ONU-Initiated Transceiver Mode Energy-saving Mechanism in SIEPON

I-Shyan Hwang, AliAkbar Nikoukar, Andrew Fernando Pakpahan and Andrew Tanny Liem

***Abstract*—Ethernet passive optical network (EPON) has the least energy consumption among access network technologies and is the best candidate to improve energy consumption by time utilization. Current studies have proposed OLT (optical line terminal initiated)-initiated schemes to turn off the transmitter/receiver of the optical network unit (ONU) for a substantial amount of time in order to save energy. In this paper, service interoperability EPON (SIEPON)-based ONU-initiated energy-saving mechanism is proposed in which the ONU calculates the transmitter (Tx) sleep duration on the basis of the current queue state and the maximum boundary delay requirements, and forwards it to the OLT. Then, the OLT calculates the receiver (Rx) sleep duration and determines whether the ONU's sleep mode is the Tx or the TRx mode. Further, the sleep manager, green dynamic bandwidth allocation, and TRx controller components are proposed in the OLT and ONU architectures to manage the energy-saving mechanism more precisely. Simulation results show that the proposed energy-saving mechanism significantly improves the energy savings by up to 47% and 42% in the upstream and the downstream direction, respectively, and guarantees the quality of service (QoS) requirement in terms of the mean packet delay, packet loss, throughput, and jitter. Moreover, the proposed energy-saving mechanism has a better delay performance than an OLT-initiated energy-saving mechanism such as upstream centric scheduling (UCS).**

***Index Terms*—EPON, ONU-initiated scheme, SIEPON, Energy-saving mechanism, QoS.**

I. Introduction

In recent years, energy consumption of access network in information and communication technology (ICT) has caught global attention due to the ever-increasing number of broadband users [1]. Among broadband access technologies, time-division multiplexing passive optical networks (TDM-PONs), such as Ethernet PON (EPON) and gigabit PON (GPON), have the most energy-saving optical access solution currently deployed to deliver high data rates to users and are key to the realization of fiber-to-the-home (FTTH) [2]. Although the TDM-PON consumes the least amount of power among the access network technologies, it still attracts considerable attention in the worldwide energy-saving plan of modern telecommunication [3].In EPON system optical network units (ONU)s have been reported to consume almost 90% of the power in a PON [4]. Therefore, a considerable amount of effort has been made to minimize the power consumption with low power modes by temporarily turning off the ONUs in a cyclic manner if they are idle [5]. Recently, the IEEE published IEEE service interoperability EPON (SIEPON 1904.1) for EPON and 10GEPON in 2013, which includes a framework for EPON power saving and defines energy saving as "a mechanism to reduce ecological impact, reduce operating costs, and extend battery backup time, while minimizing any degradation of network performance [6,7].

The SIEPON standard introduced OLT-/ONU-initiated energy-saving mechanisms [6] in which the OLT-initiated scheme is the centralized mechanism that the OLT uses to control the Tx/TRx energy-saving modes; on the other hand, the ONU-initiated scheme is a decentralized mechanism in which ONUs are responsible for the requests to enter into the Tx/TRx modes. Table 1 shows a comparison of the OLT- and ONU-initiated schemes where the energy-saving mechanism was initiated by the OLT and the ONU, respectively. The ONU-initiated scheme needs an additional message (SLEEP_INDICATION) as compared to the OLT-initiated scheme in order to inform that the OLT is entering into the sleep mode. The advantage of the ONU-initiated scheme is that the DBA and the sleep duration calculation are executed more precisely on the basis of the current status in order to satisfy the QoS requirements than in the OLT-initiated scheme.

Recently, many studies have proposed OLT-initiated energy-saving mechanisms to achieve maximum energy savings by sending the ONU into the sleep mode in 20–50 ms without considering whether the QoS metrics are dramatically scarified. Furthermore, putting the ONU into the sleep mode for a long sleep duration violates the SIEPON energy-saving definition. To tackle this problem, we introduce an SIEPON-based ONU-initiated energy-saving mechanism to guarantee the QoS requirements and improve the energy savings.

