Cycle-based Energy-saving Scheme for NG-EPON Networks with High Traffic Loading

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Abstract

The next generation Ethernet passive optical network (NG-EPON) is one of the most efficient transmission technologies for broadband access. However, the active component ONU in such network still consumes a lot of power especially in high-load traffic. Meanwhile, the high-load traffic could invoke many idle periods which could waste power in the network. This work aims to find those idle periods from current cycle and even on next cycle. The proposed scheme classifies ONUs into intra-sleep ONUs and inter-sleep ONUs and then transforms them to different range of temporal sleep modes for these ONUs to save power. Simulation results show that a satisfactory power saving effect is achieved in high-load traffic while keeping a low delay.

Keywords: NG-EPON, Cycle based, High-load traffic, Intra sleep, Inter sleep, Power saving

1 Introduction

The NG-EPON [1] network, a time and wavelength division multiplexing (TWDM) architecture, consists of optical line terminal (OLT) and a number of optical network units (ONUs). Where the OLT contains four optical subscriber units (OSUs). The interleaved polling with adaptive cycle time (IPACT) mechanism [2] is one of the best-known scheduling mechanisms for EPON network. It allows the OLT to arbitrate and grant a size, in maximum transmission window (MTW), for each ONU on downstream channel in an interleaved and round robin manner.

Usually, ONU consumes higher power in higher traffic loading because it has to stay at Active or Doze mode to deliver packet more frequently than lower loading. Moreover, a lot of previous works [3-5] designed that ONU at Active or Doze mode would not change to sleep mode if its packet queue is not empty. It is because ONU after being serviced needs to wait in current cycle and deliver remaining packets on next cycle. Such waiting for ONU in original state consumes a lot of unnecessary power. Besides, such wasting energy phenomena is getting more obvious in higher traffic loading.

This research work aims to find the idle period, i.e. waiting time, especially in high-load traffic to allow ONU changing to a temporal Sleep mode from its non-sleep mode to reduce unnecessary power consumption. The length of sleep time may be extended from the end of cycle to next cycle under certain conditions.

The paper is organized as follows. A power saving frame work adopted in this study and the related works for reducing unnecessary power consumption particularly in high-load traffic are described in Sec. 2. In Sec. 3, the proposed cycle-based scheme with combining intra-sleep and inter-sleep approach is introduced. In Sec. 4, the simulation results of applying proposed scheme for different downstream traffics are evaluated. Finally, the paper is concluded in Sec. 5.

2 Related Works

Liu et al. [4] proposed a tri-mode energy-saving mechanism for ONU switching its energy mode, i.e. Active Doze or Sleep mode, according to traffic loading. Its basic switching concept is as follows. When packet arrives at buffer of upstream channel or both upstream and downstream channels, ONU switches to Active mode. ONU turns on its receiver but turns off its transmitter, i.e. in Doze mode, if packet arrives at queue of downstream channel only. As for the case of empty queue on both upstream and downstream channel, ONU switches to Sleep mode. Besides, to achieve the short delay performance, ONU will be triggered to Active mode from either Doze or Sleep mode whenever a high-priority packet arrives at buffer of upstream channel.

The works of adding Doze mode can accommodate the downstream only traffic such as streaming service. For such scenario, ONU can enjoy the benefit of energy-saving effect by using this energy-state transition model.

Liu et al. [4] further proposed a load regulation

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scheme [5] based on above mechanism for ONU switching energy mode according to traffic loading. In which, it measures a remaining load on both upstream and downstream channels. And then it sets two thresholds, i.e. lower and upper bound, on each channel to prevent ONU from waking up too early and staying at Active mode too long to save power. Moreover, the mechanism in [5] is suitable for asymmetric traffic such as video streaming for saving energy while keeping a short delay. Therefore, this study takes it as our power saving framework of NG-EPON network to develop and enhance saving effect.

Hu et al. [6] proposed an intracycle power saving scheme in 10G-EPON network. In that work, ONU utilized idle slot within each cycle to enter sleep under heavy traffic. For light traffic, ONU might stay asleep for a longer duration lasting for several cycles to reduce frequent transition between Sleep and Active mode. Such scheme of intracycle sleep explored the idle slot in each of scheduling cycle to allow ONU to sleep before the end of cycle to reduce power consumption.

