

# Improving the Upstream Channel Efficiency of Passive Optical Networks via Frame Aggregation and Compression

João M. L. Santos<sup>†,‡,a</sup>, Pedro R. M. Inácio<sup>†,§,b</sup>, João V. P. Gomes<sup>†,§,c</sup>, Artur Arsénio<sup>†,ξ</sup>,

João J. O. Pires<sup>‡</sup>, Mário M. Freire<sup>§</sup>, Paulo P. Monteiro<sup>†,£</sup>

<sup>†</sup> Nokia Siemens Networks Portugal S.A., Rua Irmãos Siemens, 2720-093 Amadora, Portugal

<sup>‡</sup> Instituto de Telecomunicações, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

<sup>ξ</sup> Departamento de Engenharia Informática, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

<sup>§</sup> IT-Grupo de Redes e Multimédia, Departamento de Informática, Universidade da Beira Interior,

Rua Marquês de Ávila e Bolama, 6201-001 Covilhã, Portugal

<sup>£</sup> Instituto de Telecomunicações, Universidade de Aveiro, 3810-193 Aveiro, Portugal

e-mail (corresponding authors): <sup>a</sup>joao.santos@nsn.com, <sup>b</sup>pedro.inacio@nsn.com, <sup>c</sup>jpgomes@penhas.di.ubi.pt

**Abstract** — The transmission medium connecting the Optical Line Terminal (OLT) to Passive Splitter Combiners (PSCs), in Passive Optical Networks (PONs) is shared by all Optical Network Units (ONUs). Therefore, each ONU has to store the data coming from the users, prior to sending it upstream, according to a time division multiple access policy. In this paper, the authors propose using the waiting periods in each ONU to aggregate and compress the Ethernet frames into composite data structures. It is shown that the method described here can significantly improve the efficiency of the upstream channel.

## I. INTRODUCTION

The increasing end-user traffic demand is driving operators and service providers to boost the bandwidth capacity of the underlying access network infrastructure. The solution envisioned to mitigate the physical limitations in currently deployed copper and coaxial-based access networks is to extend the optical fiber communication closer to the customer premises. Following this strategy, Passive Optical Networks (PONs) are seen as the most promising technology to cost-effectively explore the fiber potential and deliver high-bandwidth volumes.

This work proposes an innovative encapsulation mechanism for PON systems considering the following:

- 1) Typical PON infrastructures assume a tree-shaped configuration shared by a group of Optical Network Terminals (ONUs). To avoid unwanted signal collision and data losses, each ONU requests an upstream slot for transmission to the central office, known as Optical Line Terminal (OLT). The data is thus stored in the ONU for an undetermined (yet limited) amount of time, before the latter receives the transmission authorization.

- 2) Due to the Ethernet equipment ubiquity in the Local Area Network (LAN), the majority of the upstream traffic is framed using the Ethernet protocol. Since only a fraction of the overall PON bandwidth is assigned to each ONU, the number of users it supports is limited. It is thus expected that a greater share of the traffic sent upwards will contain similar (or even identical) Ethernet frame header information, such as destination and source Medium Access Control (MAC) addresses, Logical Link Identifiers (LLIDs), etc.

In order to increase the upstream channel efficiency without affecting the system performance, a frame aggregation and compression mechanism, herein called *Composite Frame Format* (CFF), is proposed. This method explores the ONU waiting time mentioned in 1) and the Ethernet frame header redundancy referred in 2) to provide considerable bandwidth savings, resulting in higher bit rates per user, or enabling the support of additional ONUs (customers), with the same number of devices, and at the cost of a minor computational effort.

This paper is structured as follows. Section II introduces the *Composite Frame Format*, describes the frame construction / deconstruction and compression procedures. Section III presents important and relevant results, obtained via computer simulation, and section IV concludes the manuscript.

