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# A New ONU-initiated Doze Mode Energy-saving Mechanism in EPON

AliAkbar Nikoukar, I-Shyan Hwang, Andrew Tanny Liem, Yu-Min Su

***Abstract*—In broad-band access network, Ethernet passive optical network (EPON) mentions as a green network which has minimum power consumption compared to the other technologies. Optical network unit (ONU) due to the idle time in the upstream direction can be chosen to implement energy-saving methods in EPON. Turning the ONU's transceiver/receiver off is a common method that has been proposed by both researchers and industry. However, this method can cause an increase in packet delay and packet loss, and as a result, reduces the QoS. In this paper, we introduce a new ONU-initiated (decentralized) energy-saving mechanism to reduce the ONU energy consumption and guarantee overall QoS metrics in EPON. The doze controller component is added to the ONU responsible for doze duration calculation. The doze duration is calculated based on the status of ONU and types of traffic. The mechanism is proposed to guarantee the overall QoS, based on the incoming traffic type and queue threshold. Simulation results show that the proposed mechanism can guarantee the QoS metrics and improve the ONU energy consumption.**

***Index Terms*— EPON, ONU-initiated, Doze, QoS, Energy-saving.**

## I. INTRODUCTION

RECENTLY, the demand of bandwidth has been increased rapidly, and the power consumption was also growing significantly [1]. The power consumption of the Internet is 0.4 percent of total electricity consumption and predicted to increase 1 percent [2]. To prevent the global warming, developing the energy efficient network is being an urgent necessity to reduce the rise of power consumption. The Broadband Access networks consume above 70 percent of the entire network due to the large number of active elements. To achieve the goal of low power consumption in the near future, it is necessary to reduce the power consumption in the Broadband access networks [3]. Within the access networks technologies the FTTx offers huge bandwidth with the lowest power consumption. The FTTx can be realize either point-to-point or point-to-multi-point infrastructure; however the Ptmp has the advantage of low cost, easy deployment, less maintenance operation compare to ptp.

In order to realize PON, different optical access technologies, including time-division multiplexing PON (TDM-PON), time and wavelength division multiplexing PON (TWDM-PON), wavelength division multiplexing PON (WDM-PON), and orthogonal frequency division multiple access PON (OFDMA-PON) have been developed. TDM-PON is a point (service provider)-to-multi-point (user) technology based on tree topology. It consists of an Optical Line Terminal (OLT) with the service provider located at the Central Office (CO), linked via optical fiber and an optical passive splitter/combiner to multiple Optical Network Units (ONUs), which are connected to the users [5]. As an OLT interface is shared by multiple ONUs, TDM-PON is the most energy-efficient optical-access solution currently deployed [3]. Gigabit-capable PON and Ethernet PON are examples of TDM-PON, which is widely deployed in FTTH technologies today. Wavelength division multiplexing PON (WDM-PON) offers a virtual PtP connection via a dedicated wavelength to each ONU. Every subscriber in the WDM-PON requires its own transceiver port at the OLT, thus WDM-PON consumes more power per subscriber than a TDM-PON system. Moreover, thermo-electric cooling (TEC) is required to stabilize the wavelengths and a TEC consumes extra power, which reduces any efficiency gain offered by its virtual PtP nature. TDM-PON can combine with wavelength division multiplexing (WDM) in a hybrid time wavelength-division-multiplexing PON (TWDM-PON). TWDM-PON increases the total capacity over the PON by increasing the number of wavelength pairs, e.g., typically 4×gigabit passive optical network (GPON) or 4×XG-PON1 (10-Gb/s-capable PON as specified in ITU-T G.987). The TWDM-PON has been selected by the Full Service Access Network (FSAN) as the primary solution for NG-PON2 (ITU-T G.989). For the same total bandwidth capacity, the power consumption of an OLT will be slightly higher than for a pure TDM-PON, because there are multiple transceivers at the OLT. Finally, OFDMA-PON is of most interest in the research community as an alternative solution for next-generation PONs. OFDMA-PON employs a large number of sub-carriers, overlapping in the spectrum but not interfering with each other because they are orthogonal, hence achieving high spectral efficiency. OFDMA-PON offers a higher bandwidth granularity than WDM-PON. However, OFDMA-PON consumes additional power during digital signal processing (DSP) operations, e.g., Fast Fourier Transform (FFT) and Inverse FFT (IFFT). The requirement for high speed Analog to Digital and Digital to Analog Converters (ADCs/DACs) also contributes to its high-power consumption [4]. An Ethernet passive optical network (EPON) is a TDM-PON with a well-known infrastructure,

