❒ 1053

Performance evaluation of comprehensive bandwidth utilization for 10-gigabit passive optical network

N. A. Ismail[1], Sevia Mahdaliza Idrus[2], R. A. Butt[3], F. Iqbal[4], A. M. Zin[5], F. Atan[6]

[1,2,4,5,6]School of Electrical Engineering, Universiti Teknologi Malaysia, Malaysia
[1,5,6]Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia
[3]Dept. of Electronic Engineering, NED University of Engineering and Technology Pakistan, Pakistan

Article Info

ABSTRACT

Bandwidth allocation during upstream transmission is crucial to determine the efficiency and performance of a XG-PON. For XG-PON, bandwidth assignment is done based on T-CONT which represents a traffic class as per ITU recommendation. DBA scheme used in this paper is based on CBU to assign bandwidth to ONUs based on the T-CONT supporting QoS as per SLA. In this paper, CATV traffic is used as traffic generator which used for generation of Ethernet frames and results showed expected trend of mean upstream delay for traffic class T2, T3 and T4 as compared to recommended value which is below 1.5ms. These results prove that CBU can also be implemented on real time traffic.

Corresponding Author:

Sevia Mahdaliza Idrus,
School of Electrical Engineering,
Universiti Teknologi Malaysia,
81310 UTM Skudai, Johor, Malaysia.
Email: sevia@fke.utm.my

1. INTRODUCTION

Information and communication technology (ICT) contribute immensely to social and economic improvements, such as higher employment and productivity, increasing access to a higher quality of life. The energy consumption from the expanding use of ICT is unsustainable with present drivers, and it will impact heavily on the future climate change. The expanding of ICT gives an enormous impact on electricity consumption as well as carbon dioxide (CO_2) emissions. Over the last several years, a significant amount of research effort in improving energy saving performance in ICT equipment have been done. The fact that motivated research from industries and academia is the stupendously growing footprint of ICT in increasing energy demand. The electricity and heat production contribute 25% of global greenhouse gas (GHG) emissions reported by Intergovernmental Panel on Climate Change (IPCC) in 2014 [1]. In [2], it is reported that currently ICT is responsible between 5% to 9% of the global electricity consumption. Also, the growth rate is estimated to be 9% per year and it may rise up to 20% in year 2030.

Passive Optical Network (PON) is one of access network technologies that has been standardized by International Telecommunication Union (ITU-T) and Institute of Electrical and Electronics Engineers (IEEE). PON carries multiple services such as plain old telephone service (POTS), voice over IP (VoIP), data and video. PON consists of Optical Line Terminal (OLT) at the central office (CO), Optical Network Unit (ONU) and Optical Distribution Network (ODN) that is connecting the OLT and ONU using shared optical fiber and passive optical splitter. It utilizes the tree topology where OLT is the root of the tree. Passive elements in PON that do not require power-feeding makes it favorable as compared to other access networks to conserve energy and power consumption. The burst nature of data transmission between OLT–ONUs

contributes to significant amount of power consumption in PON. Generally, ONUs contribute major power consumption to the overall PON since OLT is connected to ONUs in point-to-multipoint connection. Data transmission between ONUs–OLT is Time Division Multiplexed (TDM), where every ONU is allocated a time slot to transmit data to OLT, avoiding collision.

As demands for higher bandwidth increases, the need for PON technologies to expand rises too. Specifically, Gigabit PON (GPON) has been extended to develop 10-gigabit capable PON (XG-PON) which supports data rate of 10Gbps in downstream (DS) and 2.5Gbps in upstream (US) and has a synchronous fixed frame duration of 125μs [3]. As mentioned earlier, US transmission of PON is in TDM, therefore bandwidth allocation algorithm is performed at the OLT to distribute bandwidth efficiently to all ONUs by allocating non-overlapping transmission slots to ONUs. Bandwidth allocation can be either static bandwidth allocation (SBA) or dynamic bandwidth allocation (DBA). However, bandwidth assignment in ITU PON is based on traffic container represented by T-CONT and DBA is normally practical to enrich the efficiency of a network. T-CONT 1 has a fixed bandwidth assignment. T-CONT 2 and T-CONT 3 have both assured and non-assured bandwidth assignment and T-CONT 4 has best-effort assignment of bandwidth. This paper presents an improvement of DBA scheduling using Comprehensive Bandwidth Utilization (CBU) [4] that is tested on Cable-TV (CATV) traffic [5] and results show that the US delay improved for T2, T3 and T4. In section 2, we will review DBA scheme for ITU PON. In section 3, we present our simulation setup. In section 4, we discussed about the results obtained from simulation. In section 5, we conclude our findings and proposed future work.

