.2 Individual part

Upon the completion of the initial states of the Common-part and the discovery of a 'new' or 'missing' ONU (n), the RDT delay measurement of ONU (n) marks the start of the Individual-ONU-dealing-part(n). The state machine of this part consists of 4 states and 6 events, and they are responsible for the activation and the operation of the ONUs.

The states are defined as:

1) *Initial state (OLT-IDV1)*
2) *Delay measurement state (OLT-IDV2).*
3) *Operating state (OLT-IDV3).*
4) *POPUP state (OLT-IDV4).*

The events are defined as follows:

1) *RTD Delay measurement start order (n) (EVT-IDV1).*
2) *Delay measurement complete (n) (EVT-IDV2).*
3) *Delay measurement abnormal stop (n) (EVT-IDV3).*
4) *Detect of LOS, LOW(n) orLOF(n) (EVT-IDV4).*
5) *POPUP test success (n) (EVT-IDV5).*
6) *POPUP test fail (n) (EVT-IDV6).*

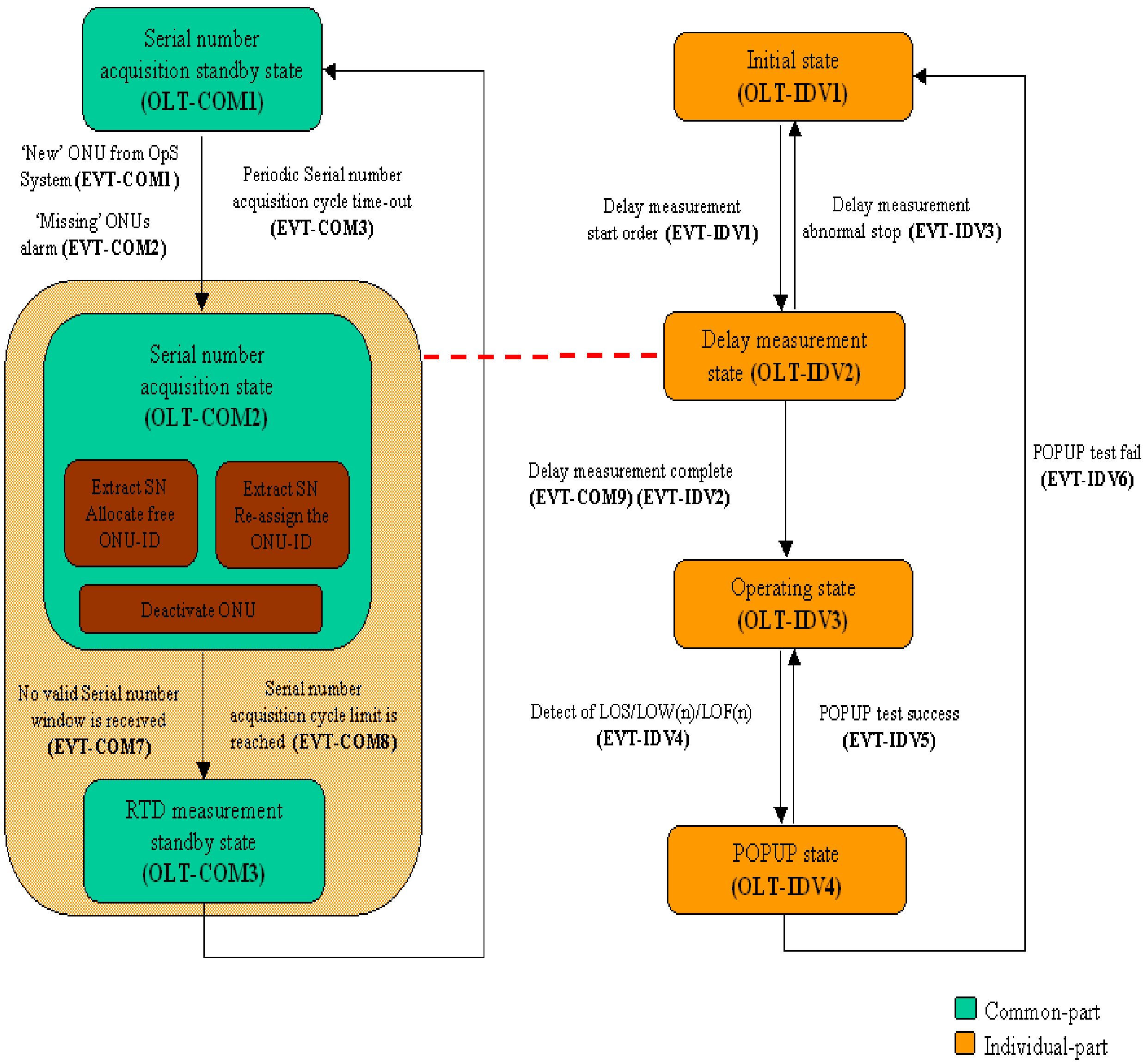

Figure 2: OLT State diagram

2.2.1.2 States of the ONU

The functional behaviour of the ONU is specified by 7 states (see Figure 3), while the actions and state transition are triggered by several events. These events are divided into message, request and alarms events.

The states are defined as:

1) *Initial state (O1).*
2) *Standby state (O2).*
3) *Serial Number state (O3).*
4) *Ranging state (O4).*
5) *Operation state (O5).*
6) *POPUP state (O6).*
7) *Emergency Stop state (O7).*

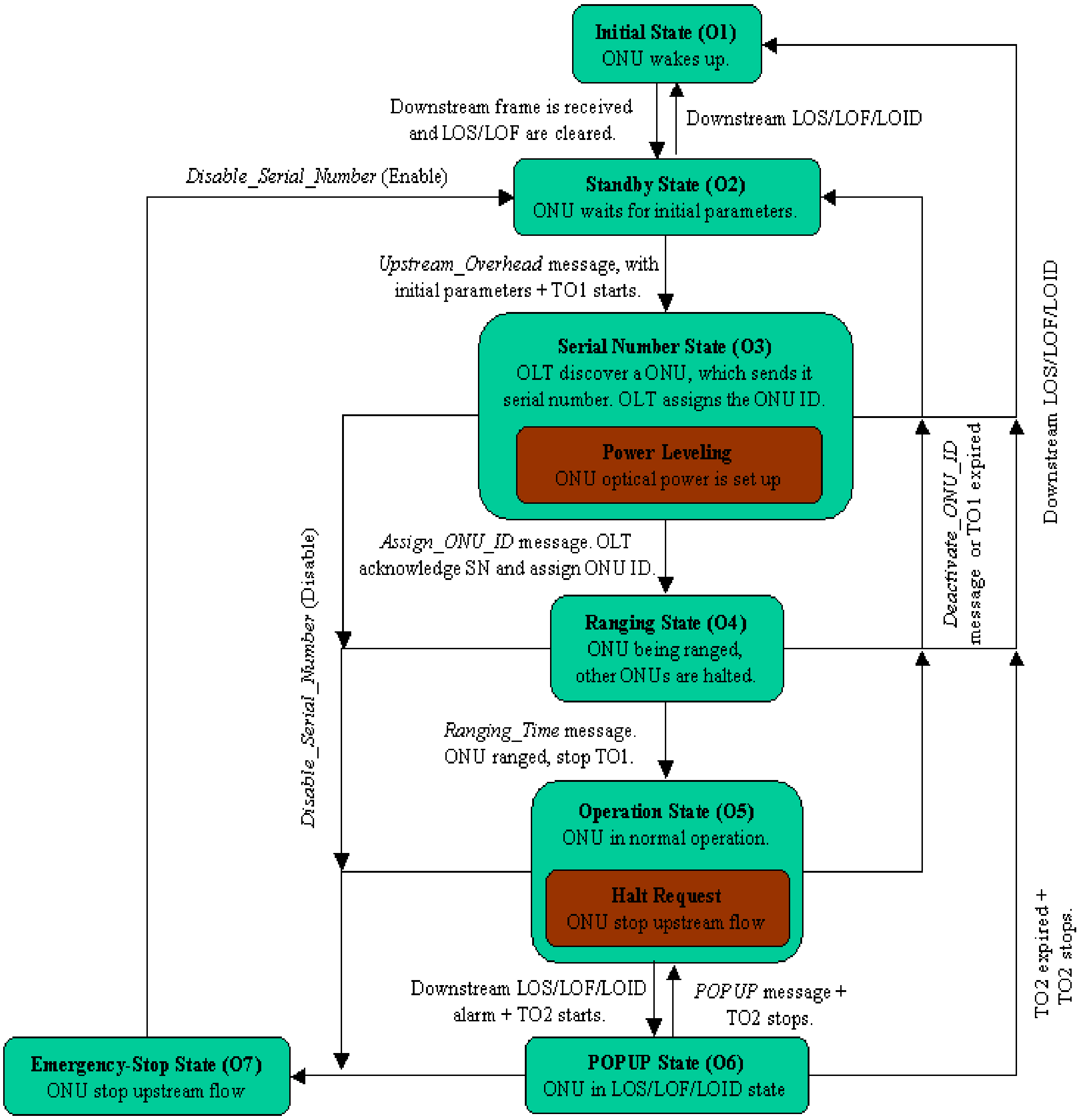

Figure 3: ONU State diagram

The message events will only generate a respective action if received at least 2 times. They are defined as follows:

1) *Upstream-Overhead message.*
2) *Change_Power_Level message with specific ONU's Serial Number.*
3) *'Increase' Change_Power_Level message with broadcast Serial Number.*
4) *Assign ONU_ID message.*
5) *Ranging_Time message.*
6) *POPUP message.*
7) *Deactivate_ONU_ID message.*
8) *Disable_Serial_Number message with Disable parameter.*
9) *Disable_Serial_Number message with Enable parameter.*

The request events are defined as follows:

1) *Serial_Number request.*
2) *Ranging request.*
3) *POPUP request.*
4) *Zero pointers (Halt) request.*
5) *Data request via valid pointers.*

The alarm events are defined as follows:

1) *Timer TO1 expire.*
2) *LOS or LOF detection.*
3) *LOID detection.*
4) *Clear of LOS and LOF.*
5) *Timer TO2 expire.*

2.2.2 Messages Definition

The GPON transmission convergence (GTC) messages convey the information amongst the Network Management station, the OLT and the ONUs. There are three mechanisms foreseen for the control and management planes in the GTC system, the embedded Operation Administration and Maintenance (OAM), the Physical Layer Operation Administration and Maintenance (PLOAM) messages and the ONU Management and Control Interface (OMCI) channel.

2.2.2.1 Embedded OAM messages

The embedded OAM channel offers a rapid and efficient way to carry urgent information along the PON network. It is conceived as field-formatted information embedded in the header of the GTC frame.