Table 1. Comparison of OLT- and ONU-initiated schemes [6]

Characteristic	OLT-initiated	ONU-initiated
Complexity	O(*N*)*	O(*N*)*
Sleep mode initiated by	OLT	ONU
Sleep mode determined by	OLT	ONU
SLEEP_INDICATION message	No	Yes
SLEEP_ALLOW message	Yes	Yes
QoS	DBA dependent	Yes

**N* denotes the number of ONUs in the EPON.

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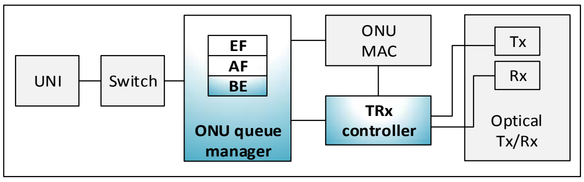
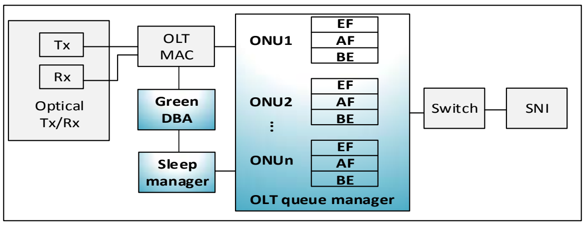


(a) ONU architecture



(b) OLT architecture

Figure 1. Proposed OLT and ONU architectures.

The rest of this paper is organized as follows: Section 2 describes the proposed OLT and ONU architectures in which new components, functions, and messages are added to the ONU and OLT architectures in order to enhance the EPON functionality and the power-saving mechanism to calculate the dynamic transceiver sleep duration. Section 3 discusses the performance evaluation of the energy-saving mechanism and a comparison of the proposed mechanism with the OLT-initiated mechanism, upstream centric scheduling (UCS) [8], in terms of the mean packet delay, packet loss, and energy-saving ratio. Finally, we summarize this paper and present some directions for future work in Section 4.

II. Proposed Mechanism

This section describes the proposed system architecture including the enhanced ONU and OLT architectures, the system operation and also the Green DBA mechanism.

A. *ONU and OLT architectures*

Figure 1(a) shows the proposed ONU architecture including the ONU queue manager and the TRx controller components. The ONU queue manager is responsible for classifying the incoming traffic from the user network interface (UNI). The queue has three sub-queues with different types of traffic, such as expedited forwarding (EF), assured forwarding (AF), and best effort (BE), to guarantee the QoS metrics and help the TRx controller to calculate the Tx sleep duration. The TRx controller has functions and algorithms that are responsible for the Tx sleep duration calculation and the control transmitter and receiver. The Tx controller is responsible for synchronization with OLT by sending the SLEEP_INDICATION, SLEEP_ALLOW, and SLEEP_ACK messages. SLEEP_INDICATION will report the Tx sleep duration when the TRx controller calculates the sleep duration.

Figure 1(b) shows the OLT architecture with three new components: the OLT queue manager, sleep manager, and green DBA. The OLT queue manager is responsible for classifying the incoming traffic from SNI. The OLT queue manager is accountable for ONU's traffic arrangement in the downstream transmission direction where each ONU has its own queue with separate sub-queues for different types of traffic. The sleep manager calculates the ONU's receiver (Rx) sleep duration, compares the reported Tx sleep duration with the ONU's Rx sleep duration, and finally, calculates the TRx sleep duration on the basis of the Tx and Rx sleep durations and determines the sleep mode (Tx or TRx).

B. *System operation*

The operation of the proposed mechanism, as can be seen in Fig. 1 can be described as follows:

1. TRx controller (at the ONU) extracts the granted times from the GATE message to calculate the ONU's transmitter sleep duration (Tx).
2. ONU's MAC forwards the Tx sleep duration to the OLT by the extended SLEEP_INDICATION.
3. Sleep manager calculates the ONU's Rx sleep duration, compares the Tx and Rx sleep durations to calculate the TRx sleep duration, and determines the ONU's sleep mode.
4. OLT's MAC sends the ONU's sleep duration and sleep mode to the ONU through the SLEEP_ALLOW message.
5. ONU responds with the SLEEP_ACK message, and the TRx controller is responsible for turning off/on the ONU's transmitter/receiver.