2. RELATED WORKS

The expansions of global access network has created more research opportunities especially in sustainable green communication area mapped to Quality of Service (QoS). Power consumption in optical access network is becoming a critical issue as demand for high speed broadband services increases. Power consumption in PON mainly caused by broadcast mechanism in downstream transmission where ONUs receive downstream frames from OLT. ONUs need to be in active mode to receive DS frame and proces it. Some of DS frames are irrelevant and will be discarded [6]. This scenario contributes to large power consumption in ONUs thus increasing total power consumption of a PON. Energy conservation techniques in PON can be looked into two distinct perspectives; physical layer based and MAC layer based. In [7] the OLT energy consumption has been studied due to the fact that the provisioning data rate keeps increasing which causes larger energy consumption. The main idea is to adapt the power-on OLT line cards in OLT chassis based on real time incoming traffic. Physical layer solutions are not favorable by network operators because they increase operation cost. MAC layer based solutions do not require additional equipment in the network and can be implemented on the existing network, thus it is more feasible and cost efficient. ITU has reccomended power saving techniques in ONU for GPON/XGPON that includes power shedding, dozing, deep sleep, cyclic sleep and watchful sleep [8].

Generally, performance measurement for DBA scheme is based on US delay because DBA schedules the time slot for ONUs to grant bandwidth based on traffic classes. The delay mainly comes from queuing time and idle time [9]. For energy efficient PON, minimum delays as an outcome of a good DBA is required as well. There are many DBA schemes presented on International Electrical and Electronics Engineers (IEEE) PONs (e.g. EPON) [10-13], however cannot be used on ITU PONs because of the differences in layers. Additionally, for ITU PONs, OLT and ONUs are required to send frames every 125us, while for IEEE PONs, OLT and ONUs only send frames when traffic arrived.

2.1. DBA schemes for ITU PON

Since OLT will grant bandwidth to ONUs, it needs to be aware of the queue reports for all ONUs. OLT maintains queue reports in the scenario of SR based DBA. ITU PON categorized traffic into four main types using traffic container (T-CONT) as shown in Table 1 [14]. Since T1 is a fixed bandwidth, it will not be considered in DBA. DBA is performed for allocation to T2, T3 and T4. The basis of DBA scheme for ITU PON started from [15] known as GigaPON Access Network (GIANT). There are two phases of bandwidth allocation namely Guaranteed Phase Allocation (GPA) and Surplus Phase Allocation (SPA). Four service parameters are calculated which are maximum and minimum service interval (*SImax* and *SImin*) and minimum and surplus allocation bytes (*ABmin* and *ABsur*). This Each queue has available byte (*AB*) counter and count down counter for faster bandwidth allocation. For fairness, the countdown counter follows round robin manner. The downside of it is that it must wait for count down counter to be expired, only will the available byte counter be recharged.