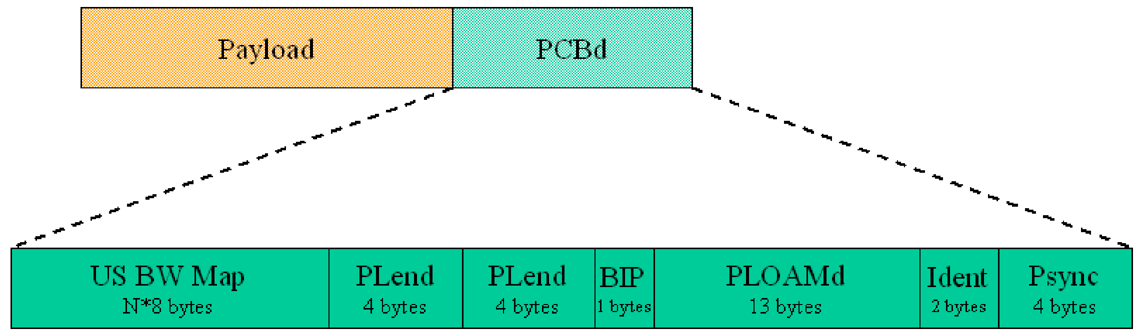

Figure 4: Downstream GTC header

The information carried by the embedded OAM is distinct between the downstream and upstream flow, reflecting respectively the messages sent by the OLT and by the ONUs. Figure 4 shows the downstream header format, where some of the embedded OAM fields can be clearly seen, such as the bandwidth granting. Likewise, Figure 5 depicts the upstream GTC header and shows the four possible header fields, which is used to transmit PMD and TC information from the ONUs to the OLT.

PLOu 15 bytes	PLSu	PLOAMu 13 bytes	PCBu 4 bytes	Payload

Figure 5: Upstream GTC header

2.2.2.2 PLOAM messages

The PLOAM channel is a message-formatted system carried in the header of the GTC frame. As can be seen from the figures above, there are two distinct set of PLOAM messages, a set of messages for the downstream and another for the upstream direction. The compositions of the PLOAM messages can be characterised by a generic structure, and by the specific data that each message convey.

2.2.2.2.1 Downstream messages

There are 18 downstream PLOAM messages defined by the G.PON.gtc standard [1]. Basically, the OLT uses these messages for the activation process and to trigger OAM alarms or performance monitoring alerts.

1) *Upstream_Overhead*
2) *Serial_number_mask.*
3) *Assign_ONU_ID.*
4) *Ranging_Time.*
5) *Deactivate_ONU_ID.*
6) *Disable_serial_ number.*
7) *Configure_VP/VC.*
8) *Encrypted_PortID/VPI.*
9) *Request_password.*
10) *Assign_AllocID.*
11) *No message.*
12) *POPUP.*
13) *Request Key.*
14) *Configure Port-ID.*
15) *Physical Equipment Error (PEE).*
16) *Change-Power-Level.*
17) *PST message.*
18) *BER interval.*

2.2.2.2.2 Upstream messages

Complementing the downstream PLOAM messages, the upstream PLOAM messages are composed by a set of 8 messages.

1) *Serial_number_ONU.*
2) *Password.*
3) *Dying_Gasp.*
4) *No message.*
5) *Encryption Key.*
6) *Physical Equipment Error (PEE).*
7) *PST message.*
8) *Remote Error Indication.*

2.2.3 Configuration Parameters

From the states and messages definition of the PTSP it is clear that a set of configuration parameters are determined by the standard or by the physical characteristics of the system. As the following section will show these parameters are fundamental for the proper operation and performance of the GPON system.

Some of the parameters defined by the PTSP:

- Timers
  - Ranging timeout
  - POPUP timeout
  - Round Trip Delay

  - Update encryption key
  - Polling period of the activation process
  - Minimum time between Halt cycles
- Counters
  - Number of frames of a Halt cycle
  - Number of encryption key update per exchange
  - Maximum number of Serial number acquisition cycle
  - Maximum number of invalid PSYNC on the OLT
  - Maximum number of invalid HEC for the ATM channel
  - Maximum number of invalid delimiter for the GEM channel

2.3 System Behaviour

The system behaviour of the PTSP protocol is at the core of the GPON network. In contrast with the last section, this section provides a dynamic view of the PTSP protocol, describing its initial configuration, installation, operation and maintenance procedures

2.3.1 Installation and Activation Method

There are different possible types, methods and triggers for the installation and activation of both the OLT and specially the ONU.

2.3.1.1 Type of activation process

There are three distinct procedures for the activation of an ONU, depending on the network status.

- **Cold PON, cold ONU:** No upstream traffic on the PON and the ONUs has not yet received ONU-IDs from the OLT.
- **Warm PON, cold ONU:** New or previously active ONU(s) added, while traffic is running on the PON.
- **Warm PON, warm ONU:** Previously active ONU which remains powered-on and connected to an active PON, but due to long alarm status, returned to Initial state (O1).

2.3.1.2 Installation method of ONUs

There are two possible methods to install an ONU:

- **Method-A:** The serial number of the ONU is registered at the OLT by the OpS system.
- **Method-B:** The serial number of the ONU is not registered at the OLT by the OpS system. It requires an automatic detection mechanism of the serial number of the ONU.

2.3.1.3 Triggers for ONU activation process

There are three triggers for initiating the activation of an ONU:

- **Trigger-1**: The network operator enables the activation process to start when it is known that a new ONU has been connected.
- **Trigger-2:** The OLT automatically initiates the activation process, when previously working ONUs are 'missing'. The frequency of this polling mechanism should be in high rate, in order that the ONU returns to service ASAP.
- **Trigger-3:** The OLT periodically initiates the activation process, testing to see if any new ONUs have been connected. The frequency of this polling mechanism should be in a relatively low rate.

2.3.2 Initial Ranging Procedure

The initial ranging procedure describes the mechanism in which the PTSP initiate the activation process of an ONU. It describes the details of the ranging mechanism, explaining how an ONU is identified and configured on the GPON system. This part of the protocol is composed the serial number acquisition, the power leveling procedure, the round trip delay measurement.

2.3.2.1 Serial number acquisition procedure

The serial number acquisition procedure refers to the initial process where the OLT discovery that a new ONU is on the PON system. A 'new' ONU can be discovery in a warm network or a cold network,. There will be no difference between the mechanism for the serial number acquisition on this two cases, expect for the halt procedure.

Serial number acquisition:

1. Depending on the installation method and trigger procedure the OLT initiate a serial number discovery.
2. In warm networks, the OLT should halt the working ONUs via zero pointers before issuing the Serial_Number request.
3. The OLT waits for a Ranging Delay, then it sends the Serial_Number request.
4. All ONUs in Serial Number state, upon receiving a Serial_Number request waits for a Random delay then transmit the Serial_Number_ONU message.
5. ONU generates a new Random Delay value for next Serial_Number request.
6. The OLT receives the Serial_Number_ONU message. In case it contains an ONU ID, the OLT check if the same ONU ID was assigned to the same OLT, if not the ONU ID is ignored.
7. For all ONUs where the same Serial Number was received twice, an Assign_ONU_ID message is transmitted.
8. The ONU ID is assigned. The ONU stops answering to Serial_Number requests and moves to Ranging state (O4).
9. The OLT goes through steps 2 to 8 until all missing ONUs answer to the Serial_Number request, or there is LOS in the upstream direction for 2 frames. This serial number acquisition process is stopped after 10 times, and will only restart by a new activation trigger.
10. The OLT continues on the delay measurement, while the new discovered ONUs are on the Ranging state (O4).

2.3.2.2 Power levelling procedure

Due to the ONUs distance from the OLT, their output power tolerances, and the general ODN losses, the OLT receiver must provide a high sensitivity and a large dynamic range for reception at high bit rates. In order to relax this dynamic range, a power leveling mechanism adjusts the ONUs optical power, so that at the OLT receiver the dynamic variation is as short as possible.

The ONU transciever should be able to operate in 3 output power modes:

- Mode 0: Normal
- Mode 1: Low 1 = Normal –3dB
- Mode 2: Low 2 = Normal –6dB

Power leveling procedure:

1. The default mode is broadcasted to the ONUs by the OLT as part of the Upstream_Overhead message.
2. During the serial number process, the OLT should measure the received optical power and compare it to the OLT Rx Thresholds. The OLT will transmit a Change_Power_Level message with ‘increase’ or ‘reduce’ option.
3. Due to the possibility that an ONU has a weak optical power, it is recommended that for every 4 Serial_Number request, the OLT transmit a broadcast Change_Power_Level message with ‘increase’ option to all ONUs that are in Standby state (O2) and Serial Number state (O3).

2.3.2.3 RTD measurement procedure

The variable distances between the OLT and the ONUs must be taken into account, different time delays are expected to happen between the moment the OLT requests a command and the time it receives the response from each ONUs. A mechanism to equalize these delays is necessary to avoid data collision and poor bandwidth utilization of the system

RTD measurement procedure:

1. The OLT should halt the working ONUs via zero pointers before issuing the Ranging request. For cases where the ONUs range is between 0-20 km, it is recommended to Halt the working ONUs for 2 consecutive frames.
2. OLT Halts the working ONUs, waits for Ranging-Delay and sends the Ranging request.

3. The Ranging request is sent by OLT.
4. The Ranging request is received by ONU.
5. ONU transmits upstream a Ranging-window.
6. OLT receives Ranging-window and calculates the ranging parameters.
7. The Ranging process is successful if the OLT transmits the ranging parameters to the ONU using the Ranging_Time message and the ONU receives it. Ranging parameters are updated and ONU moves to Operation state.
8. The Ranging process fails in case a Ranging Failure alarm is asserted by OLT, then the ONU is reset, using Deactivate_ONU_ID message.

2.3.3 Normal Operation Procedure

The normal operation procedure refers to the procedures that occur when the OLT is at Operating state (OLT-IVD3) and the ONU is also at Operating state (O5). These procedures are responsible for the correct functional maintenance of the system.

2.3.3.1 Power levelling procedure

While the ONU is in Operation state (O5), it will transmit data windows to the OLT. Every predefined time, the OLT receiver will measure the average received optical power of the ONU, and will compare it to the OLT Rx Thresholds. If required, the OLT will transmit a Change_Power_Level message with 'increase' or 'reduce' option.

2.3.3.2 RTD measurement procedure

Open point: A mechanism to monitor the Equalization Delay is still to be added on G.PON.gtc standard [1].

2.3.3.3 POPUP procedure

The POPUP mechanism is used to prevent traffic damage to working ONUs, while a specific ONU detect a LOS/LOF/LOID alarm. Upon receiving one of these downstream alarms the ONU will immediately stop upstream transmission and move to POPUP state (O6). The OLT, in detecting a LOS/LOW alarm will start a POPUP Test over the ONU. The objective of the POPUP test is to verify if the ONU is working with the correct Equalization-Delay and Window parameters. After the correction is made the ONU will be put back to Operation state.