However, a maximum energy saving timer of 1 second [7] is a watchdog timer implemented on the MPCP protocol to deregister an idle ONU from the OLT database if there is no any traffic sent from such an ONU. And typically, the cycle time duration in EPON network is 1, 2, 4, or 8 ms [8]. Therefore, for light traffic loading scenario, an idle ONU should be able to sleep automatically for lots of cycle duration as the work in [4]. Hence, for our research work, it is not necessary to extend the sleep time of light loaded ONU discussed in the work of [6]. Thus, this work also focuses on saving energy consumption of the idle duration for ONUs with higher traffic loading. However, the time length in such work can only sleep to the end of each cycle. On the contrary, the following proposed work can further extend sleep to next cycle under certain conditions. The difference for length of sleep time and sleep mode between [6] and our proposed work is shown in Table 1. Besides, there exist a few differences between work of [6] and our proposed work such as the number of adopted energy modes, the network architecture, and analysis method. For example, that work adopts only two energy modes, Sleep and Active modes. However, the operation of our adopted frame work is based on three energy modes with added Doze mode. That work analyzed power conservation in 10G-EPON TDM network and our proposed work considers power saving scheme in 100G-EPON TWDM network.

3 Proposed Scheme

A lot of previous works [3-5] designed that ONUs after being served typically wait and keep at the same energy state for next cycle delivering remaining packets. Such waiting at the original state consumes a lot of unnecessary power, especially worse in higher traffic loading scenarios. It is worthy to find the idle period in high traffic loading to reduce unnecessary power consumption.

Table 1. Comparison of sleep mode and length of sleep time

	Intracycle scheme [6]	Proposed work
Sleep mode	Intracycle sleep	Intracycle sleep + Intercycle sleep
Length of sleep time	To the end of cycle	From the end of cycle to next cycle (while a condition of 2MTWs holds), otherwise to the end of cycle

3.1 Transformation of Idle-period

On some occasions, ONU cannot send all of its packets in one cycle due to MTW limitation. Typically, it will stay at non-sleep mode, i.e. Active or Doze mode, in order to deliver packets on next cycle as soon as possible until all remaining packets are transmitted. However, the longer duration that an ONU keeps at non-sleep mode means more energy consumption. Specifically, the occurrence of an ONU with lots of remaining packets is very common in high traffic loading scenario.

Due to the method of time-division multiplexing on upstream channel, a non-sleeping ONU will only be served for some portion of duration within any single time of cycle time in the EPON networks. When and how long that an ONU can transmit packets within each cycle is arbitrated by OLT. Every non-sleeping ONU takes turns to exchange packets with the OLT in a scheduled duration. Therefore, a TDM-like operation is carried out cycle by cycle. After packet exchange, a non-sleeping ONU remains at its non-sleep mode and waits for transmission on next cycle. The period of ONU's waiting time for next transmission, called idle-period in this study, will be relatively long if there are a lot of scheduled ONUs in the cycle. The idle-period may cause significant energy wastage potentially.

In fact, after packet exchange with OLT, an ONU can be switched into Sleep mode temporarily as long as this ONU can return to its previous non-sleep mode in time before next scheduled time arrives. The length of temporary sleep time can contribute to energy saving effect. Therefore, this work proposes a cycle-based energy-saving scheme which explores the idle-period of each ONU and transfers the idle-period to sleep time for extending energy saving effect.

It is noted that the following operations are dedicated for those non-sleep ONUs, i.e. ONUs in Active or Doze mode. For those ONUs at Sleep mode, they remain at Sleep mode and will not be scheduled. Besides, in this work, OLT schedules upstream and downstream channel simultaneously as in work [4] as follows. Whenever OLT receives requested size from an ONU at upstream channel, it also checks size of downstream queue for such an ONU. The OLT then compares both sizes and reserves the same bandwidth on both channel directions with the size of bigger one for this ONU. After this, OLT allocates bandwidth as method above for next ONU accordingly.