Table 1. XGPON reference model TCONT

TCONT	Type of Bandwidth	Description
1	Fixed bandwidth	VoIP, live video streaming
2	Assured bandwidth	Basic video/voice
3	Non-assured bandwidth	VoIP/Video conferencing
4	Best effort bandwidth	Instant messaging/emails

To overcome the problem, Immediate Allocation Colorless Grant (IACG) [16] allows GPA and SPA to be executed in every downstream frame and send bandwidth grants to ONUs. It improves US delay as compared to GIANT because bandwidth grants are sent every downstream frame but this causes bandwidth redundancy due to remaining bandwidth utilization. It improves US delay performance as compared to GIANT. In [17], the efficient bandwidth utilization (EBU) improves the utilization of remaining bandwidth by allowing the available byte counter to be negative. If the available byte counter is positive then it will adjust the unused bandwidth to be allocated among the same traffic classes, and if it is negative, it means that all traffic classes are overloaded. This adjustment leads to low bandwidth availability during a SI. Improving remaining bandwidth utilization is also presented in [18] where at the end of DBA cycle, remaining bandwidth are allocated to a fixed percentage of 40%, 35% and 25% for T2, T3 and T4 respectively. Another simpler method presented in [19] uses a single available byte counter and single down counter for multiple queues and in [20], a repeated scheduling of assured bandwidth is introduced to ensure optimum bandwidth utilization. The work presented in [21] maximizes the bandwidth allocation to T2 during a SI even if it exceeds the provisioned AB. The results show an improvement in mean US delay for T2.

All of the above-mentioned DBA schemes use the four service parameters in their algorithms. According to [22], real data queuing information and independent from SI improves average delay by 40% for T2 as well as lowers bandwidth waste as compared to SI adaptive schemes. DBA method in [23] grouped four cycles to identify DBA computing time. Traffic prediction queue reports are presented in [24-26] demonstrated the NSR in GPON. In [18], [27] polling cycle time is improved and thus the idle time is also improved. A request-based polling time presented in [28] improves queuing delay such that every traffic class has its own polling order. The polling order is based on highest request bandwidth.

3.   SIMULATION SETUP

A simulation model was developed in OMNET++ to evaluate the performance of CBU scheme. A single OLT is connected to 16 ONUs over a single optical fiber using a passive optical splitter. The DS traffic load is fixed to 0.1 and US traffic load varies from 0.1 to 1. Since T1 is allocated for fixed bandwidth, T1 is not considered in this paper. The simulation setup shown in Figure 1 shows a snapshot of our simulation testbed. All the important simulation parameters are tabulated in Table 2.
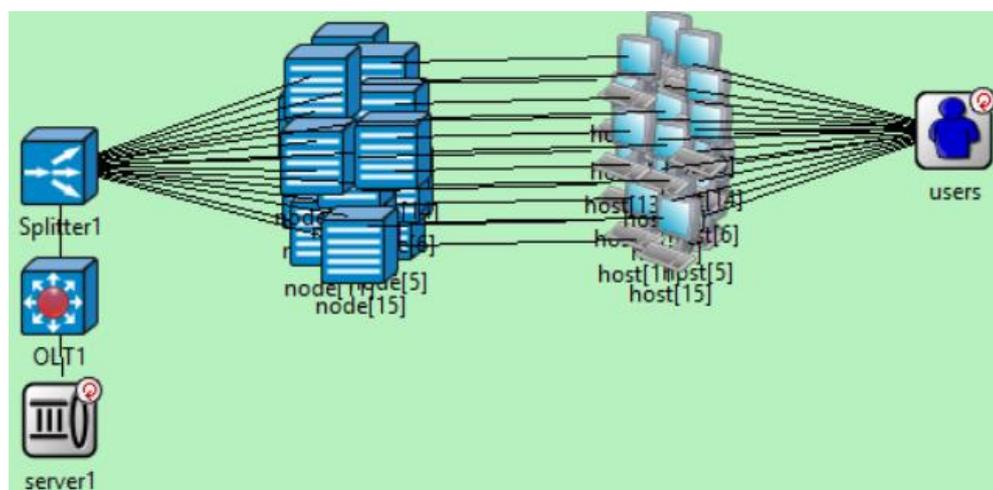

