International Journal of Engineering & Technology, 7 (3.14) (2018) 410-413

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Impact of Reciever on Time on the Energy Saving Performance of the Watchful Sleep Mode in a Passive Optical Network

A.M. Zin[1], S. M. Idrus[1*], Rizwan A. Butt[1,2], A. Ramli[1]

[1]*Lightwave Communication Research Group, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*
[2]*Department of Electronic Engineering, NED University of Engineering and Technology, Karachi, Pakistan*
**Corresponding author E-mail: sevia@fke.utm.my*

Abstract

Due to increasing bandwidth demands from users, this evolution towards next generation PON (NG-PON) with higher network capacity and split continues. However, increasing split ratio in NGPON also leads to higher power consumption of the PON network due to 60% of the power is being consumed by the optical network units (ONUs). For energy conservation of the ONU, the Watchful Sleep Mode (WSM) has been recently added to the PON standards. This is an integrated mode that combines both the cyclic sleep and doze mode in one operation by periodically turning on the ONU receiver (RX) during the sleep cycle. However, still, the impact of RX on time on the energy saving performance of WSM has not been studied. Therefore, this study presents a performance evaluation of the watchful sleep mode in a 10 GB-capable PON (XG-PON) network with varying RX ON times. The investigation is performed with a dynamic bandwidth assignment scheme and real traffic data from Broadcom CATV head end. A comprehensive review of the power saving techniques for XGPON is also presented. The simulation study results show that higher RX ON time leads to higher energy savings for the ONUs without significantly increasing upstream and downstream delays.

Keywords: *watchful sleep mode; XGPON; sleep mode PON.*

1. Introduction

Over the past decade, Passive Optical Network (PON) have been developed to bring forward high capacity fiber optic link closer to users. With affordable costs, it provides faster and more reliable services compared to copper cable. Next generation PON (NG-PON) including the 10 GB-capable PON (XG-PON) are the most popular candidates of current optical networking. It adopts the same configurations of conventional PON as illustrated in Fig. 1, having the tree topology where Optical Line Terminal (OLT) is located at the central office controlling access of multiple Optical Network Units (ONU) from users' end in downloading/ uploading data to the shared fiber medium.

The current reports [1] show an increasing trend of the broadband users globally, thus, requiring higher capacity access networks. This trend has led to the evolution of PON [2-3]. However, in PON, most of the power consumption is in the ONUs which increase the power consumption of PON. As shown in Fig. 2, the total power consumption in broadband telecommunication network is dominated by the ONU, followed by the IP core devices, Ethernet Aggregators (EA) and OLT [2]. Therefore, in relation to the worldwide agenda of 'green technology', e.g. reducing the carbon dioxide emission, service providers need to produce an energy-efficient system to lower the network's power consumption. Hence, focusing on ONU power saving mechanism is crucial and this has attracted attention from the research community.

Following this concern, the International Telecommunication Union (ITU-T) started working on the Gigabit-PON (GPON) power saving mechanism and published the ITU-T Series-G Supplement 45 "G-PON power conservation" in 2009 [3]. It standardized three basic power saving methods for its GPON and XGPON namely power shedding, cyclic doze mode (CDM) and cyclic sleep mode (CSM). Power shedding of an ONU is a method to power off the non-essential functions and services, while maintaining the operational link during the network power failure. Next, ONU dozing is proposed in accordance to the nature of data transmission in PON. The downstream (DS) data is broadcasted to all ONUs, thus require the receiver to continuously ON to receive the DS packets. When there are no US data, the ONU transmitter will power OFF for a period of time. A sleeping ONU means that both the ONU optical receiver and transmitter are off during the whole low power state. The ONU deep sleep is a period when the transmitter and receiver remains off during the entire duration of the power saving state. While the DS packet loss is possible in deep sleep, the fast/ cyclic sleep is a better mechanism where the power save state sojourn consists of sleep cycle sequences, a sleep period and an active period which occurs alternately. These cycles are determined by the OLT through the physical layer operations, administration and maintenance (PLOAM) message which is broadcasted to all ONUs.

