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Processing efficient frame structure for passive optical network (PON)

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ABSTRACT

The time division multiplexed (TDM) based passive optical networks like GPON/XGPON and EPON/10G-EPON use broadcast mechanism for downstream (DS) communication. This results in any DS frame being received and processed by all optical network units (ONUs), leading to significant processing energy wastage. Specifically, the ITU compliant PONs (GPON/XGPON) frame structure further aggravates this problem due to its inefficient frame structure and synchronous nature which requires sending of DS frames every 125 μs. This frame structure requires an ONU to completely process every DS frame completely, even if it is not destined for it. The bit interleaved PON (Bi-PON) resolves this problem by changing the frame structure to a bit interleaved pattern and introduce a decimator unit that enables an ONU to tune to its concerned bits only. However, due to additional hardware requirement, this solution is not applicable to current ONU architecture. Consequently, this study presents a processing efficient version of GPON frame that helps an ONU to identify an unrelated DS frame at its start and thus discard it without complete processing. A processing efficient strategy for the medium access layer (MAC) processor of an ONU is also presented. The simulation results show a processing energy saving of 88%, 89% and 89.47% with proposed frame structure for a split ratio of 16, 32 and 64 respectively.

1. Introduction

Due to the Information Communication Technology (ICT) revolution the need for ICT services has become a necessity for a common man instead of a comfort. This is why these networks have been tremendously expanding in last 20 years and still this trend is continued. According to ITU 2016 report, 84% of the world population today has access to broadband services [1]. This expansion is leading to increasing power generation requirements for this sector. Currently around 59% of the power generation in the world is through thermal plants which results in greenhouse gas (GHG) emissions [2] due to fuel burnings, therefore, the power generation requirements should be minimized. The ICT sector has been estimated to be responsible for 2.5% GHG emissions [3]. Specifically, the Telecom sector is responsible for 21% of these GHG emissions in the ICT. Specifically, in the Telecom sector 70% of the power consumption is in the Access Network. It has been forecasted that by 2020 this power consumption will reach up to 40 GW and by 2025 it is expected to reach 0.13 TW [4] .

The replacement of the Copper based Access Network with the optical fiber based Access Networks have not only increased the capacity and reach of the central offices (CO) but has also gradually reduced the power consumption of the Access Network due to its very low power consumption [5]. In the first phase, Active Optical Network (AON) topology replaced the legacy Copper based Access Network, which works in a fiber to the area (FTTA) or fiber to the building (FTTB) topology. However, due to still having copper cables in the last mile, its power consumption could only be reduced further with a complete end to end fiber based Access Network from the CO to the user's home. This revolution has been brought by the Passive Optical Network (PON) by offering a complete fiber to the home (FTTH) solution. The PON is energy efficient than the AON and Copper based Access Networks. However, it has a weakness that in this topology, the optical network unit (ONU) consumes up to 60% power of the whole PON and the Optical Line Terminal (OLT) consumes only 7% [6]. Therefore, energy efficient schemes for a PON ONU is an active research area.

Currently deployed PONs use broadcast and select mechanism for downstream (DS) communication and time division multiple access (TDMA) scheme for upstream (US) communication. In the downstream (DS) broadcast, each ONU has to receive and check that if the received frames is related or unrelated. This continuous processing of frames

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makes an ONU highly energy inefficient. Specifically, in ITU compliant PONs; GPON, XGPON and TWDM PON the frame structure intensifies this problem. This frame structure does not clearly delimits the data, US bandwidth grants and operation and maintenance (OAM) information fields. Thus, an ONU has to process the received frame completely and discard the unrelated portions of the frame after complete processing. This results in significant processing energy wastage. It has been reported that in worst case 97–99% DS frames received by an ONU are discarded after complete processing due to being unrelated [7].

To make a GPON frame structure processing efficient this work proposes a slight modification in the frame structure. The modified frame structure is termed as EGPON. The choice for GPON is motivated by its wide commercial deployments. However, the proposed idea is also applicable to XGPON and TWDM PONs. The proposed changes do not impact the services and functions offered by the current GPON frame structure. These changes actually add more information to the frame structure to make it processing efficient. In addition to changes in frame structure, an improved processing strategy for the medium access layer (MAC) processor of the ONU is also proposed by this study. Important abbreviations and notations used in rest of the paper are given in Table 1.

The rest of the paper is organized as follows: Section 2 reviews the related work. Section 3 explains the ONU processing model. Section 4 explains the GPON frame processing strategy. Section 5 presents the EGPON frame and processing strategy. Section 6 explains the performance evaluation approach. The simulation setup is explained in Section 7. The results are presented and discussed in Section 8. Finally, Section 9 concludes this study with future research direction.