POPUP mechanism at the ONU:

1. ONU detects LOS, LOF or LOID downstream alarm.
2. ONU moves to POPUP state (O6).
3. Timer TO2 is activated.
4. If the alarm state has terminated before the timer TO2 has expired.
    a. The ONU waits for a POPUP request from the OLT.
    b. Once the POPUP request is received, the ONU answers with a POPUP window that is transmitted following EqD + the ONU's start timeslot of the upstream window.
    c. If the POPUP window is received correctly at the OLT, the ONU will receive a PLOAM containing POPUP message. As a result, the ONU will return to Operation state (O5).
5. If timer TO2 has expired, the ONU will deactivate itself and move to Initial state (O1).

POPUP mechanism at the OLT:

1. OLT detects LOS or LOW upstream alarm, referent to a specific ONU.
2. An OLT TO2 timer is activated, and it presumes that the ONU has changed to POPUP state (O6).
3. The OLT sends a POPUP request to all ONUs that are presumed to be in the POPUP state (O6), and a single Halt grant to all other ONUs.
4. If the alarm state has terminated, the ONU will receive the POPUP request and will answer with a POPUP window.

5. The OLT receives the POPUP window
    a. If this window is received correctly, the ONU is moved to Operation state (O5), using a PLOAM containing POPUP message
    b. If the window is incorrect, the OLT will repeat the above process. If the POPUP window is received in the same wrong time slot again, the OLT will calculate the new corrected EqD and send it to the ONU.
    c. If the window is not received, the OLT assumes that the alarm status at the ONU has not terminated and repeats the process.
6. When timer TO2 at the ONU expires and it is still in POPUP state (O6), the ONU goes to Initial state (O1). The OLT timer TO2 also expires indicating to the OLT that the ONU is at the Initial state (O1). In addition, for safety measurements, the OLT will transmit a Deactivate_ONU_SN message to the ONU.

2.3.3.4 Further procedure

Other procedures foreseen for the GPON during operational states are related to the management operation and alarms to be handle by the system. Some of them are:

- Deactivate ONU: A PLOAM message is sent to deactivate a specific ONU.
- Disable ONUs: A list of ONUs is put out of service by the OLT.
- Dying gasp: The ONU goes complete out of service, precluding a power off.
- Physical equipment error: A physical failure is detected on the ONU.
- BER interval definition: Defines the interval per ONU, for counting the downstream bit errors.
- Encryption key exchange: Updated key used between the OLT and a specific ONU.

2.4 Alarms and Fault Handling

The alarms foreseen on the PTSP protocol are used to detect link failure, monitor the operational and performance of the system. There are 2 set of alarms, a set of 18 different alarms detectable by the OLT and a set of 15 alarms pertaining to the ONUs.

2.4.1 Alarms and Fault Handling on the OLT

1. *Loss of signal - LOS*: No valid optical signal at the O/E receiver received during 4 consecutive frames.
2. *Loss of Window for ONUi - LOWi*: The ONU window did not arrive at the expected place for 4 consecutive frames.
3. *Loss of Frame of ONUi – LOFi*: 4 consecutive invalid delimiters from ONUi are received.
4. *Drift of Window of ONUi – DOWi*: An ONU window is received at an unexpected place within the upstream virtual frame. DOWi means the phase has shifted but is correctable via modified EqD.
5. *Signal Fail of ONUi – SFi*: Upstream BER of ONUi becomes $\geq 10^{-y}$, where Y is in the range of 3 to 8.
6. *Signal Degraded of ONUi – SDi*: Upstream BER of ONUi becomes $\geq 10^{-x}$, where X is in the range of 4 to 9. But must be higher than Y (SF Threshold).
7. *Loss of ATM channel delineation – LCDAi*: 8 consecutive invalid delimiters or invalid HECs from ONUi are received.
8. *Loss of GEM channel delineation – LCDGi*: GEM Channel could not be delineated during 3 consecutive frames.
9. *Remote Defect Indication of ONUi – RDIi*: The RDI field of ONUi is asserted. The OLT transmission is received with defects at the ONUi.
10. *Transmitter Failure – TF*: The OLT transmitter has no nominal backfacet photocurrent or the drive currents are beyond the maximum specification.
11. *Start-up Failure of ONUi – SUFi*: The ONUi ranging has failed 2 times while the OLT has received optical bursts from this ONU.
12. *Deactivate Failure of ONUi – DFi*: The ONU does not react correctly after three DACT messages.

13. *Loss of Acknowledge with ONUi – LOAi*: The OLT does not receive an acknowledgement from ONUi after a set of downstream messages that imply an upstream acknowledge.
14. *Receive Dying-Gasp of ONUi – DGi*: The OLT receives DG message from ONUi, DGi is asserted.
15. *Loss of PLOAM for ONUi – LOAMi*: 3 consecutive PLOAM messages of ONUi are missing.
16. *Message_Error Message from ONUi – MEMi*: The OLT detects that the received PSTi and the transmitted PST are different.
17. *Link Mismatch of ONUi – MISi*: The OLT detects that the received PSTi and the transmitted PST are different.
18. *Physical Equipment Error of ONUi – PEEi*: The OLT receives a PEE from the ONU.

2.4.2 Alarms and Fault Handling on the ONT

1. *Loss Of Signal – LOS*: No valid optical signal is received for 3 consecutive frames or no electrical transitions are received during 3 consecutive frames.
2. *Loss of Frame – LOF*: 4 consecutive invalid PSYNC from OLT are received.
3. *Signal Failed – SF*: Downstream BER becomes $\geq 10^{-y}$, where Y is in the range of 3 to 8.
4. *Signal Degraded – SD*: Downstream BER becomes $\geq 10^{-x}$, where X is in the range of 4 to 9. But must be higher than Y.
5. *Loss of ATM channel delineation – LCDA*: 7 consecutive invalid delimiters or invalid HECs from OLT are received.
6. *Loss of GEM channel delineation – LCDG*: GEM Channel could not be delineated during 3 consecutive frames.
7. *Loss of ONU-ID – LoID*: The ONU does not receive its first AllocID for 3 consecutive frames.
8. *Remote Defect Indication – RDI*: The RDI field of ONUi is asserted. The ONU transmission is received with defects at the OLT.
9. *Transmitter Failure – TF*: The ONU transmitter has no nominal backfacet photocurrent or the drive currents go beyond the maximum specification.
10. *Start-up Failure – SUF*: The ranging of this ONU has failed.
11. *Message Error Message – MEM*: The ONU receives an unknown message.
12. *Deactivate ONU_ID – DACT*: The ONU receives Deactivate_ONU_ID Message. It instructs the ONU to deactivate itself.
13. *Disabled ONU – DIS*: The ONU receives a Disable_serial_number message with it's own serial number and the enable flag=0xFF.
14. *Link Mismatching – MIS*: The ONU detects that the received PST and transmitted PST are different.
15. *Physical Equipment Error – PEE*: The ONU receives a PEE Message.

2.5 Management Interface

For the correct operation, administration and maintenance of the GPON system a management interface, which controls the ONU and the OLT functions, can be divided into:

1. Configuration Information: Responsible for management of configuration parameters of the system, such as initial installation and activation method, number of ONUs, AllocID and bandwidth allocation.
2. Fault Management: Process the responses due to the alarms and reports to the management system depending on the gravity of the alarms.
3. Performance Management : Responsible for the performance monitoring and reporting the status of the connections.

3 TC COMPONENT

This chapter presents the physical component implementing the GPON TC layer for both LT and NT use. In the following sections, you can find first a description of the transport framing for GPON system, then a functional description of the LT GTC and the NT GTC components.

3.1 GTC frame structure

This section summarizes the TC frame structure. Upstream and downstream frames contain a Physical Control Block (PCBu or PCBd) and a payload. The downstream frame provides the common time reference for the PON and the common control signaling for the upstream.

The media access control concept is shown in Figure 6. The OLT sends pointers in the PCBd to indicate the time at which ONT may begin transmissions. Although the GTC frame is defined to support both ATM and GEM sections, the functionality of our TC components are restricted to Ethernet (and TDM) over GEM only. A detailed description of GTC frame can be found in [1].

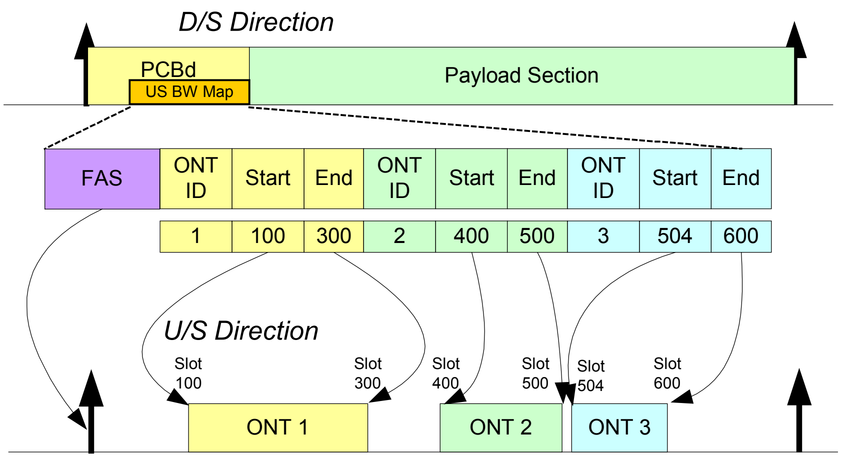

Figure 6: Media access control concept

3.1.1 Downstream frame

The TC downstream is divided into fixed size GTC frames of length 125 us. Each frame is made up of a header, PCBd, and a payload composed of pure ATM segment and GEM segment.

The downstream frame header, PCBd (Physical Control Block in downstream), contains:

- 4 bytes for frame synchronization, Psync. This is a fixed 32-bit pattern, which value is 0xF628F628.
- 2 bytes Ident containing 8 KHz counter, a DS FEC status bit, an encryption key switch-over bit. 8 MSB are reserved for further use.
- 13 bytes PLOAM message, PLOAMd, such as OAM related alarms or threshold-crossing alerts.
- 1 byte Bit Interleaved Parity, BIP, used to perform bit error rate estimation.
- 4 bytes Payload Length indicator, Plend, which gives the length of US BW Map (N) and the size of ATM segment. Plend is sent twice for extra redundancy and error robustness.
- Nx8 bytes US BW Map determines N Access structures that are granted to an upstream transmission window.

