# PON Upstream traffic coexistence in a Stacked-PON environment

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Abstract— A stacked-PON scenario using todays most deployed standards over the same fiber span was proposed and a coexistence upstream traffic scenario was simulated an experimentally evaluated.

Index Terms—GPON, EPON Stacking.

### I. INTRODUCTION

The increasing demand for broadband services and the diversification of content and services provided by the network has strongly contributed for the so-called "last mile bottleneck". As a solution, the passive optical networks (PON) emerged, offering high bandwidth and a very competitive cost per number of customers served. Nowadays, the most prominent PONs are: Gigabit PON (GPON), created by the International Telecommunication Union (ITU), and Ethernet PON (EPON) created by the Institute of Electrical and Electronics Engineers (IEEE). Both share the same basic principles such as point-tomultipoint architecture and upstream/downstream transmission principles but, due to the different institutions that support them, the coexistence between both standards was not taken in mind. Adding to the fact that no straight communication between standards is possible, both standards use the same wavelength plan for upstream and downstream communication, making the coexistence over the same fiber span difficult to happen without prohibitive packet losses.

From the functional point of view EPON and GPON are Time Division Multiplexing (TDM) systems because all the users share the same optical fiber between the OLT and the splitter in the time domain. In the downstream direction the data packets are broadcast to all ONUs in a continuous mode (Fig 1). Even if there is no data to send, the OLT sends periodically idle frames to maintain the synchronization with all ONUs. [1]

In the upstream direction, all the users share the same optical link using a Time Division Multiple Access (TDMA) scheme (Fig 1). The use of TDMA allows packet collisions to be avoided as the OLT coordinates the upstream transmission and assigns different time slots to each of the subsidiary ONUs. Each ONU transmits data in bursts, and between bursts from different ONUs there are guard times to avoid the interference from different sources. [1] [2]



Fig.1- PON Upstream/Downstream transmission [1]

It is the OLT that schedules the bandwidth allocation to each of the subsidiary ONUs. The two major methodologies are Dynamic bandwidth allocation (DBA) and Static bandwidth allocation (SBA), the first one allocates time slots based on current ONU and network traffic requirements [2] allowing a very efficient use of bandwidth. The second one, SBA, independently of the fact that one ONU has information to send or not, a certain transmission window is always reserved thus during that transmission window the ONU has the medium for itself.

Throughout this document are proposed an EPON/GPON coexistence scenario over the same distribution fiber. Due to the different specifications for the upstream and downstream transmission, different coexistence mechanisms can be implemented. For the downstream and due to the broadcast traffic nature, wavelength conversion appears as the principal option. This is out of the scope of this paper as wavelength conversion is already extensively deployed.

For upstream communication a new method can be implemented taking advantage of the "free time windows" that the fiber medium presents due to the burst nature of the upstream communication flows, to send bursts of information from another type of ONU without prohibitive collision rates (Fig 3). The statistical viability of this method was assessed using simulation and experimental corroboration.

In a Fiber-to-the-home PON (FTTH-PON) scenario, the physical link costs are of the most importance, thus any possibility of a shared medium between more subscribers, or even subscribers from different PON access topologies can imply major savings for the communications service provider, here arises the Stacked-PON described next.

#### **II. STACKED-PON**

The Stacked-PON scenario presented in the (Fig 2) is composed by one EPON network (OLT and ONUs) and one GPON network, sharing the same fiber span, from the optical splitter situated close to the OLTs, to the optical splitter close to the ONUs.

Due to the different protocols used for EPON and GPON systems, it is not possible to grant the upstream bandwidth control of both types of ONUs to a single OLT, as each one of the OLTs would only grant bandwidth upstream windows to the respective ONUs, without taking notice of the remaining ones. One possible solution to allow upstream communication without serious packet losses is based on the study of the upstream bandwidth procedures, and controlling the transmission parameters of each PON system.



Fig.2- Stacked-PON scenario



I. III. UPSTREAM COMMUNICATION SIMULATION

Fig. 3- Schematic representation of the upstream coexistence scenario in a full 32 ONUs scenario

In this section, a statistical study of the packet error rate (PER) and bit error rate (BER) for the upstream direction flows is presented, using Matlab® simulation. In this simulation the influence of different traffic profiles in the performance of the coexistence scenario is evaluated.