However, CDM offers lesser energy savings but does not impact the US and DS delays much, while CSM offers very high energy savings but significantly increases the US and DS delays. Therefore, a middle approach which is a unification of both CSM and CDM and has been recently added as Watchful Sleep Mode (WSM) by ITU to transmission convergence layer of GPON, XGPON as well as TWDM PON in G.94.3, G.987.3 and G.989.3 respectively. It simplifies the mechanism of CDM and CSM by switching on the receiver periodically to check the DS signal for remote wake up indications at OLT.

The biggest advantage of WSM is that its process can be easily converted to CDM or CSM by defining $T_{watch} = T_{listen}$ and

$T_{listen} = 0$ or by only configuring $T_{watch} = T_{Sleep}$ respectively. The energy saving (ES) with WSM can be computed in (1) where P_{AS}, P_{SA}, P_{Listen} and P_{AF} are the power consumption of the ONU Asleep (AS), Watch Aware (WA), Listen and Active states respectively. Similarly, T_{AS}, T_{WA}, T_{Rx_Init}, T_{Init} and T_{AF} are the ONU sojourn in AS, WA, receiver initialization state, transceiver initialization state and either of the Active Held (AH) or Active Free (AF) states respectively. Since $P_{Listen} > P_{Sleep}$, therefore, the ES performance of WSM is critically dependent on the RX_Timer value that periodically controls the switching between the AS and Listen states. The impact has not been studied in any of the earlier WSM study. Therefore, in this study the impact of the RX_Timer on the ES performance of WSM is studied and the most suitable choice for the RX_Timer is determined.

$$\left(1-\left(\frac{T_{AS}*P_{AS}+T_{listen}*P_{listen}+T_{WA}*P_{WA}+T_{Rx\_init}*P_{listen}+T_{init}*P_{AF}+T_{AF}*P_{AF}}{T_{Sim}*P_{AF}}\right)\right)*100 \tag{1}$$

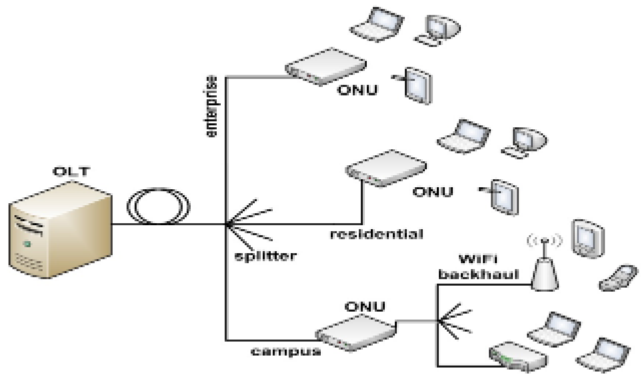

Fig. 1: XG-PON network infrastructure

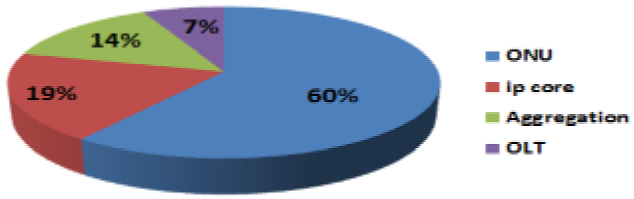

Fig. 2: Power consumption of PON

2. Related Work

The CSM [4] and CDM [5] have been extensively studied for the energy savings of PON. However, only a few studies [6-11] have investigated WSM for PON. Such a scheme was initially proposed in [12], and then studied in comparison with CSM in [9, 11]. It is shown in [11] that Watchful Sleep Mode (WSM) is more energy efficient than the CSM and DM with slightly higher values of DS delay. The impact of T_{Sleep} on the ES and delay performance was studied in [6-8] by modelling the WSM process using discrete time Markov chain. However, only the US traffic was considered and a static bandwidth assignment was assumed. The impact of the LWI event at the OLT is neglected, which is not a realistic assumption. Therefore, in this work, both US and DS traffic is considered and the IACG DBA [13] scheme is used for the US bandwidth management.