3.2 Process of Cycle-based Energy-saving Scheme

For each cycle, OLT estimates the number of required channels by accumulating the requested size from all ONUs. Besides, according to a requested size of an ONU at previous cycle, OLT classifies the ONU as intra-sleep ONU, if the requested size of the ONU is less than a predefined threshold, M. Otherwise, the ONU is classified as inter-sleep ONU. Where the threshold of 2 MTWs is chosen for M in this study.

OLT then allocates each intra-sleep ONU with time duration to transmit its requested size and schedule the specific transmission time. OLT also commands this type of intra-sleep ONU to go for temporary sleep to the end of current cycle after it finishes its transmission in current cycle. After temporary sleep, the intra-sleep ONU returns to its prior mode, Doze or Active mode.

The reason to schedule intra-sleep ONU to wake up before the end of current cycle is that the requested size of such an intra-sleep ONU is less than 2 MTWs. The requested size can be allocated in current cycle for sure but the amount of granted size to allocate on next cycle is still uncertain at the moment of scheduling process, due to that new packets may arrive in between current and next cycle. Without knowing an accurate requested size, OLT cannot schedule the length of sleep time for such type of ONU next cycle. Thus, the temporary sleep time starts from the end of ONU transmission time to the end of current cycle.

As for the inter-sleep ONU, OLT is able to schedule such type of ONU to go for the temporary sleep from the end of its transmission slot in current cycle to the beginning of its transmission slot on next cycle and then return to prior mode. Since an inter-sleep ONU requires bandwidth more than 2 MTWs, OLT needs to allocate such ONU with the time slot of one MTW size every cycle for the next two consecutive cycles. Furthermore, two time slots can be reserved at the same relative time position in the current cycle and next cycle, so that OLT can keep track of the wake-up time of ONU on next cycle. Accordingly, the temporary sleep time of such inter-sleep ONU starts from the end of its transmission time in current cycle to the beginning time of its transmission on next cycle. Note that the inter-sleep ONU which is the first ONU to transmit its packets in the next cycle has to wake up at beginning of next cycle. Such ONU can only sleep to the end of current cycle, though it is the type of inter-sleep ONU.

Besides, for a NG-EPON network with multiple channels, the channel assignment mechanism is designed as follows. Since there are two types of ONUs, OLT arranges all inter-sleep ONUs first, in the order of ONU's ID, ahead of all intra-sleep ONUs from the first available channel. ONUs will be allocated to next channel whenever one channel is full. The flowchart of proposed scheme is illustrated in Figure 1.