AliAkbar Nikoukar, I-Shyan Hwang and Yu-Min Su are with Department of Computer Science and Engineering, Yuan-Ze University, Chung-Li 32003, Taiwan (*e-mail: s1009117@mail.yzu.edu.tw, ishwang@saturn.yzu.edu.tw, f61434@gmail.com).*

Andrew Tanny Liem is with Department of Computer Science, Klabat University, Manado, 95371, Indonesia (*e-mail: andrew.heriyana@unklab.ac.id).*

because of the packets encapsulating in the ethernet frame. Whereas, with regard to Ethernet frame usage, EPON is friendlier to the user equipment, can adapt the data exchange between local-area networks (LAN), and can access the network with minimum encoding/decoding overhead and time. Moreover, EPON is a cost effective PON, having the benefit of low-cost Ethernet equipment and low-cost fiber infrastructure [5].

The Institute of Electrical and Electronics Engineers (IEEE) developed IEEE802.3ah and IEEE802.3av standards in 2003 and 2009, respectively. The fundamental principles of these two standards are the same, but IEEE802.3av enables EPON to transmit data in multi-rates up to 10 GB/s. The multi-point control protocol (MPCP) is defined in the IEEE802.3ah and IEEE802.3av standards to coordinate medium access from the OLT to each ONU using the MAC algorithm. The REPORT and GATE messages are used for facilitating centralized medium access control. The REPORT message is used to report the immediate queue occupancies from an ONU to the OLT, while the GATE message is used by the OLT to grant non-overlapping transmission windows to each connected ONU. In the upstream transmission, EPON employs TDM for transmission to assign the transmission time to each ONU which the OLT runs a dynamic bandwidth allocation (DBA) that is a key component of the EPON system. During the last decade, many DBA refinements were proposed by researchers in order to improve the efficiency of the EPON upstream bandwidth by dynamically adjusting the bandwidth among the ONUs in response to the ONU burst traffic requirement [6]. In downstream transmission, data is broadcasted from the OLT to the entire connected ONUs and each ONU needs to filter out the packet not intended for it. The IEEE standards not defining any technique required to reduce power consumption on EPON architecture, especially when the system usage is low.

Although the PON consumes the least power among the access network technologies, it still gets good attention in the global energy-saving plan of modern telecommunication. ONU potentially can be chosen to improve the energy consumption of the TDM-PON by up to 80 percent by using either hardware or software based solution [7]. Hardware solution focuses on ONU hardware redesigning architecture or/and the reuse of optical noise. Turning off/on the ONU's parts impose the extra overhead to the system that is based on the part chosen for energy-saving. Furthermore, software-based protocols embedded in these architectures need to manipulate their sleep functionality. Software-based PON power saving can be done in several ways such as ONU power shedding, ONU dozing, adaptive link rate and ONU sleep. ONU power shedding characterized by powering off or reducing power of non-essential functions and services while maintaining a fully operational optical link. ONU dozing associated with additional powering off the ONU transmitter for substantial periods of time on the condition that receiver remains continuously on. The Adaptive Link Rate (ALR) refers to the ability of selecting transmission rate dynamically. ONU sleep means that both ONU transmitter and ONU receiver are turned off for substantial periods of time [7].

Recently several studies have proposed dynamic sleep schemes to keep the ONU in sleep mode for one, or more than one, DBA cycles. Another proposed scheme uses the benefit of batch mode transmission in the upstream and downstream directions, called green DBA (GBA). The GBA lets an ONU remain in sleep mode for a period of time determined by the maximum delay requirement, rather than the availability of upstream/downstream traffic [8,9]. In [10], an adaptive delay-aware energy efficient (ADAEE) approach for solving the energy issue in TDM-PON is proposed, which aims to save as much energy as possible while also meeting the PON access delay restrictions imposed by the operator. In [11] an energy management mechanism based on the fixed bandwidth allocation (FBA) algorithm is proposed. The main idea is to schedule downstream traffic and the transmission of upstream traffic at the same timing in each ONU to maximize the sleep time. They compare upstream centric scheme (UCS) and downstream centric scheme (DCS). The OLT in the UCS sends traffic to ONU only when the ONU sends upstream traffic, which increases the delay and sleep time. However, in the DCS if there is any upstream or downstream traffic the ONU wakes up, which reduce the delay and sleep time.