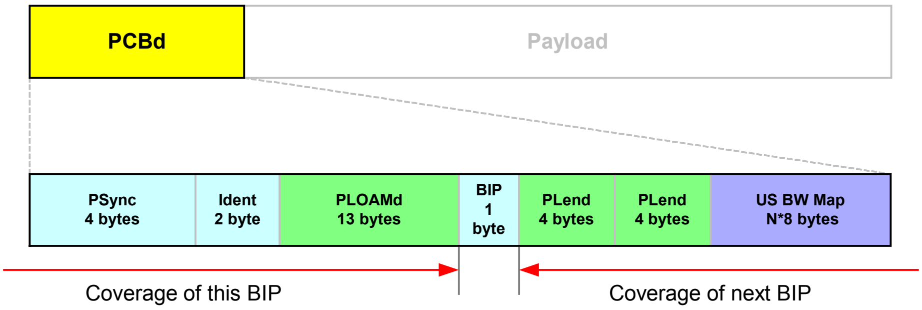

Figure 7: Physical Block Control Downstream, PCBd

The US BW Map is shown in Figure 8. It contains N entries associated to N Allocation IDs. Each entry or access structure consists of:

- 12 bits AllocID that is assigned to an ONT.
- 4 Flag bits allowing the upstream transmission of PHY overheads: PCBu, PLOAMu, FEC parity and PLSu.
- 2 bytes Start pointer, SStart, indicating the starting time for the upstream transmission window. This time is measured in bytes, starting with zero at the beginning of the upstream GTC frame.
- 2 bytes Stop pointer, SStop, indicating the stopping time for the upstream transmission window.
- 1 byte reserved field.
- 1 byte CRC providing 2-bit error detection and 1 bit error correction on the bandwidth allocation structure.

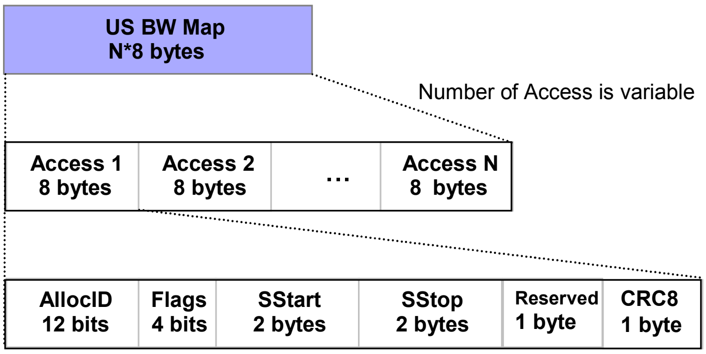

Figure 8: US BW Map

3.1.2 Upstream frame

The upstream frame, as depicted in Figure 9, contains a burst of transmissions from one or more ONTs. During each allocation period, the ONT can transmit up to four types of PON overheads and user data, based on the Flags field in the Us BW Map of the PCBd. The four types of overheads are the Physical Layer Overhead (PLOu), the Physical Layer Operation Administration and Maintenance upstream (PLOAMu), the Power Levelling Sequence upstream (PLSu), and the Physical Control Block upstream (PCBu).

The PLOu contains information that is tied to the ONT:

- 12 bytes Guard + Preamble and Delimiter for amplitude and phase recovery and frame synchronization.
- 1 byte Bit Interleaved Parity, BIP, used to perform bit error rate estimation. \
- 1 byte Indication, Ind:
    - PLOAMu status bit (MSB), indicating availability of PLOAMu at ONT side.
    - FEC status bit, indicating use of FEC coding by ONT. (Not used, set to 0).
    - Bit positions 0 to 5 are default all zeros.
- 1 byte CRC, providing 2-bit error detection and 1 bit error correction on PLOu.

The PLOAMu is 13 bytes length and contains the PLOAM message as defined in G.983.1. It is also protected by a CRC.

The PCBu is 4 bytes length and is used for DBA reporting per AllocID. In particular the PCBu provides the information on the traffic status of the AllocID in question. The PCBu is also protected by a CRC.

The PLSu is used for power control measurement by the ONT. This function assists the adjustment of ONT power levels to reduce optical dynamic range as seen by the OLT.

Transmission of PLOAMu, PCBu and PLSu are optional, depending on the downstream Flags in US BW Map.

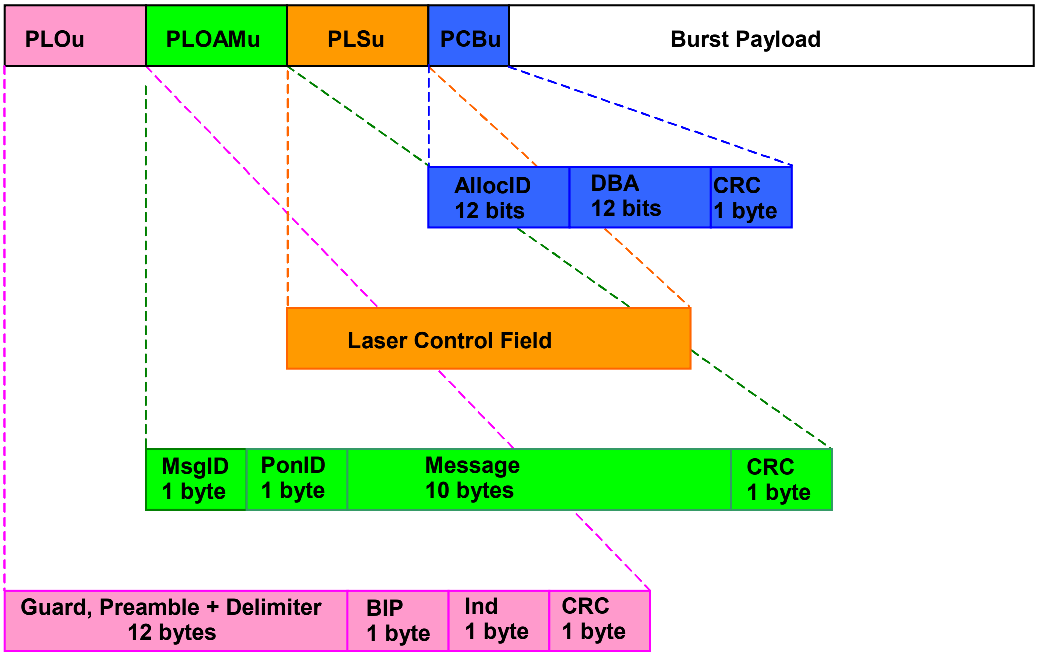

Figure 9: Upstream GTC Frame

3.2 TC component for Line Termination

This section describes the functional specification of the LT GTC component operating at 1.24416 Gbps. The purpose of the LT GTC is to provide all functionalities of the Physical and TC layer in order to process transmission and reception of GTC frames on the LT side. The LT GTC is target to process variable length packets (no ATM cell), which may support Ethernet or TDM services.

A block diagram of the LT GTC is shown in Figure 10. Basically, it may be divided into 3 main functional blocks:

- The GEM Unit, which encapsulates Ethernet and TDM packets into GEM packets in the downstream direction and extracts Ethernet and TDM packets from GEM packets in the upstream direction.
- The TC Unit, which process the GTC frames. In downstream, GTC frame is built up with GEM packets. In upstream, GEM packets are extracted from GTC frame.
- The PHY Unit, which performs the data format conversion to interface with the analog front-end.

On the top of that, the Control Unit is responsible for the configuration and the control of all functional Units.

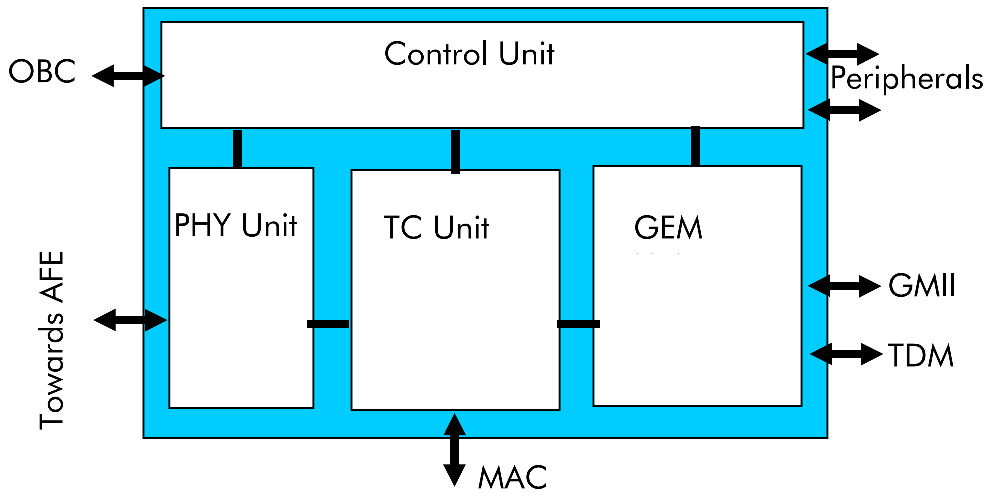

Figure 10: LT GTC Block diagram

3.2.1 LT GEM Unit

3.2.1.1 GEM frame format

The GEM frame consists of 5 bytes GEM Header followed by a GEM Payload area of variable length.

The GEM Header is made up of :

- a Payload Length Indicator (16 bits) used for delineation
- a Port-Id (12 bits)
- 2 bits for further study field
- FRAG (2 bits) used for fragmentation. 00=complete frame; 10=1st fragment of frame; 01= last fragment of frame; 11= intermediate frame fragment.
- 1 byte HEC (CRC-8)

The GEM payload may contain Ethernet frame or TDM frame.

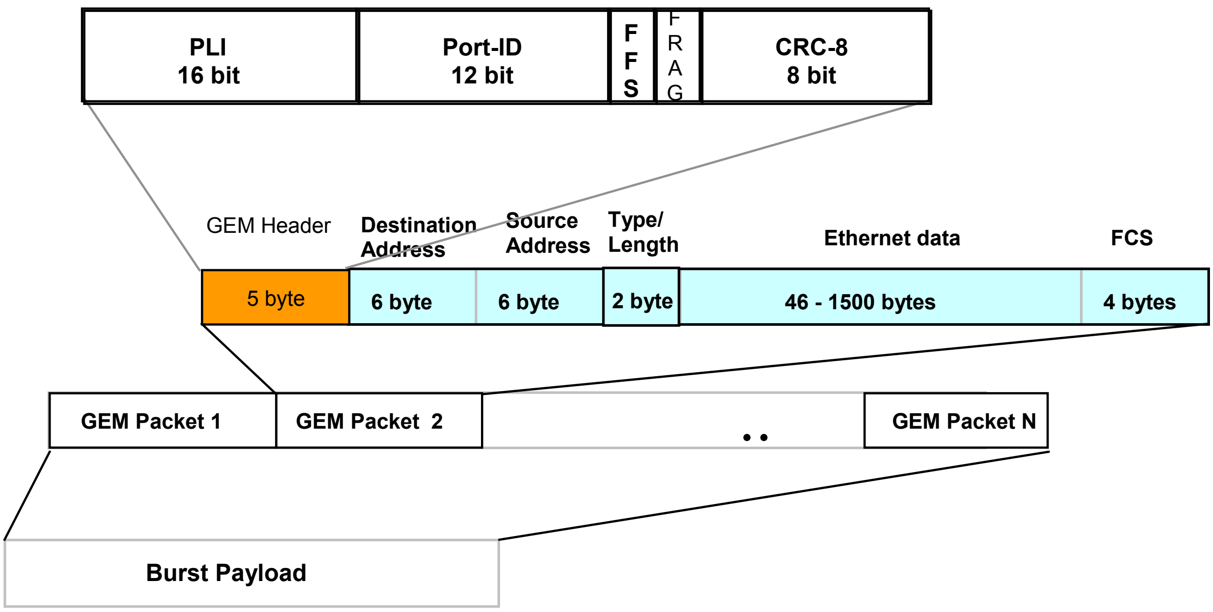

Figure 11: GEM Frame

3.2.1.2 Downstream

In the downstream direction, in one hand, Ethernet packets are received from two MII/GMII interfaces and are encapsulated into GEM payload. In the other hand, TDM packets are received from one TDM interface and are encapsulated into GEM payload.