For the considered modeling, both EPON and GPON ONUs use SBA. The drawback of using SBA is the increased packet delay, and buffer overflow that can happen as it is described in [3]. Independently of the fact that one ONU has information to send or not, a certain transmission window is always reserved, thus during that transmission window the ONU has the medium for itself. Due to the fact that the stacked PON scenario is composed by two different OLTs, and both of them grant upstream transmission windows to the subsidiary ONUs, without taking notice of the allocation plan of the other OLT, at each moment two ONUs have the medium reserved for itself, one is a GPON ONU and another is a EPON ONU.

The model proposed utilizes the EPON network as the base PON and evaluates the performance degradation that it suffers, due to the interference of the GPON ONUs. A 32 ONUs EPON was considered because it represents the operator ideal scenario (network cost/number of users).

Along this simulation different traffic parameters, such as the number of transmitting ONUs, the payload size, the inter-frame gap size and the guards times (Fig 4 and table 1) will be assessed taking in mind its relative weight in the overall network performance. It is also important to define the maximum value of PER which allows a fair performance in the upstream communication, that will be considered as 10%. The general conditions assumed to modulate the network are presented bellow.

# Assumed Conditions

• The bit pattern created to fill the Payload section, as well as the majority of the other headings, are composed by pseudorandom sequences drawn from a uniform distribution.

• The bit rate used for EPON was 1,25Gbit/s and for GPON 1,24416Gbit/s.

• 2ms "service cycles" in which every ONU transmits information.

• When the ONU has no data to send or has already finished the data to send, the remaining of the slot is stuffed with zeros.

• For each number of GPON ONUs transmitting, 32 PER measurements were made and an average value was presented.

• The ONU can be in one of two states: "idle" or "transmitting".

• Idle ONUs transmit one full Ethernet Frame with 1518 Bytes and the rest of the slot is stuffed with '0' bits.

• Payload size is variable between 512 and 1518 bytes

• Number of frames from one ONU is variable between 3 and total number of frames that can be inserted into one transmission window without fragmentation.

• One bit is wrong if it is received a "1" when was transmitted a zero, but if two "1" collide no bit error is detected.

• GPON traffic was considered to be exclusively composed by Ethernet frames.

• Packet is considered to be equal to an Ethernet frame.

• One packet is considered wrong if one or more bits are wrong in the Logical Link Identifier (LLID) or in the Destination address (DA) or Source address (SA).

• In each Payload, if more than one bit is detected wrong, the packet is considered lost (due to the CRC and FEC correction)

The considerations above were based on [4]: For a full Payload: 1518\*8=12 144 bits for a  $BER_{Input}$  of  $10^{-4}$ the  $BER_{output}$  of  $5 * 10^{-15}$  is obtained so:

in 12 144 bits only one can be wrong.

The guard time is the channel idle period between the transmission slots from two different ONUs, the inter frame gap is the channel idle period between two different frames transmitted by the same ONU, both parameters are presented in Table 1 and Fig 4



Fig. 4- Structure of the guard band (Kramer, 2006)

Table I- Guard time simulation parameters [2]

EPON	GPON
192ns	70.7ns
192ns	
512ns	25.7 ns
128 ns	
72ns	
1024ns	8 Bytes
	EPON 192ns 192ns 512ns 128 ns 72ns 1024ns

One of the most sensitive parameters when considering a PON simulation is the distribution of the number of "idle" ONUs and "transmitting" ONUs. In order to achieve a reliable simulation, different ONU distributions were studied, such as Gaussian and Gama but none of them present the behavior supposed for the ONUs usage per PON. The ONU distribution considered was named "standard" and presents high probability for a low number of ONUs connected, and a peak between 15 and 20 ONUs connected.

# A. STANDARD TRAFFIC DISTRIBUTION

The proposal of this distribution has in mind the variation of traffic presented over a day cycle [5]. This model presents high probability for the number of transmitting ONUs to be in the range of 1 to 20, as it is presented in Fig 5.