3. Watchful Sleep Mode Operation

The WSM process is shown in Fig. 3. Unless, the WSM process is not allowed by the OLT, the ONU stays in AH state and keeps on trying to enter AF state after every T_{Hold} expiry. When an OLT allows ONU to use the WSM mode, it sends a Sleep_Allow (ON) message to ONU. On receiving this message, the ONU sets its local SA (ON) flag and transitions to AF state after the expiry of T_{Hold} timer. If US and DS traffic is below a certain threshold indicated by respective Local Wakeup Indications (LWI) events then the ONU transitions to WA state for a time period of T_{Aware}. Finally, it enters its Watch. Unlike, Asleep state in CSM, here the ONU periodically keeps on turning ON and OFF its optical receiver while the optical transmitter is kept OFF. However, turning on the receiver takes an initialization time T_{Rx_Init}. The ON and OFF timing of the optical receiver are controlled by the T_{Rx_Timer}. However, its value should not exceed the 50% duty cycle of the T_{Watch}. Thus, an ONU is in doze state when the optical receiver is ON and in Asleep state when the optical receiver is OFF. This mechanism enables the ONU to listen to the forced wakeup indication (FWI) events asserted by the OLT in case of DS traffic LWI event is raised. Thus, the DS delays should significantly reduce with WSM but at a cost of slightly increased power consumption of the ONU due to reduced Asleep state time compared to CSM. Fig. 3 shows the state transition process for WSM. The power levels and states times of all the WSM states are shown in Fig. 4. The OLT configures T_{Aware} and T_{AS} according to the same criteria used for the choice of these parameters in the CSM, whereas T_{Watch} is configured according to the same criteria used to set T_{Listen} in the doze mode.

Fig. 3: Watchful sleep mode ONU state machine

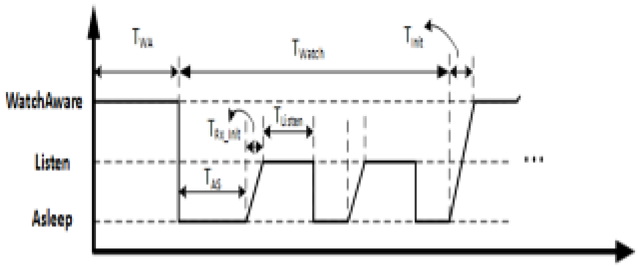

Fig. 4: State transition process of Watchful sleep Mode

4. Performance Evaluation

The simulation study was conducted using our simulation testbed developed in OMNET++ also implemented in earlier PON studies [4, 14-15]. This study comprised of a single OLT connected to total 16 ONUs through a passive optical splitter at a distance of 20Km. For simplicity, only one host and one user was configured per ONU. A snapshot of the simulation testbed is shown in Fig. 5. The downstream network traffic load varied from 0.1 to 0.7 corresponding to 15 Mbps to 550 Mbps per ONU with US load constantly being one fourth of DS as in [11]. The traffic load was not increased to full capacity as after 70% traffic load, the ONU does not obtain opportunity to exercise sleep mode and no significant energy savings are achieved as also in [11]. For traffic frame generation, we used the Broadcom CATV upstream and downstream frame distribution of [16]. The traffic load was equally distributed among the ONUs and a separate traffic generator was configured in each ONU. Each simulation runs unless the mean of recorded values of λ_{DS} converges to a value within 95% confidence interval of λ_{DS}. The complete simulation parameters for the watchful sleep process and the DBA scheme are summarized in Table 1.

Table 1: Simulation parameters

Parameter	Values / Details
P_{AH}, P_{AF}, P_A	100%
P_W	5%
ONU - OLT Line Rate	200 Mbps
RTT	200 us
US / DS Line Rates	2.5Gbps / 10Gbps
λ_{DS}	Varies from 7500 frames/s to 112000 frame/s = 15 Mbps to 550 Mbps per ONU
λ_{US}	$\lambda_{DS}/4$
T_{Watch}	1s
T_{Aware}	5 ms
T_{RX_Timer}	Variable: 10ms, 20ms, 30ms
T_{Init}	3ms
T_{Hold}	0.5ms
T_{ERI}	5ms
T_{Rx_Init}	2ms
$T_{ALERTED}$	0.5ms
Bandwidth Assignment to T1	AB_{min} = 1575 bytes with SI_{max} = 5 (equivalent to 20 Mbps)
Bandwidth Assignment to T2	AB_{min} = 7020 bytes with SI_{max} = 5 (equivalent to 90 Mbps)
Bandwidth Assignment to T3	$AB_{min} = AB_{sur}$ = 3510 bytes with $SI_{max} = SI_{min}$ = 5 (equivalent to 45 Mbps assignment to assured non-assured portions of T3)
Bandwidth Assignment to T4	AB_{sur} = 7812 bytes with SI_{min} = 5 (equivalent to 100 Mbps bandwidth assignment on best effort basis)

5. Results and Discussion

From the simulation, the ONU Asleep, Doze and Watch state times, upstream delay of T1, T2, T3 and T4 traffic class and the downstream delay were recorded for each value of network traffic load for T_{Rx_Timer} values of 10ms, 20ms and 30ms. The average energy savings achieved by the ONUs with watchful sleep mode are computed in (1). These results are shown in Fig. 5-14.