C. *Green DBA*

The proposed green DBA is an offline DBA. The OLT receives the sleep duration from the sleep manager that is either in Tx or in TRx. The ONU cannot enter into the sleep mode if the Tx and TRx values are zero; therefore, the OLT assigns a bandwidth to the ONU on the basis of REPORT Message. On the other hand, if the Tx or TRx value is more than zero, the OLT sends a SLEEP_ALLOW message to the ONU and sets the grant bandwidth to zero for all types of traffic for the ONU. The green DBA grants a bandwidth on the basis of the bandwidth available, $B_{available}$, for the entire ONUs and the maximum transmission window, W_{max}. W_{max} for each traffic type is assigned depending on the traffic priority (EF, AF, and BE). If the EF request is more than W_{max}, W_{max} is assigned to the EF; otherwise, OLT assigns the EF request. If the EF request is less than W_{max}, the green DBA assigns a bandwidth to the mid (AF) and low (BE) priority. The remaining bandwidth, W_{left}, is assigned to the AF. If the AF request is for more than W_{left}, the remaining bandwidth is assigned to the AF; otherwise, the green DBA assigns the requested bandwidth to the AF, and the remaining bandwidth is assigned to the low-priority traffic (BE).

III. System Performance

In this section, we analyze the proposed mechanism in terms of the mean packet delay, packet loss ratio, and power-saving ratio. The proposed green mechanism is compared with the system that uses the IPACT DBA [9] without an energy-saving mechanism. Moreover, we compare our system performance with that of the UCS mechanism in terms of the EF delay and the energy-saving improvement in the upstream and downstream transmissions.

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Table 2. Simulation parameters.

Parameters	Value
Number of ONUs	32
Up/down link rate	1 Gbps
OLT–ONU distance	10–20 km
ONU wake-up overhead	0.125 ms
Power consumption of active mode	3.85 W
Power consumption of Tx sleep mode	1.7 W
Power consumption of TRx sleep mode	1.08 W
ONU buffer size	10 Mb
Maximum transmission cycle time	1 ms
Guard time	5 µs
DBA computation time	10 µs
Control message length	64 bytes

Table 3. Simulation scenario.

Scenario	EF (%)	AF (%)	BE (%)
154	10	50	40
244	20	40	40
163	10	60	30
253	20	50	30

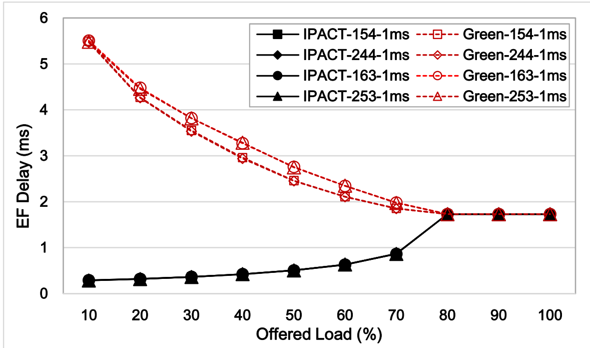
The proposed mechanism is modeled using an OPNET simulator with 32 ONUs and an OLT. The efficient downstream/upstream channel rate between OLT and ONU is set to 1 Gbps. The OLT and the ONUs are uniformly distributed at distances between 10 km and 20 km, and the ONU buffer size is 10 Mb. The overhead time is 0.125 ms when the ONU changes its state from the sleep mode to the active mode. The ONU power consumption is 3.85 W in the active mode, 1.7 W in the Tx mode, and 1.08 W in the TRx mode. The maximum transmission cycles are 1 ms. Self-similarity and long-range dependence are used as the network traffic model for AF and BE. This model generates high-burst AF and BE traffic with a Hurst parameter of 0.7. The packet size is uniformly distributed between 64 and 1518 bytes. The high-priority traffic (EF) model is based on a Poisson distribution with a fixed packet size (70 bytes) [10]. The simulation parameters are summarized in Table 2. The four scenarios shown in Table 3 are designed and analyzed with various EF, AF, and BE service proportions to show the effectiveness of high-priority traffic management.