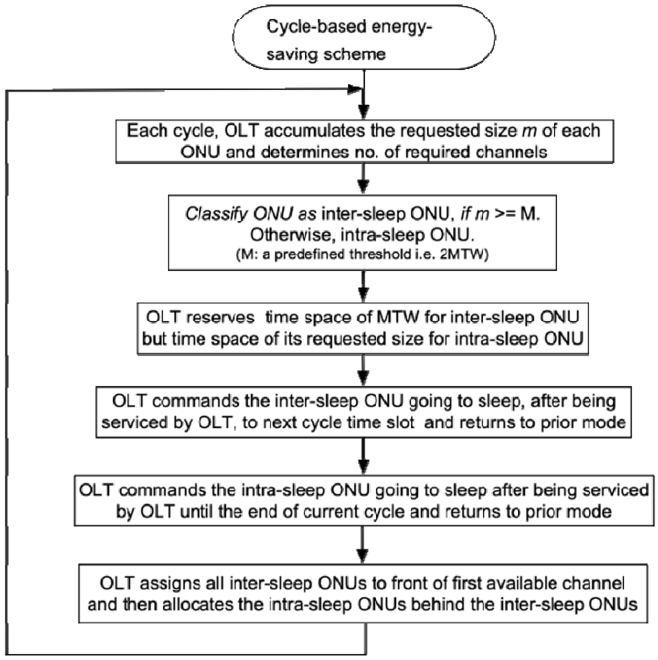

Figure 1. Cycle-based energy saving scheme

Also note that there are two kinds of time gaps which may cause overhead in such network. The first overhead is tuning time, a delay required to switch from one wavelength to another, if an ONU is scheduled to switch from one wavelength channel to another for transmission. Such delay could be a noticeable overhead if the occurrence of switching wavelength channel happens too often.The second one is the wake-up time, which varies from different circuit technologies [6] and [9], i.e. time required for ONU to wake up from Sleep to Active/Doze mode. To schedule each Active/Doze ONU for the temporary sleep, such overhead should be taken into consideration. In this study, the ONU will not switch to sleep if the remaining cycle time, estimated by total amount of packets from all ONUs in each cycle, is too short.

Figure 2 shows an example of end-of-sleep time for inter-sleep ONUs, ONU 1 to 6, and intra-sleep ONUs, ONU a to g, in a two channels EPON network. All inter-sleep ONUs can extend the end-of-sleep time from current cycle i, to next cycle j, except ONU 1 and ONU 5. These two ONUs are the first ONU to transmit packets in next cycle j but they can only sleep to the end of current cycle i. As for the intra-sleep ONUs, their requested size on next cycle, unlike the requested size for inter-sleep ONU to be at least one MTW, is unknown because new packets may arrive. Therefore, at the moment of scheduling stage for the current cycle i, the starting time of these intra-sleep ONUs to transmit packets on the next cycle j is undermined yet. Thus, the end-of-sleep time of all intra-sleep ONUs is limited, and is to set to the end of current cycle. That is the end-of-sleep time for ONUs a, b and c, which are granted at cycle i, is set to be the end of cycle i. Similar setup holds for the ONUs d, e, f and g granted at cycle j and is set to be the end of cycle j.

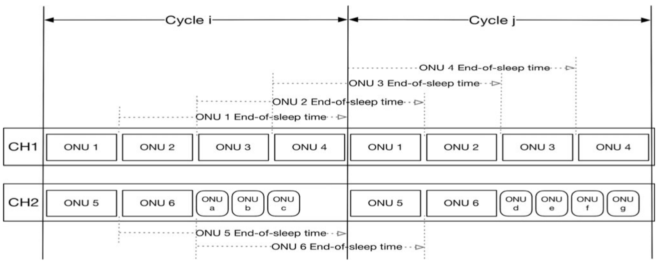

Figure 2. End-of-sleep time of inter-sleep and intra-sleep ONUs

3.3 State Transition Path of Intra-sleep and Inter-sleep States

The state transition diagram for ONUs operated in intra-sleep and inter-sleep state is shown in dash-line rectangle of Figure 3. Both states can be triggered from either Active or Doze mode. The paths (1) and (2) indicate that an ONU classified as intra-sleep ONU at Active mode can switch into and out the intra-sleep state for a temporary sleep. The paths (3) and (4) are used by Doze mode for starting and finishing intra-sleep state. The paths (5) and (6) present that the inter-sleep ONU in Doze mode can switch into inter-sleep state and return back. As for paths (7) and (8), it represents the inter-sleep ONU in Active mode with the path into and out the inter-sleep state.