From Fig. 5-7, it is evident that by increasing the receiver ON time, the ONU AS state time increases. While the Listen state time decreases, but the Watch state time remains almost the same which is certainly logical. This happens due to delayed release (DR) approach used to control the LWI events delays the current state of ONU in case of a frame arrival during the Watch state. Therefore, when T_{Rx_Timer} has of higher value, the ONU sojourn in AS state increases and consequently the sojourn in Listen state proportionally decreases. Thus, with the increase in traffic load the sojourn in Asleep, Doze and Watch states decreases.

Due to increase in AS state time and consequently reducing ONU listen state time for higher values of T_{Rx_Timer}, the energy savings (ES %) also increases as evident from Fig. 8.

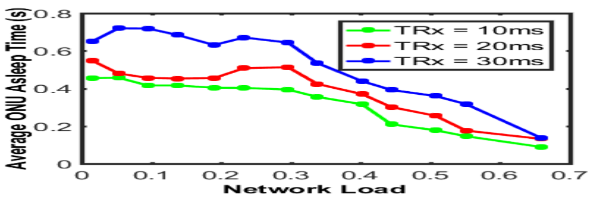

Fig. 5: Average ONU Asleep State time

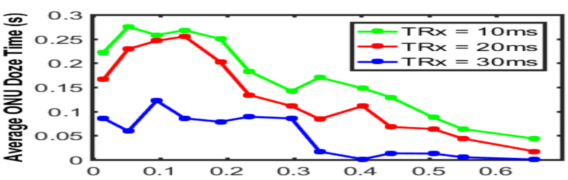

Fig. 6: Average ONU Doze State time

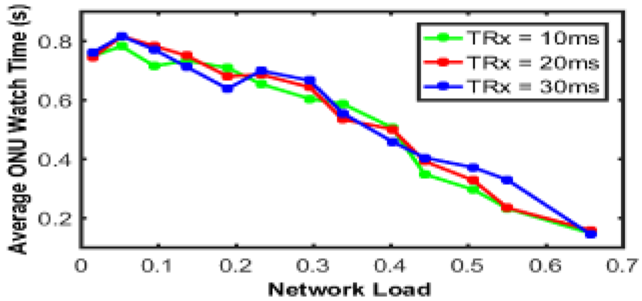

Fig. 7: Average ONU Watch State time

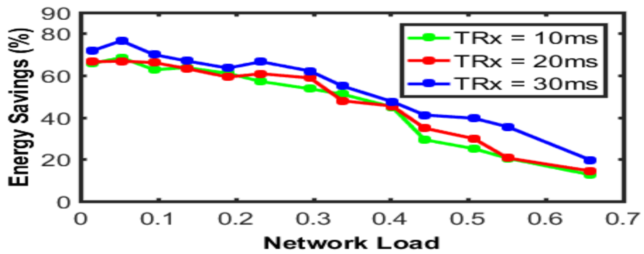

Fig. 8: Average Energy savings per ONU

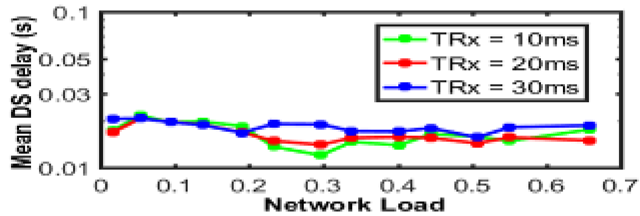

Fig. 9: Mean downstream delay per ONU

Although with increase in Asleep state, the upstream and downstream delay slightly increases but this increase is not substantial as evident from Fig. 9-14. The rationale behind this is that the OLT is actually unaware of the Listen state of the ONU and actually queues the traffic until the Watch state is over after the Watch $T_{Lowpower}$ expires or the LWI event at OLT is raised. With increase in network traffic load, the delays decrease due to reduced ONU sojourn. From these results, it can be fairly concluded that a higher value for the TRx timer is suitable for the Watchful sleep process to maximize the ONU energy savings without significantly impacting the upstream and downstream delays.