A multiplexer allows GEM payload multiplexing based on configurable priorities. Possible paths by order of priority are:

- TDM traffic from TDM port
- Ethernet traffic from MII/GMII ports
- OMCI client path from OBC or ARM
- Loopback traffic from the upstream path.

3.2.1.3 Upstream

In upstream direction, data stream comes from the LT TC Unit. A GEM frame delineation is performed based on the HEC check on the GEM header. More precisely, a modified version of the HEC check algorithm specified in ITU-T I.432, clause 4.5.1.1 (ATM HEC) is used to provide GEM frame delineation. This modified algorithm uses the PDU Length Indicator (PLI) in the GEM header to find the end of the GEM frame. The state diagram for the GEM frame delineation is shown in Figure 12.

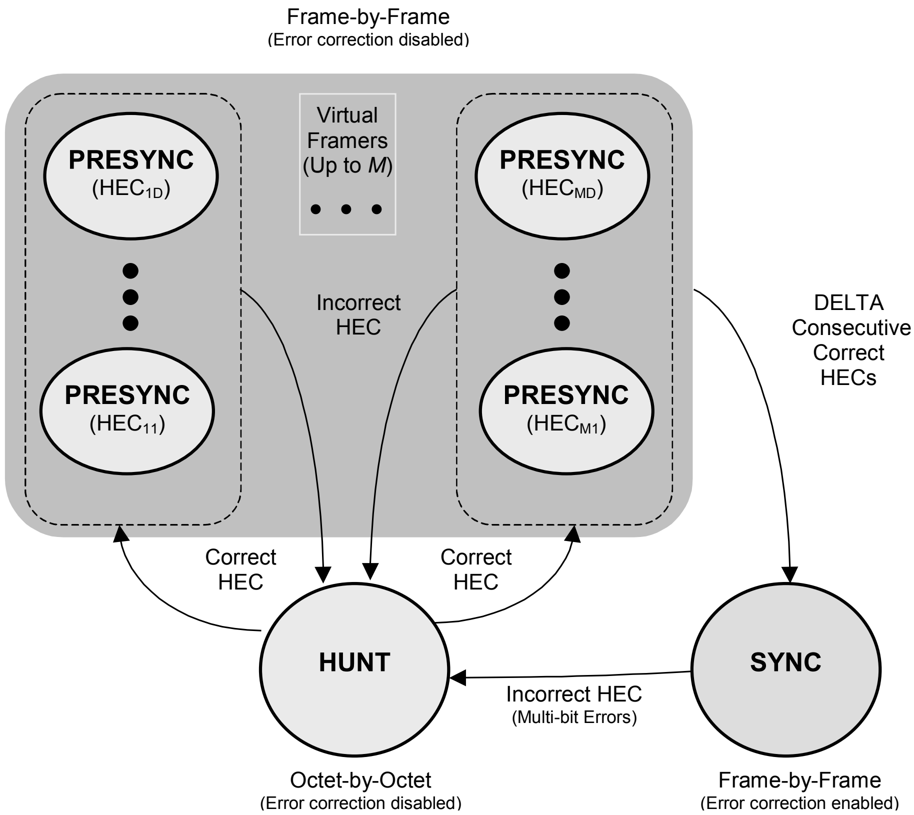

Figure 12: GEM frame delineation state diagram

After frame delineation, GEM frames are re-assembled based on the US BW MAP information coming from the LT TC Unit downstream. Then, GEM frames are demultiplexed based on the PDU type.

- GEM client management frame is forwarded to the embedded ARM in the Control Unit.
- GEM frame with PortID assigned to a traffic flow supported by the OLT is forwarded to the Ethernet or TDM access.
- GEM testing frame is loopback in downstream direction.
- Frame with corrupted header is discarded.

The De-capsulation operation is performed before sending out Ethernet or TDM packets towards respectively the GMII access or the TDM access. The GMII access may be configurable as MII access.

3.2.2 LT TC Unit

3.2.2.1 Downstream

In downstream direction, this unit is responsible for the assembly of GTC frames every 125 µs. The downstream GTC frame is composed of a header, PCBd and a data payload.

The PCBd structure is given in Figure 7. It contains the following fields:

- Psync: Physical synchronization field, 4 bytes.
- Ident: Ident field, 2 bytes.
- PLOAMd: downstream Ploam field, 13 bytes.
- BIP: Bit Interleaved Parity, 1 byte.
- PLend: downstream Payload Length field, 4 bytes.
- US BW Map: Upstream Bandwidth Map field, Nx8 bytes. N being the number of Access structures that are granted a window in a given upstream GTC frame.

The data payload contains concatenated GEM packets received from the LT GEM Unit. The data payload may be encrypted for security matter (see LT GEM Unit).

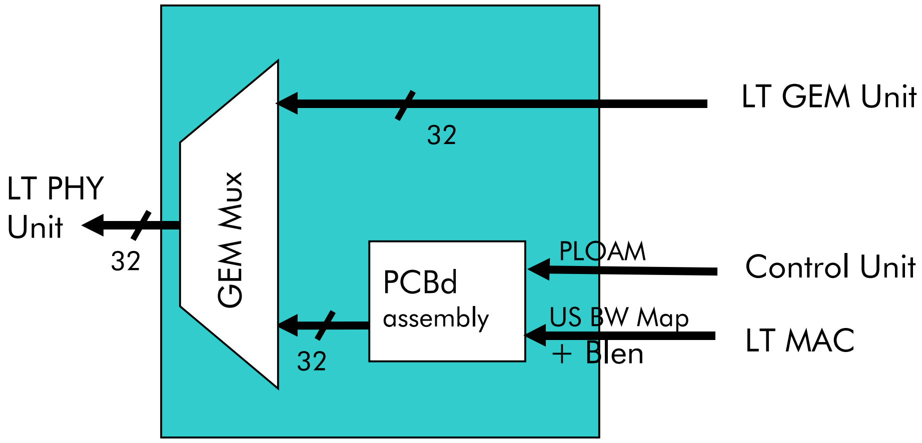

Figure 13: LT TC downstream

3.2.2.2 Upstream

The upstream GTC frame received from the LT PHY Unit includes a data payload and up to four types of overheads (PLOu, PLOAMu, PLSu and PCBu), as shown in Figure 9.
Each component of the upstream GTC frame is de-assembled for further processing.

1. PLOu disassembly:
   - The Ind byte processing.
   - The CRC byte processing.

2. PLOAMu disassembly:
   - The MsgID indicates the type of message.
   - The PonID identifies the sourcing ONU.
   - The Message is transmitted to the Control Unit. It uses the same format as the one defined in G.983.2.
   - The PLOAMu is protected by a CRC8.

3. PLSu disassembly:
   - The PLSu field is used for power control measurements by the ONU.

4. PCBu disassembly:
   - The AllocID identifies the sourcing ONU
   - The DBA field contains the traffic status of the AllocID in questions.
   - The PCBu is protected by a CRC8.

5. GEM disassembly:
   - Upstream data payload may contain multiple GEM packets belonging to the same AllocID. GEM packets are extracted and forwarded to the LT GEM unit upstream.

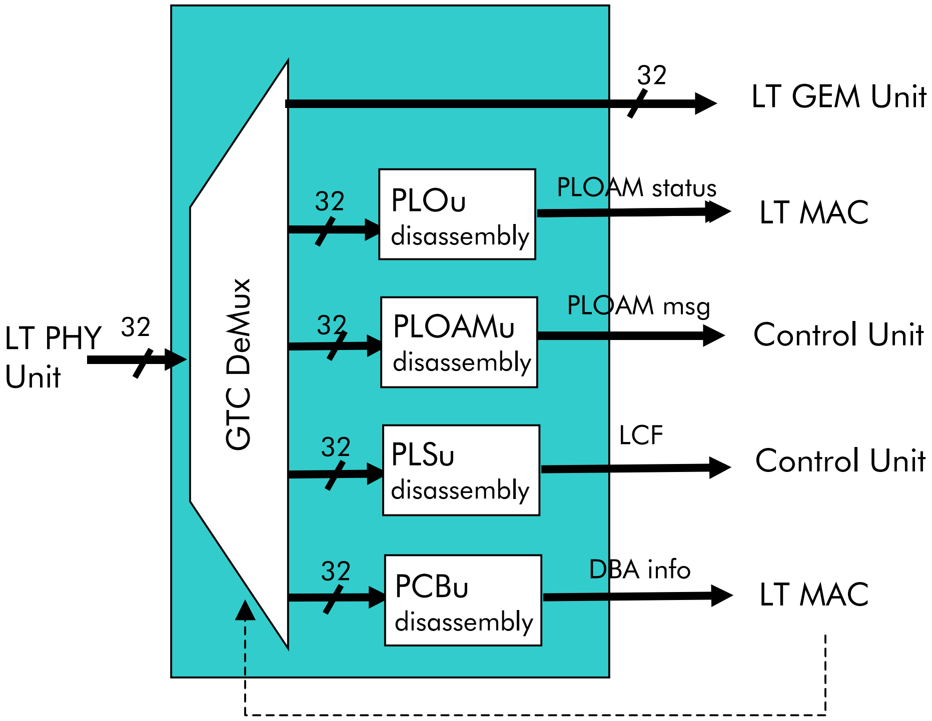

Figure 14: LT TC upstream

3.2.3 LT PHY Unit

3.2.3.1 Downstream

In downstream direction, every 125 µs a GTC frame is received from the LT TC Unit. Some processing is done to the frame before sending out the date towards the analog front-end. Theses processing by order in time are as follow:

- Calculation of the BIP and insertion in the corresponding field in the PCBd.
- FEC encoding. The FEC allows errors detection and correction in the data payload.
- Insertion of controlled bit errors upon software request for testing purposes.
- The downstream frame is scrambled using a frame-synchronous scrambling polynomial. The Psync is not scrambled, allowing fast frame synchronization at the NT side.
- Data conversion from 32-bit parallel into 8-bit parallel.