Fig. 5 Number of EPON ONUs transmitting, following a "Standard" Distribution

Fig 6 presents a linear relation between the number of interfering ONUs and PER. It is important to notice that for the "maximum number and frame sizes" PER is never lower than 10%, thus no stacked-PON scenario can be implemented. In the "normal" setup, up to 4 GPON ONUs can be connected for a PER lower than 10%.



Fig.6- Mean PER as a function of the number of plugged GPON ONUs

Regarding the BER values achieved is important to note the influence of the 4 traffic "setups". When the frame size or the number of frames was fixed to the maximum the BER suffered a strong increased proportional to the number of interference ONUs connected.



Fig. 7- BER as a function of the number of connected GPON ONUs

To allow the stacked-PON scenario to be viable, the traffic patterns and the subsequent channel "free window times" should be carefully controlled. For the scenario presented here, which corresponds to a generic traffic model, stacked-PON was proved possible for up to 4 GPON interferometer ONUs in a 32 EPON network.

In the presence of a network where all the ONUs send data at its full potential, PER is never lower than 10%, thus no stacked-PON can be implemented, (Fig 6).

## **III. UPSTREAM EXPERIMENTAL EMULATION**

In this section the stacked-PON upstream coexistence scenario was assessed, using the laboratorial setup presented in Fig 8. A traffic analyzer, which is not pictured in Fig 8 was connected to both EPON and GPON OLTs and ONUs, in order to generate traffic and evaluate the performance of the stacked-PON scenario.



Fig. 8- Upstream experimental emulation setup

EPON and GPON OLTs are responsible for the registration and upstream scheduling process of the subsidiary ONUs, thereby, for testing the upstream coexistence scenario, the downstream channel has to be free of interferences. To allow this, EPON downstream channel was separated from the upstream, by means of optical triplexers, then both signals were sent separately

using fibers with similar length not to unbalance the ranging processes [6].

In previous simulation the upstream bursts power in both PON systems are considered to be equal, since further power differences would greatly increase the complexity of the desired model. On the other hand, in a real context, simulated by the experimental setup presented in Fig 8, the upstream power settings of the different ONUs are of the most importance. Fig 9 assesses the power setting configurations by presenting the packet loss and number of EPON registered ONUs as a function of the relative power difference between the EPON and GPON ONUs. The GPON ONUs, that are referred in this dissertation as white and black, present different packet losses, due to the different sensitivities, -26 dBm and -25 dBm, respectively. EPON ONUs, differ not only in the sensitivity but also in the upstream signal power.

To better evaluate the accuracy of the simulations performed in section III the minimum gap between ONUs and the gap between bursts were set to the simulated values (table 4.1), and are presented below:

- Minimum GPON gap 12 Bytes
- GPON Burst gap 75 ns
- GPON bitrate 100 Mbit/s
- Minimum EPON gap 160 Bytes
- EPON Burst gap 192ns
- EPON bitrate 80 Mbit/s



Fig.9- Packet loss as a function of the upstream power difference between EPON and GPON ONUs

In Fig 9 is presented the packet loss for both GPON ONUs, and the number of registered EPON ONUs, as a function of the difference between the upstream power of the EPON and GPON systems. The interference related to the EPON system is only due to the registration and synchronization process, because no traffic was applied to this system.

The GPON ONU upstream power was set to 2,7 dBm and the upstream power of the most sensitive EPON ONU was varied from 0,7 dBm to 3,7dBm. For a GPON upstream signal power 2 dB higher than the EPON signal, the packet loss is 0 and the EPON ONUs cannot register due to the low relative power. For a power difference around 0 dB, only two EPON ONUs are registered and the packed loss for the GPON systems is very low, less than 8%, this happens because the GPON ONUs are approximately 3 dB more sensitive than the EPON ones. When the EPON upstream power around 0,7 dB higher all the ONUs are registered and the GPON packet loss is around 70%.