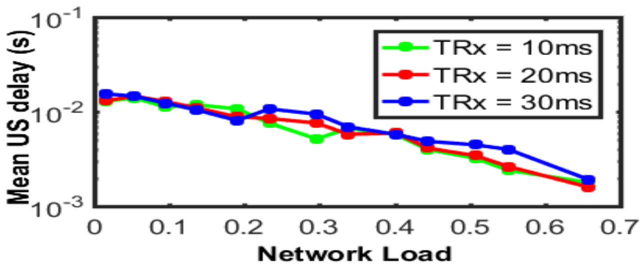

Fig. 10: Overall mean upstream delay per ONU

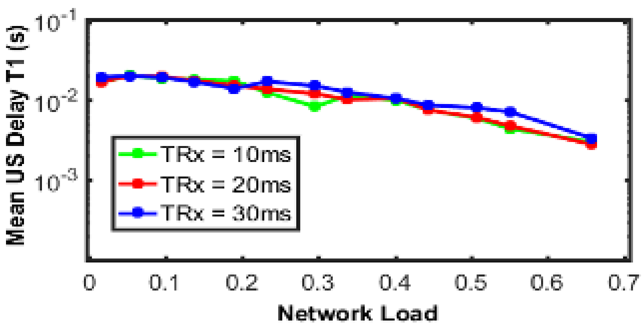

Fig. 11: Mean upstream delay T1 traffic per ONU

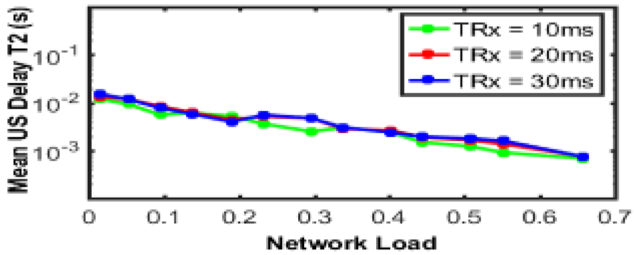

Fig. 12: Mean upstream delay of T2 traffic per ONU

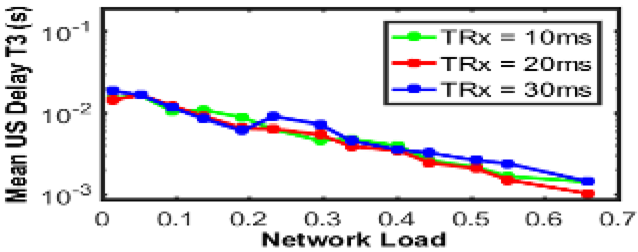

Fig. 13: Mean upstream delay of T3 traffic per ONU

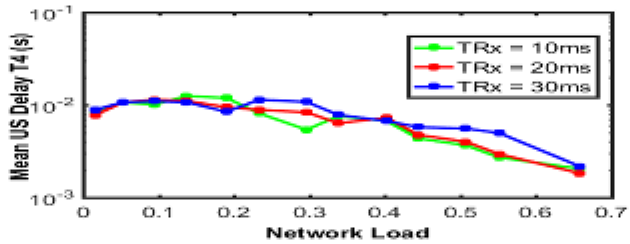

Fig. 14: Mean upstream delay of T4 traffic per ONU

6. Conclusion

In this work, we have studied the impact of varying the TRx timer values on the Watchful sleep mode for XGPON. The study was performed in a simulation testbed developed in OMNET++. Contrary to existing studies, an existing reported dynamic bandwidth assignment scheme was used and all the traffic classes T1 to T4, defined by ITU were considered. A Poisson distributed traffic generator with exponentially varying inter-arrival times was used to inject the traffic frames in the network. To emulate the behavior of real CATV data from Broadcom, the traffic frame sizes were generated using the Probability Distribution (PDF) values from the real recorded traffic data. The simulation study shows that increasing the TRx timer value leads to higher ONU energy savings with negligible increase in upstream and downstream delays.