The previous energy-saving studies are centralized and govern by the OLT. The OLT calculates sleep modes (include sleep and doze) and determines the sleep duration. Moreover previous studies cared about how to achieve the maximum energy saving without concerning about high priority traffic QoS requirements. The previous studies assume that the ONU has infinite buffer size, which is far from the real world. Moreover, keeping the packets for long time at the queue in the ONU causes the packet loss, and the user needs to regenerate these packets which lead the user consumes more energy. To remedy this problem, we introduce a new ONU-initiated energy-saving mechanism that the ONU is responsible for change its status and doze duration calculation. The ONU architecture is enhanced by adding the doze controller components. The ONU informs the OLT by sending the doze time with the REPORT message. The doze duration satisfies the high priority traffic QoS metrics. The rest of this paper is organized as follows. Section II briefly introduces the proposed decentralized mechanism and evaluates the system performance. We conclude our work in the Section III.

## II. ENERGY-SAVING ARCHITECTURE AND MECHANISM

This section presents the proposed system architecture, including the enhanced ONU and energy-saving mechanism. The proposed mechanism allows the ONU decides to enter to the doze mode based on the current traffic types, queue status and maximum DBA cycle time. The figure 1 shows the ONU architecture. The traffic classifier, queue manager and doze controller (DC) components are added to the ONU to enhance its functionality. The traffic classifier could be implemented as hardware or software to classify the packets based on the CoS & ToS classifier, and then forwards the

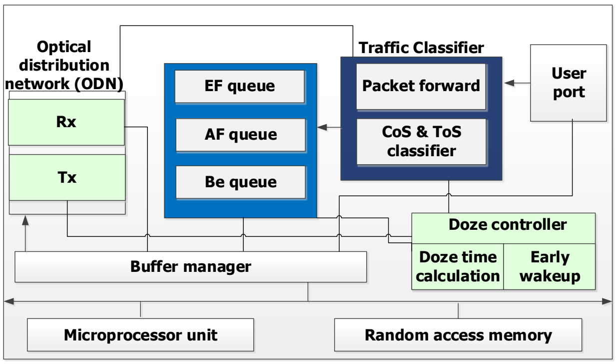


Figure 1. Function block diagram for ONU.

packets to other parts. These modules help the ONU to process the arriving traffic from the user side. Moreover, traffic classifier classifies the incoming traffic in three different types of traffic, which includes Expedited-Forwarding (EF), Assured-Forwarding (AF) and Best-Effort (BE) traffic. The queue manages the incoming traffic in the different queue with various strategies. The DC aims to calculate the doze time, responsible turning off/on the transceiver and also has to inform the OLT when it changes the ONU's status. Moreover the doze controller has to be able to interrupt the doze mode and turn on the transceiver in any unexpected situation such as highly load or detect incoming high priority while the doze duration is longer than QoS boundary requirements. The doze time calculation (DTC) and early wakeup (EW) subcomponents construct the DC that the DTC is responsible to calculate the doze duration time. The doze duration is a critical value to satisfy the QoS metrics, in which setting overlong doze duration reduces the QoS, while short doze time increases the ONU power consumption. The doze duration comprises of the time that ONU is in the doze mode, and the time power off/on delay for turning off/on transceiver, clock recovery, and synchronization. The power off/on delay is a hardware-based with fixed value, and the maximum doze duration is dynamical in the doze mode. Different doze duration thresholds based on traffic priorities are defined to guarantee the QoS metrics. The threshold for expedited-forwarding (EF) and assured-forwarding (AF), which are high-priority traffics, is set to 5ms, and maximum doze duration for best-effort (BE) is set to 20ms. Moreover, if there is no incoming traffic from user side the threshold can be set to hundreds of millisecond and less than one second. The function is added to the OLT to add the cycle time to the end of the GATE message. The DTC components read the GATE message and extract the cycle time and save it. To make accurate calculation, last ten cycle time is saved in the DTC. If the ONU also in the doze mode the DTC can receive the GATE message and save the cycle time. The $T_{mean}$ is the mean cycle time of last ten of two sequential cycle time calculate as Eq(1):