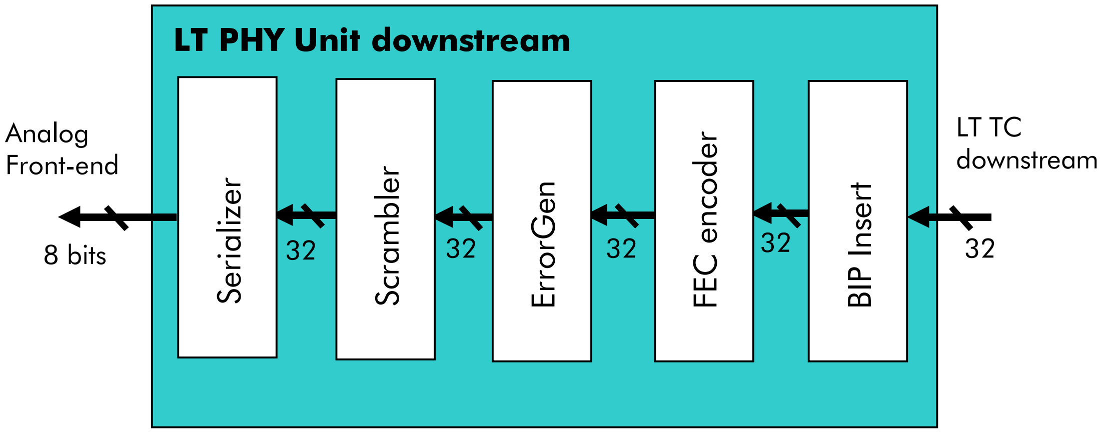

Figure 15: LT PHY downstream

3.2.3.2 Upstream

In the upstream direction, the incoming frames from the analog front-end contain a burst of transmissions from multiple ONTs (please refer to Figure 9). The following operations are done before data is transferred to the LT TC Unit.

- Deserialization from 8-bit data bus to 32-bit data bus.
- Data descrambling. The upstream payload is descrambled on a burst basis, per ONU (with possible multiple ALLOC-IDs per ONU), by mean of a modulo-2 addition of the transmitted data stream with a Pseudo Random Bit Sequence (PRBS).
- FEC decoding. The FEC allows errors detection and correction in the data payload.
- A Bit Interleaved Parity byte is used to estimate the BER per ONT. Note that the BIP is calculated on the unscrambled data.

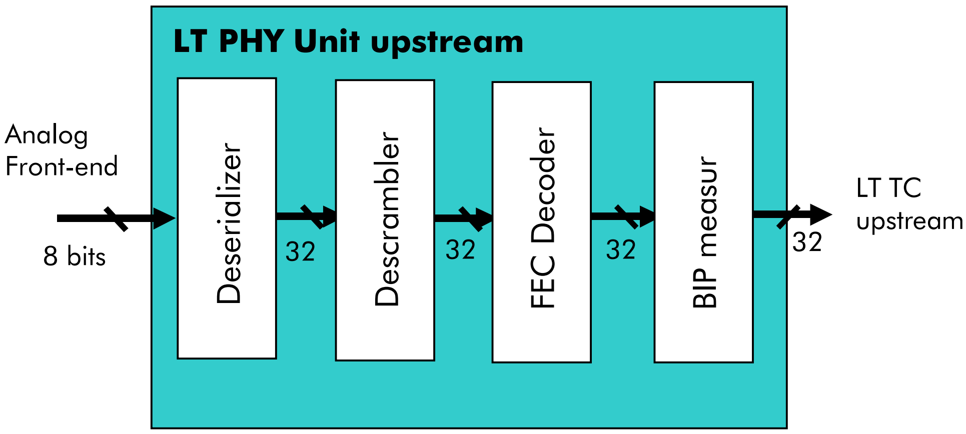

Figure 16: LT PHY upstream

3.2.4 The Control Unit

On the top of the processing Units mentioned above, the Control Unit allows a proper functioning of the system. The Control Unit contains an embedded processor, but also an interface for external OBC. The embedded processor is involved in the PTSP software processing, whereas the OBC deals with management issues (OMCI).

The OBC interface is a simple peripheral bus with the usual control signals to communicate with the Motorola MPC860. While, the internal processor is an ARM946ES connected to various peripherals as shown in Figure 17.

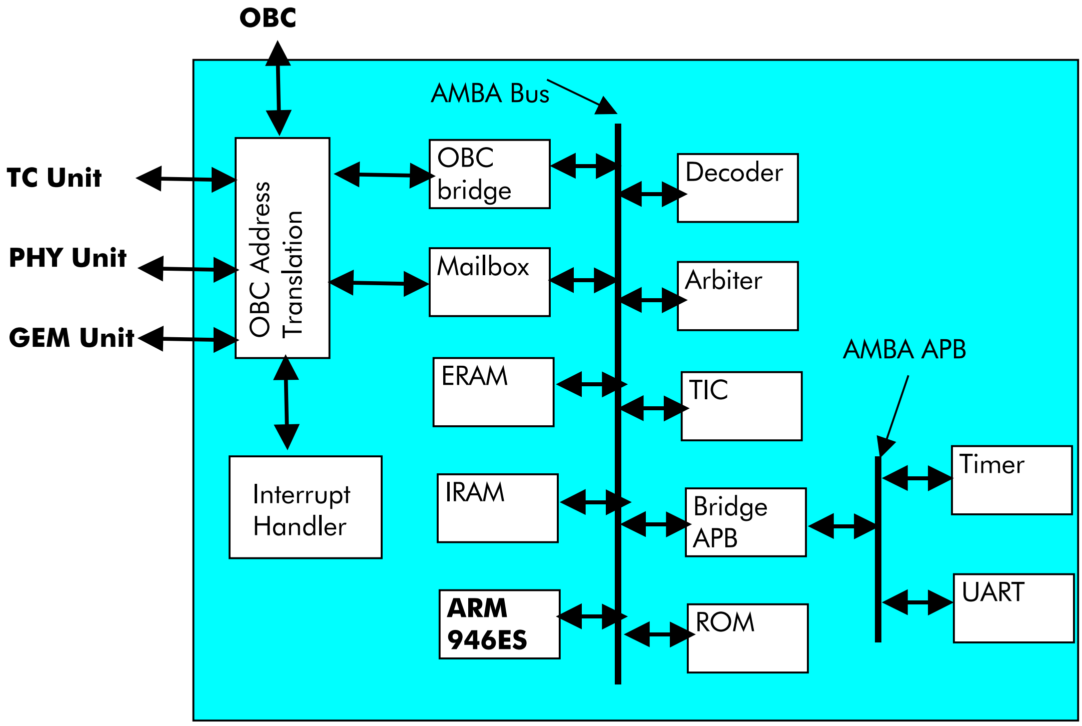

Figure 17: Control Unit

3.3 TC component for Network Termination

This section describes the functional specification of the NT GTC component operating at 1.24416 Gbps. The purpose of the NT GTC is to provide all functionalities of the Physical and TC layer in order to process transmission and reception of GTC frames on the Network Termination side. The NT GTC is target to process variable length packets (no ATM cell), which may support Ethernet or TDM services.

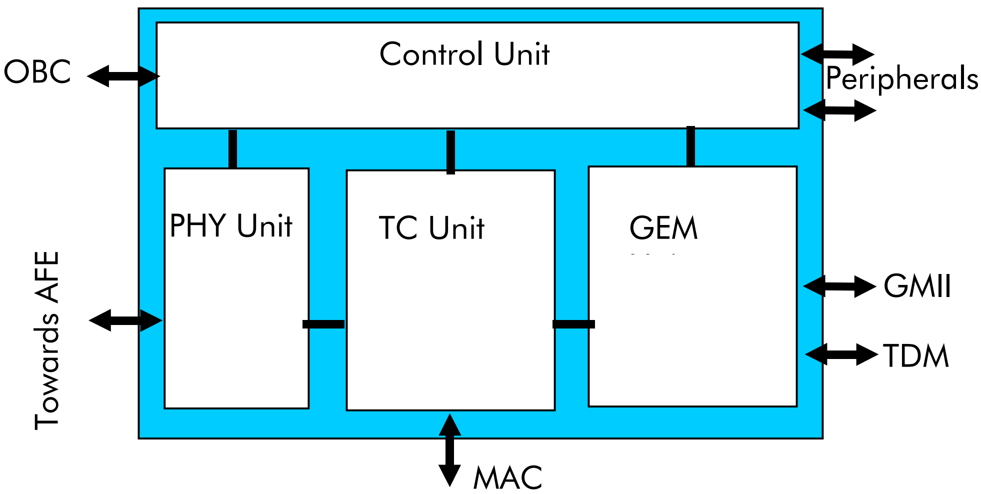

Figure 18: NT GTC Block diagram

A block diagram of the NT GTC is shown in Figure 18. Basically, it may be divided into 3 main functional blocks:

- The GEM Unit, which encapsulates Ethernet and TDM packets into GEM packets in the upstream direction and extracts Ethernet and TDM packets from GEM packets in the downstream direction.
- The TC Unit, which process the GTC frames. In upstream, GTC frame is built up with GEM packets. In downstream, GEM packets are extracted from GTC frame.
- The PHY Unit, which performs the data format conversion to interface with the analog front-end.

On the top of that, the Control Unit is responsible for the configuration and the control of all functional Units.

3.3.1 NT GEM Unit

3.3.1.1 Downstream

In downstream direction, data stream comes from the LT TC Unit. A GEM frame delineation is performed based on the HEC check on the GEM header. The state diagram for the GEM frame delineation is shown in Figure 12.

GEM frames are re-assembled based on the PLI information coming from the LT TC Unit downstream. Then, GEM frames are demultiplexed based on the PDU type.

- GEM client management frame is forwarded to the embedded ARM in the Control Unit.
- GEM frame with PortID assigned to a traffic flow supported by the OLT is forwarded to the Ethernet or TDM access.
- GEM testing frame is loopback in downstream direction.
- Frame with corrupted header is discarded.
- Frames with PortID not assigned to the ONU are filtered.

The De-capsulation operation is performed before sending out Ethernet or TDM packets towards respectively the GMII access or the TDM access.

3.3.1.2 Upstream

In the upstream direction, in one hand, Ethernet packets are received from two MII interfaces and are encapsulated into GEM payload. In the other hand, TDM packets are received from one TDM interface and are encapsulated into GEM payload.

A multiplexer allows GEM payload multiplexing based on configurable priorities. Possible paths by order of priority are:

- TDM traffic from TDM port
- Ethernet traffic from MII/GMII ports
- OMCI client path from OBC or ARM
- Loopback traffic from the upstream path.

A simplified gateway function is required if multiple traffic connections coexist on the same ONU, with each one being granted upstream access by a separate AllocID.