Figure 1. Simulation setup for CBU

Table 2. Simulation parameters

Parameter	Values/Details
US/DS Line rates	10Gbps/2.5Gbps
DS Traffic Load	Fixed to 0.01
US Traffic Load	Varied from 0.1 to 1
Bandwidth Assignment for T2	AB_{min}=7812 bytes with SI_{max}=5 (100 Mbps)
Bandwidth Assignment for T3	$AB_{min} = AB_{sur}$=7812 with $SI_{max} = SI_{min}$=10 (50 Mbps Assured and Non-assured portions).
Bandwidth Assignment for T4	AB_{sur}=15,624 and SI_{max}=10 (100Mbps)

4. RESULTS AND ANALYSIS

To measure the performance of a DBA scheme, mean US delay is taken into consideration, where it is a summation of $T_{Queueing}$ and T_{Idle}. T_{Idle} is waiting time of the frame until bandwidth is obtained and $T_{Queueing}$ is waiting time of the frame in the queue after being reported to OLT [29]. The average US delay results for T2, T3 and T4 traffic are illustrated in Figure 2, 3, and 4. ITU-T recommendation in [8] recommends that XGPON system must accommodate services that require a maximum mean delay of 1.5ms. We compare the result with the ITU-T recommendation and observe a significant less delay for T2, T3 and T4 for every network load. The results are analyzed based on CATV traffic which used for generation of Ethernet frames and they show expected trends as compared to recommended mean delay.

T2 traffic class shows the least delay as network load increases due to its highest priority. This proves that the algorithm satisfies ITU standard which T2 and T3 are supposed to be given priority bandwidth allocation and T4 has the least priority. T4 traffic class has the highest US delay as network load increases. The increased of delay for T4 starts at network load 0.8 where it is already beyond XG-PON requirement. This is expected because T4 is best effort type of bandwidth and given the lowest priority with 25% of bandwidth assignment. T2 and T3 have the average US delay less than ITU-T recommendation.

Bandwidth wasted in CATV traffic shows a decreasing trend as network load increases as shown in Figure 5. The trend is acceptable because as network load increases, bandwidth demand increases hence there is not much bandwidth wasted per cycle. The results show that CBU can also be implemented on a real time traffic.
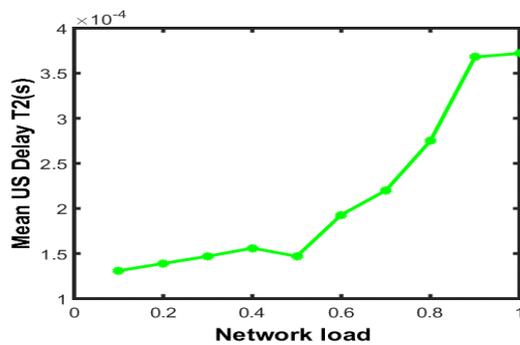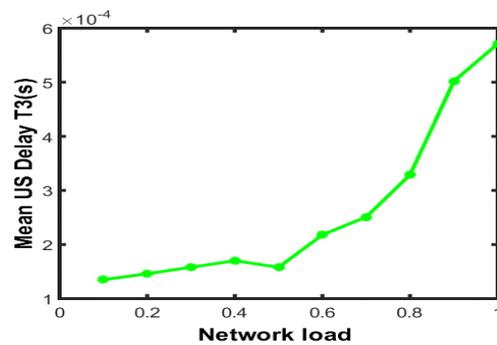

Figure 2. Mean US delay for T2
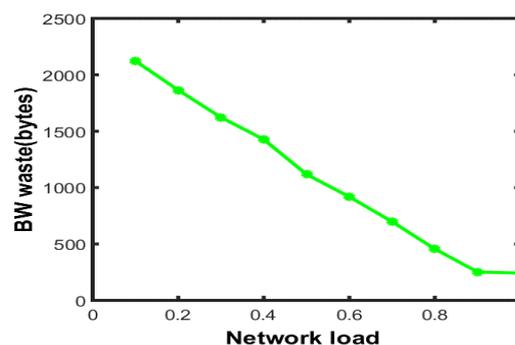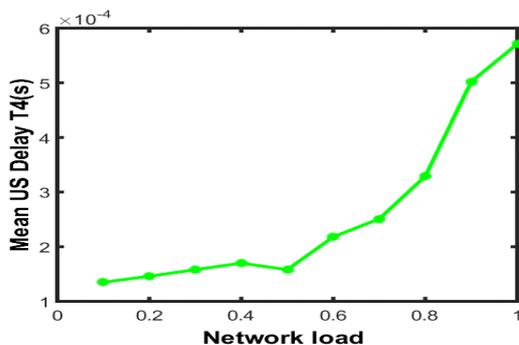