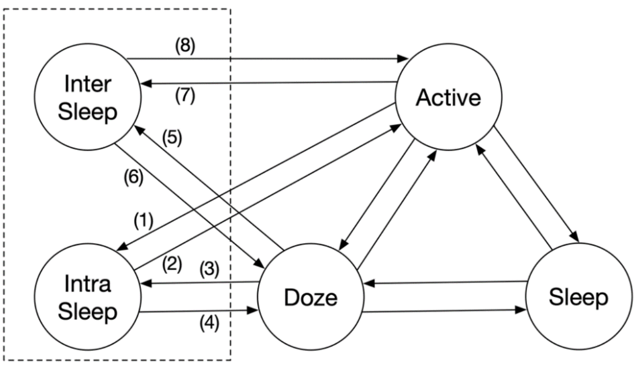

Figure 3. State transition diagram for intra-sleep and inter-sleep state

4 Performance Evaluation

The simulation is to observe the effect of cycle-based energy saving-scheme on a Tri-mode EPON system while applying intra-sleep or/and inter-sleep policies for ONU. It is conducted by OMNet++ 4.6 in a NG-EPON network with 128 ONUs and 4 OSUs in an OLT at a distance of 20 km between each ONU and OLT. Each ONU is equipped with a pair of tunable transmitter and receiver. There are 4 upstream/downstream channels, each channel with maximum capacity 25 Gbps. The frame size is between 64 and 1518 bytes, randomly generated by Uniform distribution. The algorithm of DBA for allocation bandwidth is IPACT with limited service. The wake-up and tuning time are chosen from [9] and [10]. The traffic pattern is set as self-similar traffic [11]. The power consumption weight represents the normalized power consumption ratio of Doze and Sleep modes with respect to Active mode, referred and averaged from results of [12-16]. The consumed power ratios of Doze and Sleep to Active are 0.3 and 0.1, respectively. The main simulation parameters are shown in Table 2.

Table 2. Simulation parameter settings

Parameter	Value
Number of ONUs	128
Downstream Channel Capacity (4 channels)	100 Gbps
Upstream Channel Capacity (4 channels)	100 Gbps
OLT-ONU Distances	20 km
Traffic Pattern	Self-similar
Guard Interval	1 μs
Frame size	64 bytes~1518 bytes
ONU queue size	100 Gbytes
Maximum transmission window (MTW)	187500 bytes
Simulation Time	10 seconds
Bandwidth Allocation	IPACT Limited Service
Tuning time	10 μs
Wake up time	125 μs
Power Consumption Weight	Active (1), Doze (0.3), Sleep (0.1)

The compared schemes include the proposed cycle-based scheme, denoted as CycleBase, the intra-cycle sleep scheme, denoted as IntraSleep, and the Tri-mode scheme, denoted as Tri-mode. Where the CycleBase combines intra-cycle and inter-cycle sleep scheme. The main difference for three schemes is the length for temporary sleep time of ONU, i.e. the time of a temporary sleep after ONU completes transmission and reception of packets for the underlying cycle. The maximum temporary sleep time of the proposed CycleBase scheme can be extended to next cycle, if ONU requests a size over 2 MTW. The maximum temporary sleep time of IntraSleep scheme is up to the end of current cycle. As for the Tri-mode scheme, the temporary sleep time is zero because it does not support an ONU to switch into temporary Sleep mode.

Figure 4 and Figure 5 show the percentage of time that ONUs spend in Active and Doze modes, the most and the secondary power-consumption mode among three modes, for three schemes. These results of both IntraSleep and CycleBase schemes are lower than the TriMode scheme. Besides, the proposed CycleBase scheme has lowest portion in Active or Doze mode after downstream loading goes beyond 48 Gbps especially.