A. Mean packet delay

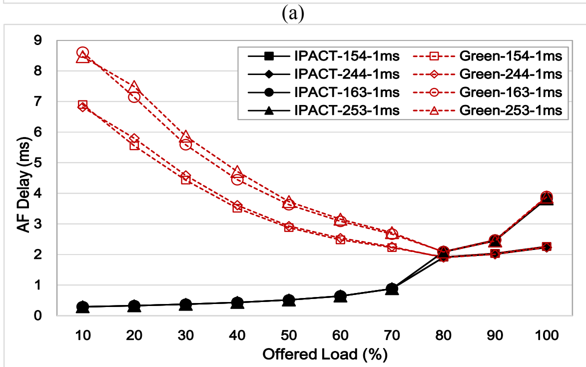
Figures 2 shows the mean packet delays versus the traffic loads of EF, AF, and BE for maximum DBA cycle times of 1 ms. The EF, AF, and BE traffic delays of the proposed green DBA are more than those of the IPACT in the case of a light load for maximum DBA cycle because the ONU enters into the sleep mode for the sleep duration in the proposed mechanism. The EF, AF, and BE delays show a decreasing trend when the traffic load increases. The EF, AF, and BE delays of the proposed mechanism have the maximum value when the traffic load is 10%; however, the EF and AF delays still satisfy the QoS boundary requirement.

B. Packet loss ratio

The cycle time and the buffer size are two main factors that affect the packet loss. An increase in the cycle time decreases the packet loss but leads to an increase in the packet delay. On the other hand, increasing the buffer size decreases the packet loss but increases the packet delay. The EF and AF packet losses of the proposed green DBA and IPACT are zero in all scenarios and for all cycle times. Figure 3 shows the BE packet loss ratio versus the offer load. The BE packet loss of the green DBA and IPACT with a cycle time of 1 ms is zero when the traffic load is less than 70%. The BE packet losses of the green



(a)



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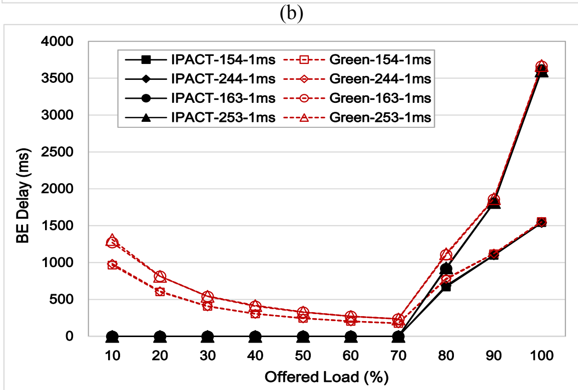

(c)

Figure 2. Mean packet delay comparison of green DBA and IPACT in different scenarios with a cycle time of 1 ms.

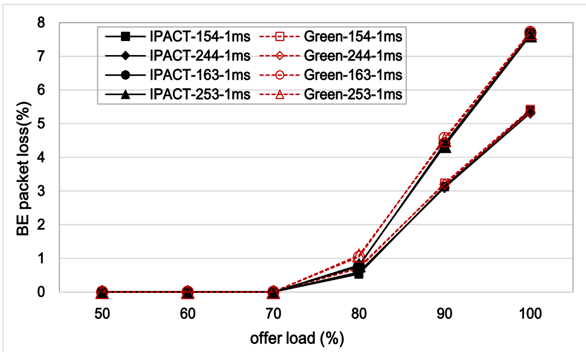

Figure 3. Packet loss ratio of green DBA and IPACT in different scenarios.

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DBA and IPACT in the case of a high traffic load are the same in all scenarios and for all cycle times, which implies that the proposed green DBA will not affect the packet loss.