Figure 3. Mean US delay for T3

Figure. 4 Mean US delay for T4   Figure. 5 Bandwith waste

5. CONCLUSION

In this paper we have reviewed DBA schemes for ITU-PON also we have studied the DBA scheme for XG-PON using CBU to analyze the mean US delay for T2, T3 and T4. T1 is not included because it is a fixed bandwidth. Broadcom CATV is used as traffic generator to imitate real time traffic. The results summarized that CBU can be implemented to real time traffic as the US delay is below target value as recommended by ITU. The analysis on CBU DBA scheme can be further studied on uniform and triangular distribution, thus comparing the three types of distributions. This will be the next step of the research. In future, we will further improve CBU in terms of fairness as well as combining sleep assistive ONU to study the energy efficiency of XG-PON.

REFERENCES

[1] "Global Greenhouse Gas Emissions Data | Greenhouse Gas (GHG) Emissions | US EPA." [Online]. Available: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data. [Accessed: 12-Feb-2019].

[2] "Information & Communication could consume up to 20% of electricity in 2030." [Online]. Available: https://www.enerdata.net/publications/executive-briefing/expected-world-energy-consumption-increase-from-digitalization.html. [Accessed: 12-Feb-2019].

[3] D. Systems, "ITU-T," 2014.

[4] R. A. Butt, S. M. Idrus, N. Zulkifli, and M. Waqar Ashraf, "Comprehensive bandwidth utilization and polling mechanism for XGPON," *Int. J. Commun. Syst.*, vol. 31, no. 3, 2018.

[5] "Packet Size Distributions." [Online]. Available: http://research.glenkramer.com/code/pcktsize.shtml. [Accessed: 13-Feb-2019].

[6] R. A. Butt, S. M. Idrus, R. Z. Radzi, and K. N. Qureshi, "Energy Efficient Frame Structure for Gigabit Passive Optical Networks," *Int. J. Electr. Comput. Eng.*, vol. 6, no. 6, pp. 2971–2978, 2016.

[7] J. Zhang, T. Wang, and N. Ansari, "Designing energy-efficient optical line terminal for TDM passive optical networks," *2011 34th IEEE Sarnoff Symp. SARNOFF 2011*, 2011.

[8] 987.1 ITU-T Recomendation, "10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms," *ITU-T Recomm. G.987*, pp. 1–19, 2012.

[9] R. A. Butt, M. Waqar Ashraf, M. Faheem, and S. M. Idrus, "A Survey of Dynamic Bandwidth Assignment Schemes for TDM-Based Passive Optical Network," *J. Opt. Commun.*, no. January, 2018.

[10] X. Bai, A. Shami, and C. Assi, "On the fairness of dynamic bandwidth allocation schemes in Ethernet passive optical networks," *Comput. Commun.*, vol. 29, no. 11, pp. 2123–2135, 2006.

[11] N. a. M. Radzi, N. M. Din, M. H. Al-Mansoori, I. S. Mustafa, and S. K. Sadon, "Efficient dynamic bandwidth allocation algorithm for upstream EPON," *Commun. (MICC), 2009 IEEE 9th Malaysia Int. Conf.*, no. December, pp. 376–380, 2009.

[12] L. Li, S. Xin, and D. G. Duan, "Research of DBA schemes and QoS in PON system," in *2016 2nd IEEE International Conference on Computer and Communications, ICCC 2016 - Proceedings*, 2017, pp. 2148–2153.