Acknowledgement

The authors would like to thank the Ministry of Higher Education of Malaysia and the administration of Universiti Teknologi Malaysia (UTM) for the financial assistance through Research University Grant (GUP) fund vote number 17H24.

References

[1] B. Sanou, “ICT Facts and Figures 2017,” Geneva, Switzerland, 2017.
[2] D. Nesset, “PON Roadmap [Invited],” J. Opt. Commun. Networkin, vol. 9, no. 1, pp. A71–A76, 2017.
[3] R. A. Butt, S. Hasunah Mohammad, S. M. Idrus, and S. U. Rehman, “Evolution of access network from copper to PON - Current status,” ARPN J. Eng. Appl. Sci., vol. 10, no. 18, pp. 1–10, 2015.
[4] R. Aslam Butt, S. Mahdaliza Idrus, K. Naseer Qureshi, P. M. A. Shah, and N. Zulkifli, “An energy efficient cyclic sleep control framework for ITU PONs,” Opt. Switch. Netw., vol. 27, no. June 2017, pp. 7–17, 2018.
[5] A. A. Nikoukar, I. S. Hwang, Y. M. Su, and A. T. Liem, “An adaptive two-stage energy-efficiency mechanism for the doze mode in EPON,” Opt. Fiber Technol., vol. 30, pp. 81–88, 2016.
[6] X. Zeng, M. Zhu, L. Wang, and X. Sun, “Optimization of sleep period in watchful sleep mode for power-efficient passive optical networks,” Photonic Netw. Commun., 2017.
[7] M. Zhu, X. Zeng, Y. Lin, and X. Sun, “Modeling and Analysis of Watchful Sleep Mode With Different Sleep Period Variation Patterns in PON Power Management,” J. Opt. Commun. Netw., vol. 9, no. 9, p. 803, 2017.
[8] M. Zhu, X. Zeng, Y. Lin, and X. Sun, “Modeling and analysis for watchful sleep mode in PON power management,” ICOCN 2016 - 2016 15th Int. Conf. Opt. Commun. Networks, pp. 15–17, 2017.
[9] R. O. C. Hirafuji, A. Dhaini, and D. Khotimsky, “Energy efficiency analysis of the Watchful Sleep mode in next-generation passive optical networks,” in IEEE Symposium on Computers and Communication (ISCC), 2016, pp. 689–695.
[10] R. A. Butt, S. M. Idrus, and N. Zulkifli, “Comparative analysis of cyclic and watchful sleep modes for GPON,” in IEEE 6th International Conference on Photonics (ICP), 2016, pp. 6–8.
[11] R. O. C. Hirafuji, K. B. Cunha, D. R. Campelo, A. R. Dhaini, and D. A. Khotimsky, “The Watchful Sleep Mode : A New Standard for Energy Efficiency in Future Access Networks,” IEEE Commun. Mag., vol. 58, no. 3, pp. 150–157, 2015.
[12] D. A. Khotimsky, D. Zhang, L. Yuan, R. O. C. Hirafuji, S. Member, and D. R. Campelo, “Unifying Sleep and Doze Modes for Energy-Efficient PON Systems,” IEEE Commun. Lett., vol. 18, no. 4, pp. 688–691, 2014.
[13] M.-S. Han, H. Yoo, B.-Y. Yoon, B. Kim, and J.-S. Koh, “Efficient dynamic bandwidth allocation for FSAN-compliant GPON,” J. Opt. Netw., vol. 7, no. 8, pp. 783–795, 2008.
[14] R. A. Butt, S. M. Idrus, N. Zulkifli, and M. Waqar Ashraf, “Comprehensive bandwidth utilization and polling mechanism for XGPON,” Int. J. Commun. Syst., 2017.
[15] R. A. Butt, S. M. Idrus, K. N. Qureshi, N. Zulkifli, and S. H. Mohammad, “Improved dynamic bandwidth allocation algorithm for XGPON,” J. Opt. Commun. Netw., vol. 9, no. 1, 2017.
[16] G. Kramer, B. Mukherjee, and A. Maislos, Ethernet Passive Optical Network (EPON)., 1st ed. New York, USA: McGraw-Hill Education, 2005.