## II. COMPOSITE FRAMING IN PONS

### A. EPON and GPON Standard Frame Formats

The PON market is currently dominated by two technologies: Ethernet PON (EPON) and Gigabit PON (GPON). In face of the broad adoption of Ethernet in the customer premises, EPON was intentionally designed to support native Ethernet frames over the optical interface [1]. As depicted in Fig. 1(b), only the LLID information, used to identify the source / destination ONU, is added by the EPON to the standard Ethernet frame. However, the Ethernet framing protocol is known to suffer from high overhead, which can consume up to 9% of the total amount of information transmitted in the EPON [2]. To reduce the

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Ethernet overhead impact, GPON [3] adopted the GPON Encapsulation Method (GEM) that replaces the Inter-Frame Gap (IFG), preamble, and Start Frame Delimiter (SFD) headers (totalising 20 bytes) with a single 5-byte header, as shown in Fig. 1(c). Using this frame format, the total inefficiency (overhead) is reduced to 4%-5% of the total bandwidth.

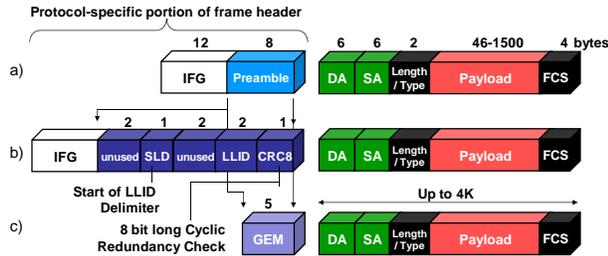


Fig. 1. a) standard Ethernet frame format; b) EPON frame format; c) Ethernet over GPON frame format.

### B. The Composite Frame Format

The frames of a communication flow will be identified by their identical pair source / destination MAC addresses on the frame header. The frame format proposed herein, depicted in Fig. 2, was designed with the purpose of aggregating Ethernet frames, while reducing the overhead caused by the repetition of the information about the source and destination address, preamble, and IFG. The CFF defines a non-standard data structure, divided by blocks that carry the legacy Ethernet frames payloads, and demarked by the fields that allow for the referred structure to be as *elastic* as possible. Thus, several Ethernet frames, with variable lengths, can be aggregated up to a total size of 9KB for EPONs and of 4KB for GPONs<sup>2</sup>.

As depicted in Fig. 2, the CFF is similar to the EPON and GPON framing, except for a few fields, as the Size of Block (SB), and the Total Length (TL) or Total Number of Frames (TNF), being the first used to indicate the size of the next block of data in the frame, and the second to indicate the total length (in bytes) of the composite frame. The Frame Check Sequence (FCS), at the end of the frame, carries the 32 bit long CRC code calculated for the whole data structure. The size of the FCS field is equal to the one of Ethernet framing, because 4 bytes are considered to be enough to handle most of the errors in a 9KB long message [4].

### C. Ethernet Frame Aggregation / De-multiplexing

The aggregation procedure delineates the process by which the device identifies several frames belonging to the same flow and constructs (or adds frames to) the composite frame. This is done via isolation of the header of the first Ethernet frame of the flow and by stripping all the following data from their FCS and addressing fields.

<sup>2</sup> The typical maximum value for Ethernet Jumbo frames is 9KB [5], being 4KB the maximum GEM size, in the case of GPONs

Aggregation works as follows. Each time a new frame arrives at the ONU, it must first be checked if a Composite Frame (CF) for the specific source / destination pair (and LLID, in the EPON case) already exists and if the addition of another block does not surpass the maximum payload size (9 KB). If such is the case, the block consisting of the new Ethernet frame payload + type / length + block size field can be added to the CF. The global FCS value should then be updated and the TL field incremented. If the CF reaches the maximum size of 9 KB, the remaining space is less than the size of the Ethernet frame or the time to transmit has come, the CF is completed and should be wrapped up by appending the global FCS value to its end. It must be kept in mind that, in the case of EPONs, the logical addressing scheme should also be applicable to the CFs, by assuring that the aggregation is made while taking the LLIDs into account. In other words, frames should be aggregated according to the 3-tuple source / destination MAC addresses and source LLIDs. In EPON implementations where an LLID is assigned exclusively to each ONU, the aggregation should be made on a per ONU basis, whereas in implementations where an LLID is assigned to individual queues or users, the aggregation should be made on a per queue or per user basis.