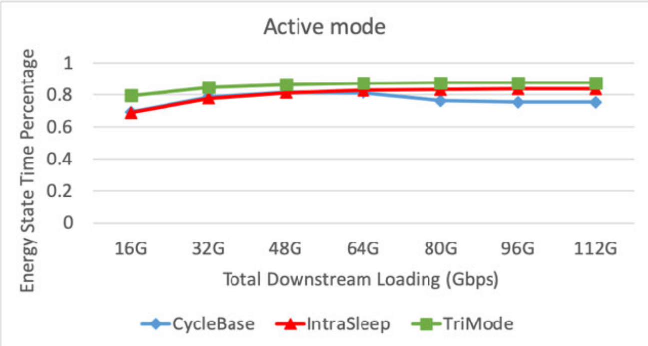

Figure 4. The power consumption in Active mode on three schemes

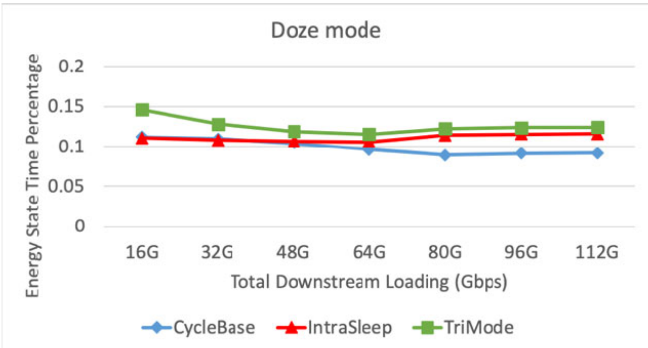

Figure 5. The power consumption in Doze mode on three schemes

As for the percentage of time in Sleep mode, the lowest power-consumption mode among three modes, the result of IntraSleep scheme is a little bit lower than CycleBased scheme when loading is below 48 Gbps. It is because that the threshold setting for going in or out a Sleep mode for IntraSleep is measured in a bit rate, i.e. bit per second in our adopted frame work, unlike CycleBase scheme uses a fixed value in bit, i.e. 2 MTWs. Therefore, if OLT measures traffic for IntraSleep scheme in a low loading traffic, a very small value may be obtained because the data rate is small in lower loading. According to the framework design in [5], if the measured value is less than a certain threshold value, it will prevent slept ONU from entering Active or Doze mode.

However as shown in Figure 6, the percentage of time that ONUs stay Sleep mode for the proposed CycleBase scheme is significantly high when loading goes beyond 48 Gbps. It is because that more ONUs in the proposed scheme tend to meet the requested size of more than 2 MTW in higher loading, thus a longer temporary sleep across to next cycle is enabled.

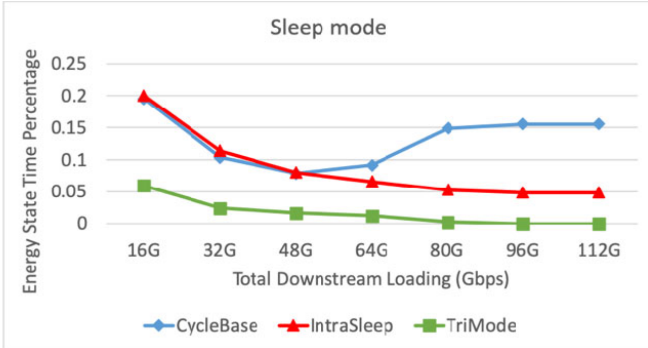

Figure 6. The power consumption in Sleep mode on three schemes

Figure 7 exhibits the total normalized energy consumption calculated by the sum of multiplying the percentage of time at each mode shown in Figure 4, Figure 5 and Figure 6, with its power consumption weight in Table 1, for three schemes. On average, the proposed scheme, denoted as small grid, outperforms the other two schemes particularly in higher loading. The overall trend of energy consumption for the proposed scheme on higher 64, 80, 96, and 112 Gbps loading shows lower energy consumption, in contrast to lower loading (16, 32, 48, and 64 Gbps). That is because a lot of idle-period will be formed in higher loading, which results in the temporary sleep time for ONU in proposed CycleBase scheme. Therefore, these ONUs in overall consume a smaller amount of energy.

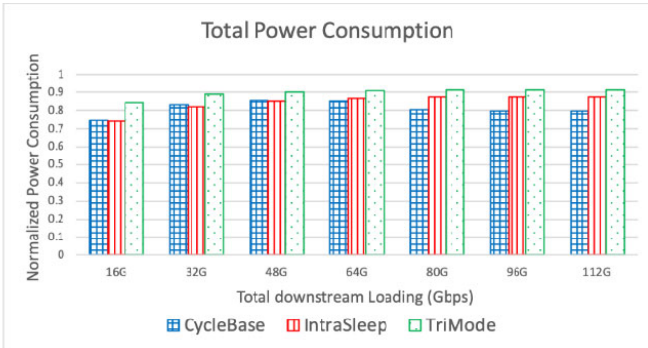

Figure 7. The total power consumption on three schemes

Figure 8 shows the average delay of high-priority packets in downstream channel. The proposed scheme, denoted as small circle, induces higher delay before channel is full because the inter-sleep ONUs of proposed scheme will be always gathered in front of first available channel and then put the other ONUs at the back until channel is full. The other two schemes assign ONUs randomly among all available channels. As a result, the length of all channels is prone to balance. Therefore, the channel length of proposed CycleBase scheme would be slightly longer that causes a higher delay. However, the delay discrepancy among all three schemes is quite small. As for the loading beyond 80 Gbps, all channels are getting full and thus the delay discrepancy of all three schemes decrease and converge to the same values.