$$T_{mean} = \sum_{i=1}^{10} Tc_i \Big/ 10 \qquad (1),$$

where $Tc_i$ is the ith DBA cycle time. The $\varepsilon$ is the mean difference between $T_{mean}$ and cycle times and is calculated as Eq(2):

$$\varepsilon = \sum_{i=1}^{10} (Tc_i - T_{mean}) \Big/ 10 . \qquad (2)$$

The queue threshold for the EF traffic is calculated as Eq(3):

$$EF_{queue-threshold} = \frac{5 \times \sum_{i=1}^{10} EF_i \Big/ 10}{T_{mean} + \varepsilon}, \qquad (3)$$

where $EF_i$ is the number of EF bits accumulated in $Tc_i$ time. The AF and BE queue thresholds are defined as Eq(4) and Eq(5), respectively:

$$AF_{queue-threshold} = \frac{5 \times \sum_{i=1}^{10} AF_i \Big/ 10}{T_{mean} + \varepsilon}, \qquad (4)$$

$$BE_{queue-threshold} = \frac{20 \times \sum_{i=1}^{10} BE_i \Big/ 10}{T_{mean} + \varepsilon}, \qquad (5)$$

where $AF_i$ and $BE_i$ are the numbers of AF and BE bits in $Tc_i$ duration. The $T_{EF}$ is the time which ONU can enter to the doze mode if EF traffic is present and is calculated as Eq(6) as:

$$T_{EF} = \frac{Tc_i \times EF_{queue-threshold}}{EF_i} . \qquad (6)$$

The $T_{AF}$ and $T_{BE}$ are the time which can ONU enter to the doze mode if the AF and BE traffic are present and are calculated as Eq(7) and Eq(8):

$$T_{AF} = \frac{Tc_i \times AF_{queue-threshold}}{AF_i} . \qquad (7)$$

$$T_{BE} = \frac{Tc_i \times BE_{queue-threshold}}{BE_i} . \qquad (8)$$

Figure 2 shows the Tdoze duration calculation that ONU receives the GATE message, extracts the DBA cycle time and calculate the doze duration time based on the queue status, and maximum QoS requirements. The algorithm chooses Tdoze dynamically based on the present traffic types. The proposed mechanism is cyclic which allows the ONU to upload its data after Tdoze time. The Tdoze assigns to the REPORT message as the last queue number and forwards to the OLT. Therefore, the OLT informs status of ONU and prevent bandwidth allocation during doze mode. This mechanism helps the DBA to assign more bandwidth to the active ONUs and improves the system throughput of the EPON.

To evaluate the system performance, we analyze our proposed architecture in terms of packet delay and power saving. The system model is set up in the OPNET simulator with one OLT and 32 ONUs. The downstream/upstream channel rate is 1Gbps between OLT, and ONU. The ONU

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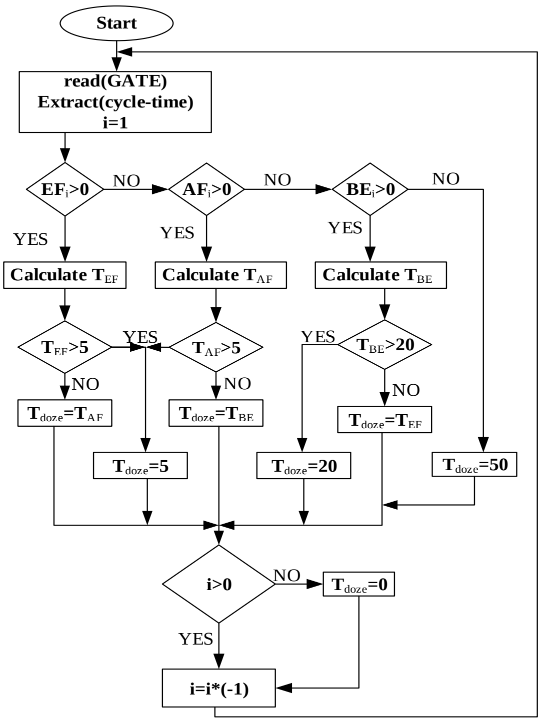