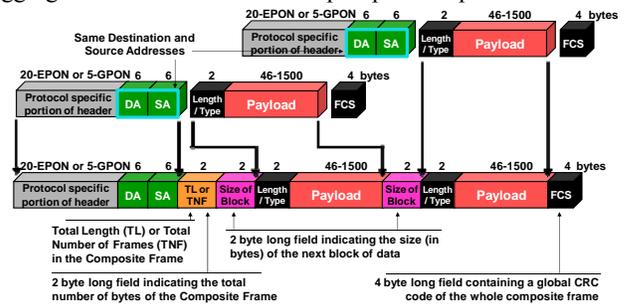


Fig. 2. Proposed format for the composite EPON and GPON frames. The protocol specific portion of header is detailed in Fig. 1.

Once the composite frame is received at the OLT side, a de-multiplexing algorithm has to be applied in order to recover the individual system compliant frames. This procedure is basically the inverse of the previously described one: first of all, the FCS of the CFs is examined; if valid, the MAC destination and source addresses can be read and stored in memory and the frame can be further processed; the procedure must get all the blocks in the composite frame payload and append them to the IFG plus Preamble, in the case of the EPON, or the GEM header, in the case of the GPON. Finally, the FCS value is calculated for each newly constructed frame and added to the end of the data unit.

### D. Compression / Decompression

The waiting period to which the frames are subdued in ONUs can also be exploited to compress the data transmitted to the OLT, through the inclusion of a compression algorithm at the ONU logics, and of a correspondent decompression algorithm at the OLT. This approach decreases the amount of data sent upstream, bringing an additional benefit at the cost

of supplementary computational effort. To achieve a higher compression ratio, the compression mechanism should act after data aggregation, taking advantage of the increased size of the CF. There are several high performance compression / decompression algorithms available, which operate in an iterative manner and are ideal for a fast network implementation. During our simulations, the data was compressed with the DEFLATE algorithm [5], used by ZIP and GZIP formats.

### III. SIMULATION RESULTS AND DISCUSSION

The bandwidth efficiency improvements resulting from the application of the CFF method in the EPON upstream channel were evaluated via computer simulation. Note that due to space limitations, we chose to focus on the results obtained for the EPON case only, though the case of GPON has been studied also. Firstly, synthetic traffic traces were used to estimate the gains provided by the aggregation function. Secondly, real traces were applied to assess the benefits of aggregation *and* compression.

In the first case, a Fixed Slot Allocation (FSA) scheme is employed in the Dynamic Bandwidth Allocation (DBA) [6] where the ONUs are sequentially pooled in the upstream cycle and awarded an equal bandwidth share. The frames received by the ONU from the client interface are transmitted over the upstream time-slot using the proposed CFF. The REPORT message, which is used to inform the OLT of the traffic waiting in the ONU, is itself encapsulated in a CFF frame and sent upwards in the same time-slot used for normal data. The traffic to each ONU from the user side is generated by means of a trimodal distribution [7] with an average frame size of 397 bytes. For the sake of simplicity, we assume that the source and destination MAC addresses are maintained equal in every incoming frame. Hence, the transmitted frames are aggregated in more than one CF only if its payload limit is exceeded. The average percentage of frame headers in the upstream time-slots of a 1 Gbit/s EPON is depicted in Fig. 3. As the time-slot duration increases (due to the cycle length augmentation), a higher number of client frames can be incorporated and the volume of overhead stabilizes in about 2% for the CFF approach and 9% for the standard Ethernet framing.

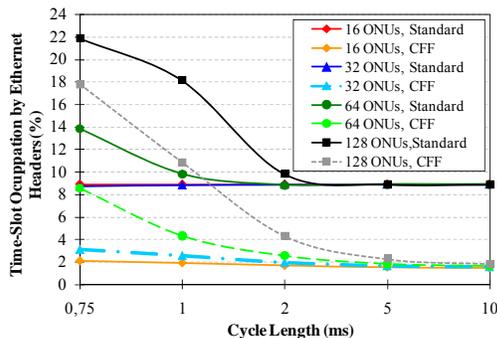


Fig. 3. Time-slot occupation efficiency with CFF and standard Ethernet frames in 1 Gbit/s EPON.