3.3.2 NT TC Unit

3.3.2.1 Downstream

In downstream direction, this unit is responsible for the disassembly of GTC frames, which are received every 125 µs. The downstream GTC frame is composed of a header, PCBd and a data payload.

The PCBd structure is given in Figure 7. The following information are retrieved for further processing:

- Psync: Physical synchronization field, 4 bytes.
- Ident: Ident field, 2 bytes.
- PLOAMd: downstream Ploam field, 13 bytes.
- BIP: Bit Interleaved Parity, 1 byte.
- PLend: downstream Payload Length field, 4 bytes.
- US BW Map: Upstream Bandwidth Map field, Nx8 bytes. N being the number of Access structures that are granted a window in a given upstream GTC frame.

The data payload containing concatenated GEM packets is transmitted to the NT GEM Unit.

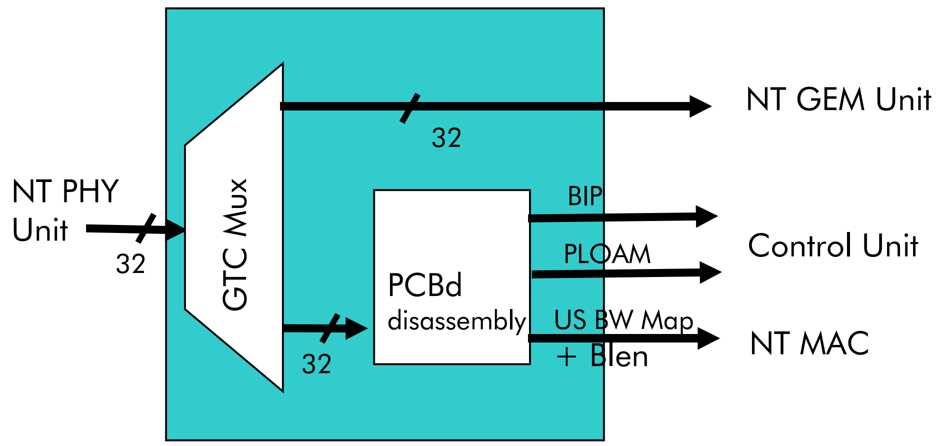

Figure 19: NT TC downstream

3.3.2.2 Upstream

In the upstream path, up to four types of overheads (PLOu, PLOAMu, PLSu and PCBu) are appended to the data payload to form the GTC frame. The GTC frame is shown in Figure 9.

1. PLOu assembly:
   - The Ind byte processing.
   - The CRC byte processing.

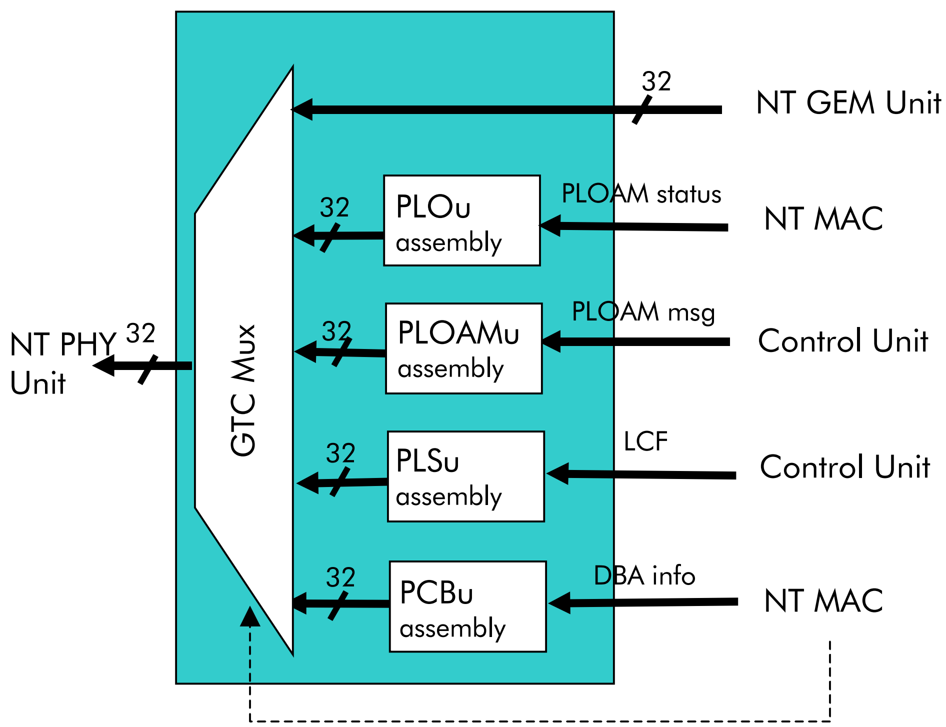

Figure 20: NT TC upstream

2. PLOAMu assembly:
   - The Controller Unit generates PLOAMu.
   - The MsgID indicates the type of message.

- The PonID identifies the sourcing ONU.
- The PLOAM uses the same format as the one defined in G.983.2.
- The PLOAMu is protected by a CRC8.

3. PLSu assembly:
   - The PLSu field is used for power control measurements by the ONU. Optional.

4. PCBu assembly:
   - The AllocID identifies the sourcing ONU.
   - The DBA field contains the traffic status of the AllocID in questions.
   - The PCBu is protected by a CRC8.

5. GEM assembly:
   - Upstream data payload may contain multiple GEM packets belonging to the same AllocID. GEM packets come from the NT GEM Unit upstream.

3.3.3 NT PHY Unit

3.3.3.1 Downstream

In downstream direction, a GTC frame is received from the analog front-end every 125 µs. The following processing are done by order in time:

- Data conversion from 8-bit parallel into 32-bit parallel.
- PCBds are received every 125 µs. This will be used to do GTC frame delineation. Searching the sequence of 4 bytes Psync performs the downstream frame synchronization. The synchronization FSM has three states and is described below. In the HUNT state a valid Psync is searched. The preSYNC state will be reached when one valid Psync has been found. The SYNC state is reached when delta consecutive correct PCBd's are found. As long as frame synchronization (SYNC state) is not achieved, all downstream packets are discarded.

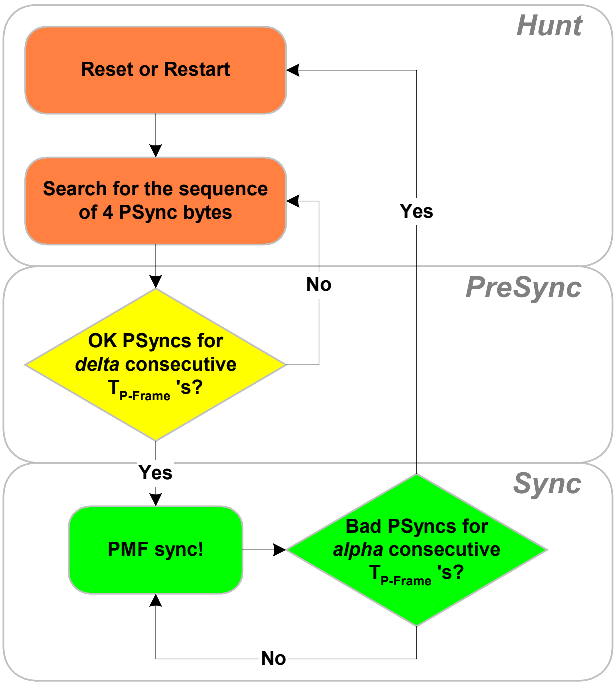

Figure 21: FSM for GTC frame delineation

- Frame Descrambling starts when the Frame synchronization SYNC state is achieved. The Psync is not scrambled, allowing fast frame synchronization at the NT side. The descrambling operation can be enabled/disabled by the Control Unit.
- FEC Decoding. The FEC allows errors detection and correction in the data payload.

- Calculation of the BIP and checking with in the corresponding field in the PCBd. The result is used to perform BER estimation on the downstream link.

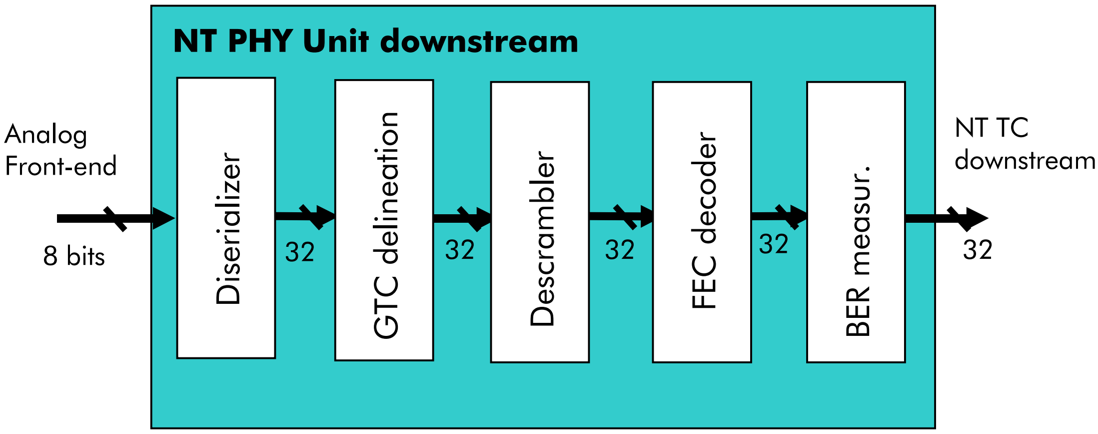

Figure 22: NT PHY downstream

3.3.3.2 Upstream

In the upstream direction, the GTC frames coming from the NT TC Unit upstream are processed and sent out towards the analog front-end. The following operations are done before data is sent out:

- Calculation of the BIP and insertion in the corresponding field in the PLOu.
- FEC encoding. The FEC allows errors detection and correction in the data payload.
- Insertion of controlled bit errors upon software request for testing purposes. The error insertion is done on a GEM packet basis. Packets with their Port-ID in pre-defined range are altered.
- The upstream payload is scrambled by mean of a modulo-2 addition of the transmitted data stream with a Pseudo Random Bit Sequence (PRBS).
- Data conversion from 32-bit parallel into 8-bit parallel.