Fig 10 presents EPON and GPON packet loss as a function of the number of connected GPON ONUs. Due to the equipment limitations, only two GPON ONUs and four EPON ONUs were available, thus the thirty-two ONUs scenario was emulated assigning an equal amount of traffic to each ONU and multiplying that amount of traffic for the connected ONUs, until thirty-two unitary amounts of traffic are reached. In EPON system only one EPON was connected due to the unbearable packet loss values attained for the upstream power difference, which allows all the EPON ONUs to be registered, Fig 9.

In the test performed, the EPON ONU sent four million frames, representing a thirty-two EPON ONU network. In all packet loss measurements taken, the GPON traffic was incremented with 125 thousand frames in each ONU (white and black), thereby 2 more virtual GPON ONUs were simulated at each step.



ONUs

For up to six connected GPON ONUs, the packet loss is equal or bellow 10%, the condition previously assumed to be the maximum loss allowed for the upstream coexistence scenario feasibility. In the experimental part, the number of GPON ONUs that could be connected for the same 10% PER were 4, therefore the simulated and experimental results present a considerable difference explained by the power settings referred before.

The higher packet loss observed for the black ONUs is explained by its lower sensitivity, in the case of the white ONU the PER was never above 40%, even when all the packets suffer interference from EPON traffic. This shows that with correct power setting and ONU sensitivity it may be possible to connect more that 6 GPON ONUs to the EPON system.

For more than 24 connected GPON ONUs the EPON ONU loses connectivity with the respective OLT, therefore all the packets were lost. On the other hand, GPON system controls the medium, as the EPON cannot connect, and the packet loss strongly decreases to less than 10% (this is due to the EPON registration and synchronization frames that corrupt some traffic).



Fig. 11- Packet loss as a function of the minimum EPON/GPON payload size

In the IXIA traffic analyzer, the frames generated when the payload is set to random, can vary from a minimum to a maximum value defined by the standards [6] and (IEEE 802.3ah, 2004). For EPON systems the minimum payload size is 512 and the maximum is 1518 bytes due to the Ethernet specifications. For GPON systems the minimum payload size is 128 and the maximum is also 1518 Bytes.

Fig 11 presents the packet loss variations when the minimum payload size is increased from the minimum to the maximum value possible. The increased size of the payload implies a decrease of the inter frame gaps for the same amount of traffic transported, thus the medium will have less "free time" and the collisions will increase. When the minimum payload size is less than 512 bytes, the GPON and EPON systems maintain the packet loss in relative low values, whereas for minimum payload sizes above 512 a fast increase of the packet loss is verified, reaching 100% for 1300 bytes in the GPON starts with higher values of packet loss, the system is less dependent on the minimum payload size as is proven observing the less steep curve in Fig 11.



Fig12 Packet loss as a function of the interburst gap

Fig 12 presents the "weighted" evaluation of the interburst gap time between time slots from different ONUs. Both EPON and EPON standards have defined a certain time when the channel is "empty", in order for traffic flows from different ONUs not to overlap each other. In EPON there are different interburst gap possibilities, however, for the simulation realized in section III and for the experimental setup evaluation, 192 ns was used; in GPON the interburst gap used was 75 ns. For the EPON system a strong PER decrease occurs (30%) when the interburst changes from 192ns to 2000ns, but for higher values, such as 4000ns, just a slightly PER improvement happens. In GPON the same behavior is observed, but the PER decrease when the interburst gap increases from 75 ns to 2000 ns is not so evident, 24% for the White ONU and 15% for the Black one.

#### **IV. CONCLUSIONS**

This paper is divided into two sections, first is presented a simulation to assess the feasibility of the upstream coexistence scenario with interference of several ONUs. From this simulation and considering that a packet error rate bellow 10% enables the communication without prohibitive degradation, only up to 4 interference ONUs (GPON) can be connected to a full 32 EPON ONUs network. In the second section the experimental setup was set and evaluated using the available material, 2 GPON ONUs and 4 EPON ONUs. The upstream power transmitted and the ONUs sensitivity were not taken into consideration in the previous section, but from the experimental measurements performed (Fig 9) it is possible to conclude that the power balance between all the ONUs has the same importance, if not more, as the traffic congestion for the upstream coexistence.

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