The overhead savings obtained with the CFF aggregation scheme can be quantified in terms of bandwidth gains per ONU and for the overall EPON system, as depicted in Fig. 4 (a) and (b), respectively. For a moderate number of active ONUs, such as 16, the gain per terminal can exceed 4 Mbit/s. These bandwidth savings are reduced to about 2 Mbit/s for 32 ONUs, which is the number of active terminals recommended by the EPON specification [1].

The total bandwidth savings for an EPON system are plotted against the cycle length and number of supported ONUs in Fig. 4(b). The lowest gain of 30 Mbit/s is obtained for high-splitting ratios (128 ONUs) and short polling cycles (750µs) scenarios, as expected. When considering a smaller terminal diversity and longer cycles, the improvements are of approximately 70 Mbit/s. The results shown in Fig. 3 and Fig. 4 reflect the obvious trade-off between the performance of the solution, and the number of ONUs and cycle length. Nonetheless, bandwidth improvements are noticeable in all the evaluated cases.

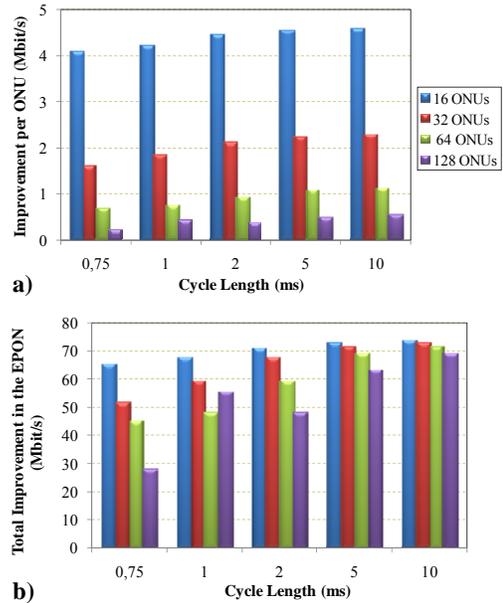


Fig. 4. Bandwidth improvement (a) per ONU and (b) in the EPON (1 Gbit/s).

The second study case is based in traffic traces obtained from a real local network setup, containing data from several telematic applications. Three collected traces with an average packet size of 83, 225, and 351 bytes were tested in the EPON upstream channel simulator assuming that 16 active ONUs were being served with different cycle lengths. The original MAC addresses of the captured traffic are maintained and each CF unit is composed of the frames which detain identical source and destination MAC address pairs. The bandwidth improvements due to the CFF aggregation are illustrated in Fig. 5(a). Again, smaller frame sizes and larger cycles lead to bigger saving. This results in total gains ranging from 300 Mbit/s, for a cycle of 1 s, to 50 Mbit/s, for a more conservative cycle length of 1 ms. With

the average frame size increasing, the gain tendency is to decrease to values varying between 25 Mbit/s and 80 Mbit/s. By comparing the results from Fig. 4(b) with the ones of Fig. 5, one can conclude that the latter embodies a more realistic outcome of the aggregation procedure, since it considers the MAC address diversity present in the upstream traffic, whereas the former evaluation assumed that all the incoming frames detained equal addresses, thus comprising an overly optimistic scenario (upper bound of the performance).

The application of payload compression reduces the amount of transferred information inside the time-slot, resulting in further bandwidth savings. As depicted in Fig. 5(b), the bandwidth improvements may surpass 600 Mbit/s (corresponding to 60% of the available network capacity) in the EPON case, though they are dependent on how entropic the user data is. For typical cycle lengths, the global CFF performance can range between 120 Mbit/s and 450 Mbit/s.