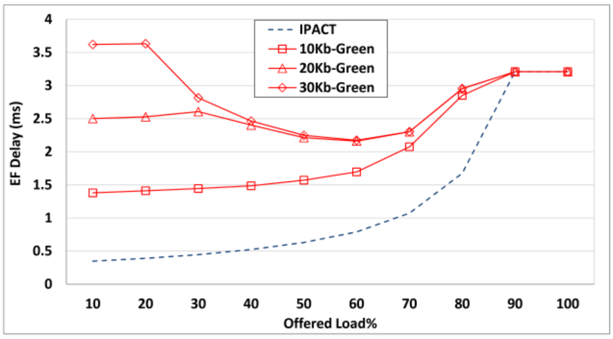

Figure 2. Doze duration calculation.

buffer size is set to 10Mb and distance between OLT, and ONUs is uniform in the range from 10 to 20km. The self-similarity and long-range dependence is used as the network traffic model for AF and BE. This model generates highly bursty AF and BE traffics with Hurst parameter of 0.7. The packet size is uniformly distributed between 64 to 1518 bytes. The high-priority traffic i.e., EF traffic is modeled using Poisson distribution with fixed packet size (70 bytes). We modify the IPACT DBA based on the proposed, called as Green DBA. We compare the Green DBA with IPACT DBA. To investigate facts of EF queue threshold, three significant scenarios are analyzed with 10Kb, 20Kb, and 30Kb EF threshold 10Kb-Green, 20Kb-Green and 30Kb-Green, respectively.

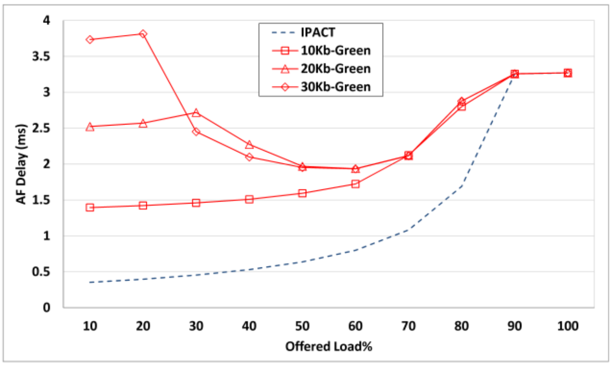
Figure 3 depicts the EF and AF mean packet delay versus the offered load in 32 ONUs. The Green DBA has a higher delay compare to the IPACT in the lightly load. The reason is that the Green DBA allows the ONU to enter the Doze mode however the delay is under the acceptable boundary. Moreover when the EF queue threshold is increased the delay is also increased. Figure 4 shows the power saving versus the offered load with 32 ONUs. The proposed Green scheme can save more power when the offered load is light because in the high offered load all ONUs are in active state.

## III. Conclusion

In this paper, we introduced a new ONU-initiated energy-saving mechanism that the ONU architecture is enhanced by doze controller component. The QoS aware energy-saving mechanism is proposed based on the different types of traffic requirements which is calculated based on the queue threshold, DBA cycle time and type of traffic in the ONU. Simulation results show that the proposed mechanism can significantly utilize the power consumption without affecting the QoS metrics.




a) Comparison of average EF Delay for different queue thresholds.




b) Comparison of average AF Delay for different queue thresholds.

Figure 3. Average delay of IPACT and Green DBA with different queue thresholds.

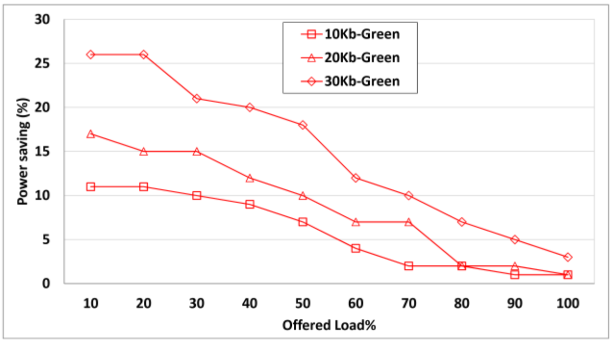



Figure 4. Energy efficiency of Green DBA with different queue thresholds.

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