2. Related work

The unrelated processing problem due to broadcast nature of the DS link of PON can be completely eliminated by using a wavelength division multiplexing (WDM) based PON [8] topology in which each ONU has dedicated channel to OLT at a different assigned wavelength. The improved WDM architectures now eliminates the need for dedicated wavelength for ONU by introducing the colorless ONUs [9]. However, the need of costly tunable receivers at the ONU and the thermoelectric Cooling (TEC) required to stabilize the wavelengths in tunable transceivers diminishes such energy savings. The use of reflective semiconductor optical amplifier (RSOA) based ONUs eliminates the need for laser sources in the ONUs by reusing the DS carrier signal. However, although, this reduces the ONU cost [10] but still this technology is costly due to the requirement of extra optical filters for wavelength selection and consume higher power compared to PON [11]. Similarly, OFDMA based PON [12] has also been proposed to be another energy efficient option as it uses multiple orthogonal sub-carriers on a single fiber to provide higher bandwidth with separate communication links between ONUs and OLT. However, the problem with this technology is its complexity and additional processing power requirements for advanced digital processing and operations like FFT and IFFT [13]. Moreover, it still suffers with unrelated processing as each ONU has to read all the OFDM symbols to check for the frame relevancy. Another such processing efficient option reported in literature is code division multiple access (CDMA) based PON [14] in which ONUs can simultaneously transmit to OLT on the same wavelength with their traffic encoded with different spreading codes. However, this technology suffers from inter-channel interference problem. Moreover, it requires the ONU transceiver components to handle signal rates much higher than the line rate which leads to very costly optical transceivers. Therefore, TDMA PON is till-to-date the most economical and commercially deployed PON technology.

The ONU energy conservation schemes presented in literature are mostly for ONU idle mode like ONU Doze mode [15,16], ONU Sleep mode [17–19] and ONU Watchful sleep mode [20–22]. In these schemes only the ONU energy can be saved by turning off the transmitter and receiver units when ONU is idle or traffic volume is very low. However, these schemes cannot provide energy savings when the ONU is in active state. Another, proposal is Adaptive Link Rate (ALR) [23,24] which tries to reduce the dynamic power consumption of an ONU by reducing the DS line rate when the traffic load is low. A combination of sleep and ALR has been shown to be more effective and able to save up to 80% of the ONU energy. However, the ALR proposal requires dual rate transceivers at the OLT and ONUs which is practically and commercially not a viable option.

Overall, none of these schemes address the problem of processing energy wastage by an ONU occurring due to the broadcast nature of the DS link. This issue has only been addressed by Bi-PON [7,25] studies. The Bi-PON proposal introduces a new bit interleaved frame pattern so that each ONU only tunes to its specific bits in a DS frame and only reads its related bits in BWmap, Payload and OAM sections of the frame. However, this scheme is disruptive and cannot work with current ONU architecture as it requires a Decimator unit to parse the frame bits from the DS bit stream. In our earlier study in Ref. [26] we proposed a new frame structure to resolve this matter at the MAC layer without requiring any hardware change in ONU. In this study the savings of the proposed frame structure were evaluated using an instruction level energy model of the MAC processor. However, this study only assumed a single TCONT per ONU and did not consider a DBA scheme during analysis. Moreover, the results were only based on analysis and no simulation was performed for different traffic load variations.

This study is inspired from the studies in Ref. [27–31] that show that processing power consumption of a communication device is a function of the traffic packets being processed by it. Specifically, the studies [27,28] show that by using the sleep mode for a MAC processor, significant processing energy savings can be achieved because if the processor is in active state it keeps on processing the received traffic frames/packets. The study in Ref. [27] presents a processor active and sleep mode control mechanism based on the incoming packet type. This study demonstrated processing power savings for a home gateway node by controlling the processor sleep and active modes based on the type of incoming traffic packet. To the best of our knowledge, this is the first study for PON that investigates the achievable processing energy savings for a GPON ONU by using the sleep mode for the ONU MAC processor to avoid the unrelated frame processing of a DS frame.

Table 1
Important abbreviations and notations.

BWmap	A field in DS GPON frame that carries the US bandwidth allocations for all ONUS
FFT/IFFT	Fast Fourier Transform/Inverse Fourier Transform
Bi-PON	Bit Interleaved PON.
PCBd	Physical Control Block Downstream
TCONT	Transmission container
GEM	Generic Encapsulation Module
$N_{un\_related}$	Number of unrelated frames received by an ONU
PLOAMd	Physical Layer Operation And Management downstream
T_{Frame}	Duration of a DS GPON frame
E_{Frame}	Processing energy for a DS GPON frame
$T_{related}$ / $T_{unrelated}$	Duration of the related/unrelated portion of a DS GPON frame
$E_{unrelated}$ / $E_{related}$	Processing Energy for the unrelated/related portion of a DS EGPON frame
N_F	Number of downstream frames received by an ONU

3. ONU processing model

The analysis of processing efficiency of GPON and EGPON frames requires the knowledge of the ONU hardware architecture and MAC layer processor. The actual hardware architecture of commercially deployed ONUs is inaccessible due to copyright issues. Therefore, from the ONU power models presented in Ref. [32–35] and the study of CDR datasheets especially [36,37], a GPON ONU hardware model shown in Fig. 1 is considered for the processing analysis of the GPON and EGPON frames. It comprises of analogue optics, CDR, DEMUX, MAC and Application processor sections. The analogue optics section comprises of the optical transceiver, which receives these frames as optical signals from the OLT