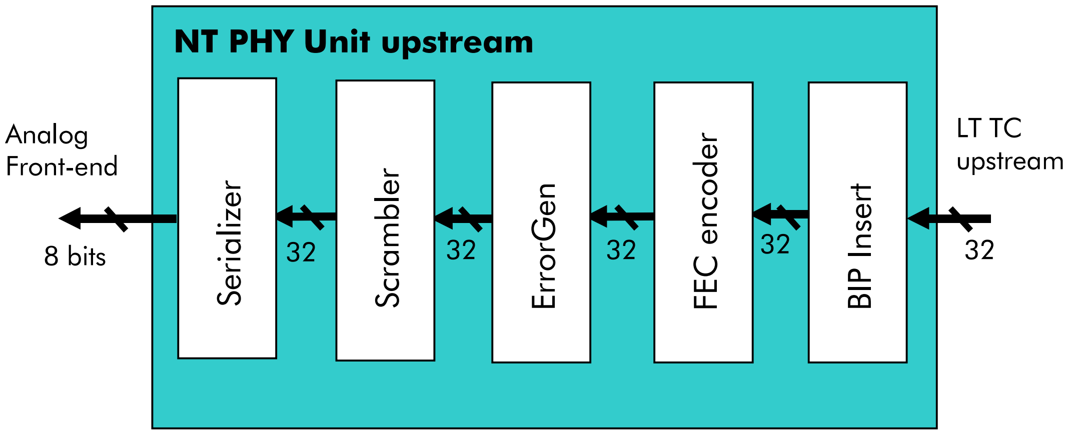

Figure 23: NT PHY upstream

3.3.4 The Control Unit

Please refer to section 3.2.4.

4 MAC COMPONENT

The access in the upstream is arbitrated by the MAC protocol, which dictates in the GPON that the upstream bandwidth is allocated on the basis of parameters negotiated for each AllocID during the activation phase and on the queue status that is dynamically changing. The bandwidth allocation is decided by the MAC controller residing at the OLT and announced in the BW map field of each frame traveling downstream. The MAC entity at the ONU side has to process this field in order to identify the time that it is allowed to transmit as well as the duration of the granted transmission. It also has to prepare the queue status reports.
Having identified the split of MAC functionality between the OLT and ONU MAC components, we present in the sequence the top-level specifications of each MAC module.

4.1 The MAC controller at the OLT

The MAC controller at the OLT is responsible for the construction of the BW map. It will be implemented in a Virtex II Xilinx FPGA that will be placed at the OLT board designed and implemented by ABELL (part of which is depicted in Figure 24). It will interface the GXTP module that executes TC- layer functions and the On Board Controller.

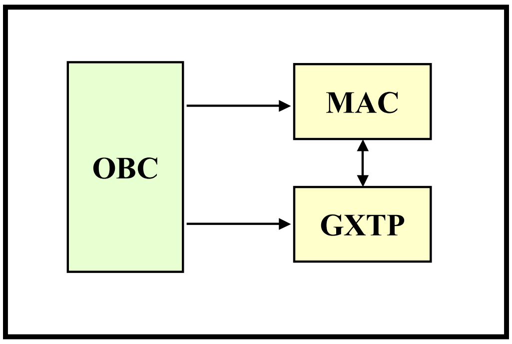

Figure 24: OLT board (for TC-layer processing) overview

The interface between the MAC FPGA and the GXTP as well as the interface between the MAC FPGA and the OBC will be described in the following sections while the description of the internal organization of the MAC FPGA will follow in 4.1.3.

4.1.1 MAC - GXTP interface

The MAC FPGA provides the GXTP FPGA with the BW map while in the opposite direction the received DBA information is forwarded to the MAC controller. Additionally, the GXTP informs the MAC whether an ONU should be granted a PLOAM message or a PLSu. It also announces to the MAC the start of a ranging cycle.
The MAC controller prepares the BW map, following the structure described in D3.1, through which ONUs' transmission is controlled to avoid collisions.
The BW map is variable in length and consists of a number Blen of 8-bytes access structures. The Blen field is included in the downstream header and will be calculated by the GXTP FPGA. As will also be described in the GXTP-MAC interface section, the MAC controller will prepare the access structures including the CRC field.
Each Access structure consists of 6 fields: AllocID, Flags, Sstart, Sstop, Reserved, CRC, exactly as specified by D3.1. Further elaborating on the flags field:

- The *PLSu flag* indicates that an ONU should insert the respective overhead. The MAC controller asserts this flag when the GXTP FPGA signals such an action for a specific ONU. This implies that the MAC controller must be aware of the relation between allocIDs and residence ONU and assert the PLSu flag for the first AllocID granted belonging in the ONU indicated by the GXTP module.
- The *PCBu flag* is asserted by the MAC controller who inspects the AllocID configured parameters and decides whether the PCBu overhead should be granted or not.
- The *PLOAM flag* which indicates whether a PLOAM message transmission is granted to an ONU and is asserted by the MAC controller in the two following cases:

- Regularly on per ONU basis. (The PLOAM interval per ONU is set by the OBC. The respective register has to be implemented by the MAC controller.)
- When the GXTP indicates to the MAC controller that an ONU has requested a PLOAM transmission grant.

In case that these signals coincide in time, one PLOAM message will be granted.

In the GXTP-MAC direction, the DBA messages are exchanged. The information that the GXTP FPGA delivers to the MAC FPGA is organized in pairs of (AllocID, DBA), which means that the CRC field is not delivered to the MAC controller. The DBA field is 12 bits wide and expresses the queue length measured in ATM cell (53 bytes). Linear coding is implemented.

The GXTP also informs the MAC controller in the following three cases where special actions must be performed:

- An ONU must be granted PLSu overhead.
- An ONU must be granted a PLOAM messages.
- Ranging will start after x frames or cycles.

Ranging procedure
During the ranging procedure, in order to detect new attached ONUs, the US traffic of all ONUs in operational state is interrupted. The MAC controller is responsible for the preparation of the halt pointers as well as for the proper service of the AllocIDs belonging to QoS sensitive T-CONT types.

4.1.2 MAC FPGA - OBC interface

The MAC FPGA interface with the OBC will control registers for three different reasons:

1. Configuration of AllocIDs
2. Control of PLOAM and other functionality in ms or sec timescales.
3. Control and test of MAC controller hardware

Configuration of AllocIDs
According to the TC-layer specs, each AllocID may be of any type (1 to 5) and belong to any ONU. For the GIANT prototype, T-CONT 5 will not be implemented, meaning that any activated AllocID has to be assigned T-CONT 1 to 4 to trigger the respective service strategy. The OBC is responsible to configure all active AllocIDs, defining a set of parameters:

- Residence ONU
- T-CONT type
- Maximum Transmit Byte,
- Minimum Transmit Byte,
- Minimum Successive Data Interval,
- Maximum Successive Data Interval
- FEC Flag.
- Auxiliary MAC parameters that will be defined in D4.2.

The use of FEC is an ONU attribute and will be taken into account during the dynamic bandwidth allocation phase.

MAC control and debugging
A number of registers may be defined for control and debugging reasons. A software reset may be included, as well as Dynamic Bandwidth Assignment control register (indicating whether DBA is enabled) and DBA payload enable registers. Registers to read/write the internal memories are also included.

4.1.3 Description of the MAC controller

A brief overview of the internal organization of the MAC controller at the OLT is given in Figure 25. The “BW map manager” represents the HW logic, which defines the next BW map based on the AllocID information and the requests formed by the DBA reports. To be more precise, it will be divided in two sub-blocks: one allocating the guaranteed part of bandwidth based on the BW Allocation parameters, and another assigning surplus bandwidth, upon requests, based on the reports. A FIFO memory structure is used to temporary store the BW map before delivery to the GXTP FPGA.

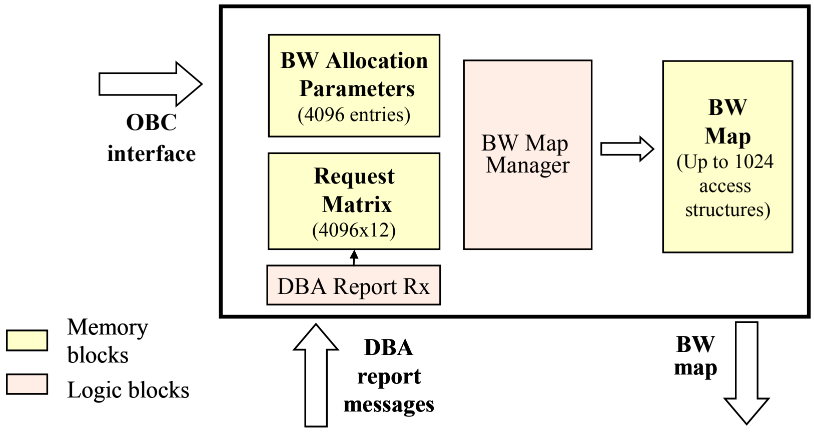

Figure 25: A high level overview of the MAC controller internal organization

Although the exact algorithm that the BW map manager will execute will be described in D4.2, the basic concept mandates that within a frame time the following set of operations are executed (not necessarily sequentially) to form the BW map:

- As the Max SDI parameters (see D3.1) define the maximum distance of AllocID service, the respective table (keeping the SDI parameters for all the SDIs) is inspected and all these timers are decreased by one. The AllocIDs corresponding to expired timers are stored in the "Expired timers FIFO".
- A "timers service" unit, for each expired timer, uses the negotiated parameters and the report matrix contents to form the relevant access structures, which results in the guaranteed bandwidth allocation.
- In the sequence, a "surplus bandwidth allocation unit" is triggered. Requests are scanned in a prioritised way. If pending requests are detected and Min SDI timer has reached 0, then the AllocID is granted a number of min {MaxTB, requests, threshold, weight}, where the threshold is a programmable value and the respective requests are decreased.

When all eligible T-CONT 3 requests have been serviced, the T-CONT 4 service is enabled. For the T-CONT 4 request service no such threshold applies.

4.2 The MAC controller at the ONU

The MAC block at the ONU is responsible for:

1. The reception of the BW map and its processing
2. The definition of the next transmission for the AllocIDs that belongs to the ONU
3. The preparation of the DBA report message.

The MAC controller interfaces the NT-TC FPGA, depicted in Figure 18, and the OBC.

4.2.1 MAC block-NT-TC block interface

The NT MAC block has to be provided with two Information structures:

- BW map (to define the Transmit bytes and inform appropriately the data queues implemented at the GNTP)
- Queue length info (to prepare the DBA report)

The exchange of information between the MAC controller and the NT-TC blocks includes 4 information flows:

1. The BW map is forwarded to the MAC controller, through the interface indicated in Figure 19. This interface is expected to be similar with the one used at the OLT TC layer board between the MAC controller and the GXTP.
2. The arrival of a new user packet at the data memory has to be announced to the MAC controller accompanied by the AllocID it belongs to since the queue length per AllocID has to be formed in order to be included in the DBA report messages. Details on this interface will be included in D4.2.

3. The MAC controller provides the AllocID and the number of granted bytes, as indiacted in figure 30 and controls the types of overhead that should be transmitted, as indicated in Figure 20.
4. The MAC controller forwards the prepared DBA report payload to the NT-TC unit as illustrated in Figure 20.

4.2.2 MAC controller-OBC interface

The MAC controller at the ONT has to be aware of the AllocIDs handled by the ONU where it is placed. It should also know which AllocID is used for DBA payloads for this specific ONU. As a result, it can either be directly connected to the OBC or via the NT-TC FPGA.