C. Proposed energy-saving mechanism vs. UCS

This section compares the proposed energy-saving mechanism with UCS in terms of the mean EF delay and the energy-saving improvement.

1. Mean EF Delay

Figure 4 shows the EF delay of the proposed ONU-initiated energy-saving mechanism and the OLT-initiated UCS versus the offer load in the upstream. The EF delay of the UCS scheme is higher than that of the proposed mechanism because the OLT assigns a fixed time slot to the ONU for an upstream/downstream transmission in the UCS scheme.

2. Energy-saving improvement

Figure 5 compares the mean packet delay and the energy-saving improvement versus the offer load for the UCS and the proposed green DBA in the upstream and downstream directions. The mean packet delay of the UCS is higher than that of the proposed green DBA. Therefore, UCS has a better energy-saving improvement than the proposed green DBA. However, UCS reduces the QoS requirement by increasing the delay. When the traffic load increases, the energy savings decrease.

IV. CONCLUSION

In this paper, we proposed a new ONU-initiated SIEPON-based energy-saving mechanism for the TRx sleep mode that can have more control over the energy-saving mechanism. The TRx controller monitors the ONU's traffic, calculates the Tx sleep duration on the basis of the incoming traffic ratio and the traffic types, and reports it to the OLT. The sleep manager calculates the Rx sleep duration on the basis of the different traffic types and the queue threshold in the downstream direction, compares the Tx and TRx sleep durations to achieve optimal energy savings, and determines the ONU's energy-saving mode (TRx or Tx). The simulation result proves that the proposed power-saving mechanism saves the transmitter/receiver power, while satisfying the QoS boundary requirements. In the future, we intend to find the optimal sleep duration for both the transmitter and the receiver without scarifying the QoS and QoE.

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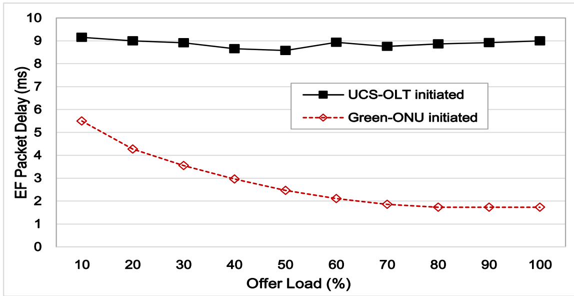
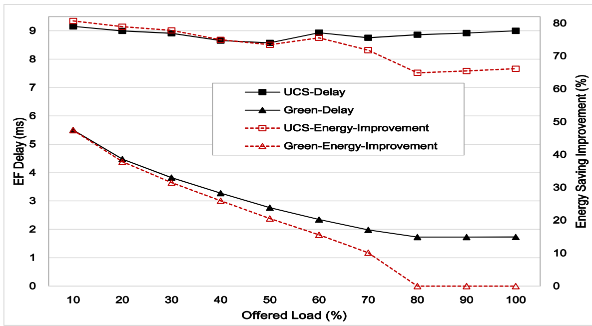
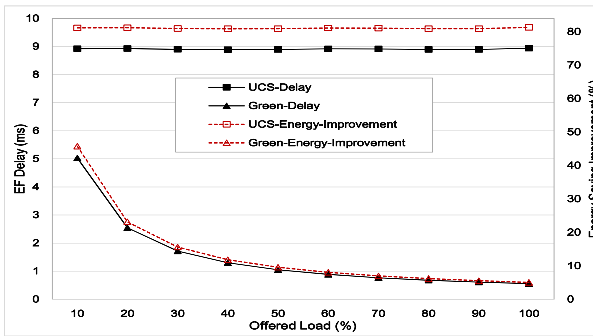


Figure 4. EF delay comparison with the UCS mechanism in the upstream direction.



(a) Energy saving improvement in the upstream direction with a cycle time of 1ms.



(b) Energy saving improvement in the downstream direction.

Figure 5. Energy saving improvement of green DBA and UCS in different scenarios.