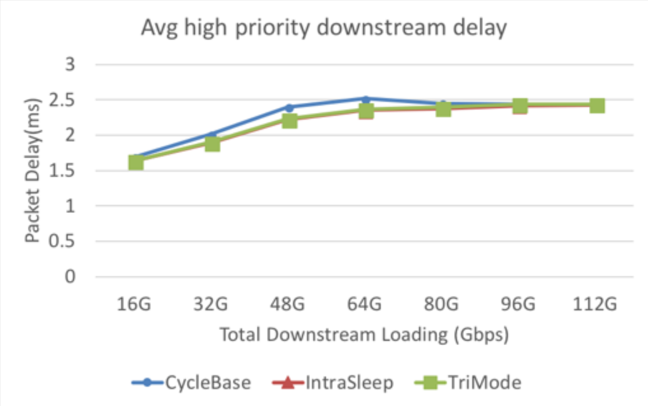

Figure 8. The average delay of high-priority packet in downstream channel

Figure 9 shows the average delay performance of high-priority packets in upstream channel. The delay of the proposed scheme is lower than the other two schemes beyond loading 64 Gbps since the inter-sleep ONU of proposed scheme is arranged in the same channel from current to next cycle. It avoids a frequent channel switching on downstream channel, leading to the significant reduction of tuning delay, which in term, also speeds up the process of transmitting upstream packets.

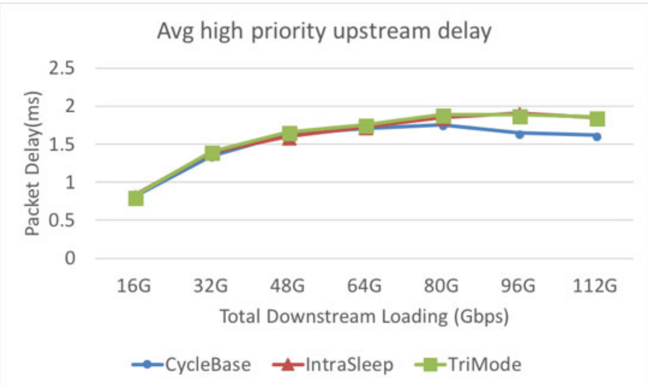

Figure 9. The average delay of high-priority packet in upstream channel

Figure 10 shows the average delay performance of low-priority packets in downstream channel. The proposed scheme has lower delay when all channels are full because the inter-sleep ONUs in proposed scheme is always arranged in the same channel for next cycle. The tuning delay for these ONUs can be thus decreased.

The arrival of low-priority packets does not trigger the early wake-up mechanism. In addition, the inter-sleep ONUs in the proposed scheme can sleep at least two cycles that slows down transmission process on upstream channel. Therefore, such delay will be slightly higher than the delay of the other two schemes as shown in Figure 11. On the contrary, the ONUs of the other two schemes will be waken up or kept in non-