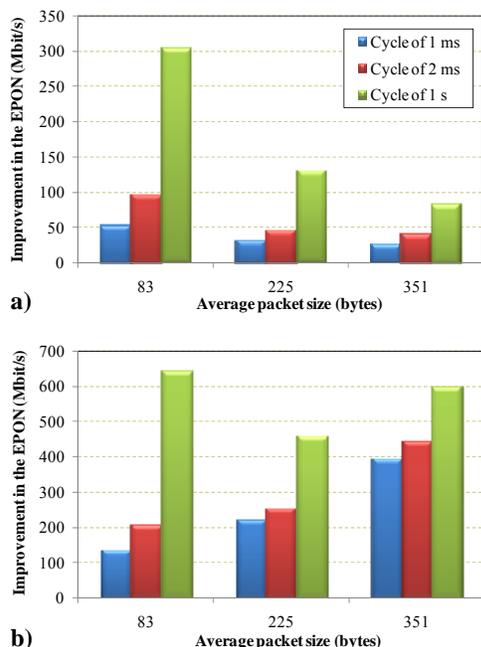


Fig. 6. (a) Aggregation and (b) compression bandwidth gains in 1 Gbit/s EPON with real traffic.

The application of frame aggregation and compression mechanisms in PON systems results in several advantages for PON systems, namely: (i) elimination of redundant Ethernet headers by means of a simple re-encapsulation method that is transparent to all the PON users (both operators and end-users); (ii) clever exploitation of the PON specific wait-and-burst upstream operation, i.e. usage of the ONU “idle time” (when data is not being transmitted) to perform re-encapsulation and compression, thus avoiding further delays in the already waiting traffic; and (iii), the CFF method imposes no additional constraints on the optical physical requirements of the active devices of the network. The major drawback of the proposal is that its implementation requires the modification of the active devices of PON systems, which have to be capable of aggregating the PON specific frames

into the format of the CF, or de-multiplexing these latter into the former. Additionally, the said equipments have to include compression / decompression functions, conceptually located after / before the aggregation / de-multiplexing functions at the MAC layer (Layer 2), respectively. Both compression and aggregation functions can be implemented in firmware, software, or hardware, mostly due to their simple specification.

Regardless of the previously enunciated disadvantage, the solution is backward compatible with already deployed systems, since its application in a per time-slot basis, makes it possible to operate in a PON with legacy ONUs (using the standard Ethernet frames) and with the efficiency-improved ONUs (which use the CF method introduced here). Furthermore, both aggregation and compression functionalities are complementary, i.e., both can be applied separately or together.

Contrarily to other solutions, the performance of the proposed mechanisms increases as the traffic load (i.e. number of frames) increases. Hence, the higher the load, the higher will be the compression and aggregation ratio, and therefore the gains. In addition, the proposed method can also be applied in future 10 Gbit/s EPON systems where Ethernet-based traffic will have a prominent role in leveraging Triple and Quadruple Play services to the end-customer.

#### IV. CONCLUSIONS

This paper discusses and evaluates the combination of a novel frame encapsulation format with data compression functionalities for increasing the upstream transmission efficiency in PON systems. The results it includes demonstrate that relevant bandwidth savings can be attained by eliminating redundant Ethernet frame headers and applying simple, but effective, compression algorithms. Computer simulations with real network traffic show that it is possible to obtain gains varying between 100 Mbit/s to more than 600 Mbit/s, in a 1 Gbit/s EPON.

#### REFERENCES

- [1] IEEE 802.3ah, “Media Access Control Parameters, Physical Layers, and Management Parameters for Subscriber Access Networks,” 2004.
- [2] M. Aquilina, and C-J. Chae, “Scalability of Ethernet Passive Optical Networks,” in *ATNAC*, 2006.
- [3] ITU-T G.984.3, “Gigabit-capable Passive Optical Networks (GPON): Transmission convergence layer specification,” 2004.
- [4] A. Networks, “Extended Frame Sizes for Next Generation Ethernets,” *White paper*, 2000.
- [5] P. Deutsch, “RFC1951 - DEFLATE Compressed Data Format Specification version 1.3.,” May 1996.
- [6] G. Kramer, B. Mukherjee, and G. Pesavento, “Interleaved Polling with Adaptive Cycle Time (IPACT): A Dynamic Bandwidth Distribution Scheme in an Optical Access Network,” *Photonic Network Communications*, vol. 4, no. 1, pp. 89–107, 2002.
- [7] K. Claffy, “The nature of the beast: Recent traffic measurements from an Internet backbone,” in *INET*, 1998.