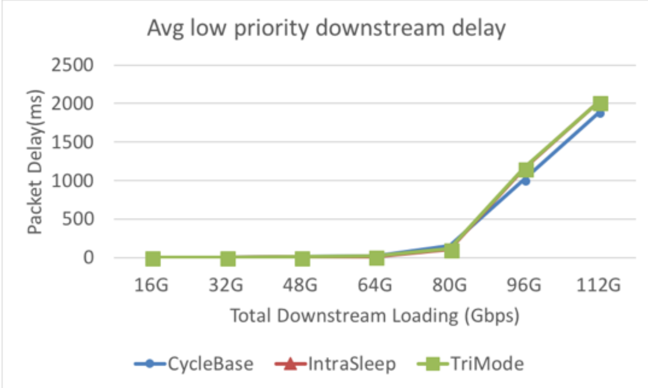

Figure 10. The average delay of low-priority packet in downstream channel

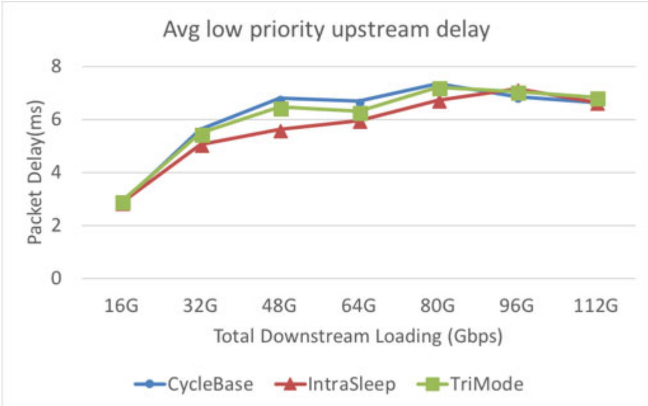

Figure 11. The average delay of low-priority packet in upstream channel

sleep mode, Active or Doze mode, before the end of current cycle. Again, the discrepancy of such delay among all three schemes is small.

Figure 12 shows the average channel usage for downstream loading. The proposed scheme has higher number of used channels for downstream loading between 32 and 80 Gbps. The proposed scheme as well as the other two schemes estimates the number of required channels according to total requested size in current cycle before scheduling. However, proposed scheme will allocate all inter-sleep ONUs to first available channel and then arrange remaining ONUs at the back of inter-sleep ONUs or assign them to another channel if current channel is full. It is prone to using an extra channel if process in channel assignment exists a size of an ONU which cannot fit into the remaining space of one channel while the channel is almost full, in contrast to the other two schemes with randomly assigning to one of available channels.

In summary, the key idea of this work is to identify and transfer the idle-period to a temporary sleep time. A significant amount of idle-period has been transferred to its respective sleep time especially in the case of high traffic that can be observed from performance results exhibited from simulations. It is because the idle-period is prone to be longer in the scenario of heavy load than light traffic in such

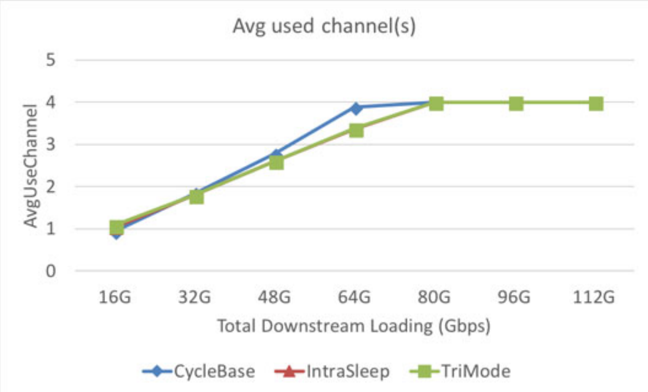

Figure 12. The average used channel(s) for downstream loading

polling-based EPON network. Therefore, the proposed scheme can transfer more idle-periods into sleep time. It is noted that the arising sleep time has increased energy-saving effect significantly.

5 Conclusion

In this study, the ONU is classified into type of intra-sleep ONU or inter-sleep ONU in each cycle. The proposed scheme then jointly applies intra-sleep and inter-sleep approach interactively for ONU according to its requested size in each cycle. It then transfers idle-period to a temporary sleep time. In aspect of power consumption, the proposed scheme outperforms the other two schemes particularly in higher loading while it still keeps at lower power consumption for other loading. In delay metric, the delay of high-priority and low-priority packet on upstream and downstream channel is small. Therefore, the impact of delay on applying proposed scheme is minor. For channel usage, the number of channel usage for proposed scheme is slightly higher than the other two schemes due to different channel assignments. However, it represents that the number of opened OSU(s) at OLT is higher than the other two schemes. Currently, there is a limitation that the proposed scheme must allocate inter-sleep ONU in original channel for keeping track the wake-up time slot from current cycle to next cycle. In the future, it is worthwhile to break such limitation between current and next cycle to allow the inter-sleep ONU to allocate on different channels for channel balance purposes.

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