[13] H. Song, B. W. Kim, and B. Mukherjee, "Multi-thread polling: A dynamic bandwidth distribution scheme in long-reach PON," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 2, pp. 134–142, 2009.

[14] ITU-T, "ITU-T Recommendation G. 983.4 A broadband optical access system with increased service capability using dynamic bandwidth assignment," *ITU-T G.983.4 Recomm.*, 2001.

[15] H. C. Leligou, C. Linardakis, K. Kanonakis, J. D. Angelopoulos, and T. Orphanoudakis, "Efficient medium arbitration of FSAN-compliant GPONs," *Int. J. Commun. Syst.*, vol. 19, no. 5, pp. 603–617, 2006.

[16] 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, p. 783, Aug. 2008.

[17] M. S. Han, H. Yoo, and D. S. Lee, "Development of Efficient Dynamic Bandwidth Allocation Algorithm for XGPON," *Etri J.*, vol. 35, no. 1, pp. 18–26, 2013.

[18] R. A. Butt, S. M. Idrus, S. Rehman, P. M. A. Shah, and N. Zulkifli, "Comprehensive Polling and Scheduling Mechanism for Long Reach Gigabit Passive Optical Network," *J. Opt. Commun.*, 2017.

[19] M.-S. Han, "Simple and feasible dynamic bandwidth and polling allocation for XGPON," *16th Int. Conf. Adv. Commun. Technol.*, vol. 2, no. 5, pp. 298–304, 2014.

[20] Man-Soo Han, "Iterative dynamic bandwidth allocation for XGPON," *14th Int. Conf. Adv. Commun. Technol.*, pp. 1035–1040, 2012.

[21] V. Sales, J. Segarra, and J. Prat, "An efficient dynamic bandwidth allocation for GPON long-reach extension systems," *Opt. Switch. Netw.*, vol. 14, no. PART 1, pp. 69–77, 2014.

[22] J. A. Arokkiam, K. N. Brown, and C. J. Sreenan, "Refining the GIANT dynamic bandwidth allocation mechanism for XG-PON," *IEEE Int. Conf. Commun.*, vol. 2015-Septe, pp. 1006–1011, 2015.

[23] K. Triningsih, E. S. Sugesti, and H. S. Naning, "Multipartition DBA method on GPON," *2017 IEEE 13th Malaysia Int. Conf. Commun.*, no. Micc, pp. 203–206, 2017.

[24] Y. A. Mahmud, N. A. M. Radzi, F. Abdullah, and N. M. Din, "Fuzzy-logic based NSR DBA for upstream GPON," *2015 IEEE 12th Malaysia Int. Conf. Commun. MICC 2015*, no. Micc, pp. 169–174, 2016.

[25] A. Walid and A. Chen, "Efficient and dynamic bandwidth allocation for Non-Status Reporting Gigabit Passive Optical Networks (GPON)," *IEEE Int. Conf. Commun.*, vol. 2015-Septe, pp. 1000–1005, 2015.

[26] H. B. H. Bang, S. K. S. Kim, D.-S. L. D.-S. Lee, and C.-S. P. C.-S. Park, "Dynamic bandwidth allocation method for high link utilization to support NSR ONUs in GPON," *Adv. Commun. Technol. (ICACT), 2010 12th Int. Conf.*, vol. 1, pp. 1–6, 2010.

[27] I. Hwang, J. Lee, and T. Yeh, "Polling Cycle Time Analysis for Waited-based DBA in GPONs," *Imecs*, vol. II, pp. 6–11, 2013.

[28] C.-T. Chiu and Y.-C. Wang, "Request-based Dynamic Bandwidth Allocation of Gigabit Passive Optical Network," *Opt. Photonics J.*, vol. 03, no. 02, pp. 165–170, 2013.

[29] M. Han, "Simple and Feasible Dynamic Bandwidth and Polling Allocation for XGPON," in *ICACT Transactions on Advanced Communications Technology (TACT)*, 2013, vol. 2, no. 5, pp. 298–304.

BIOGRAPHIES OF AUTHORS

Nur Asfahani Ismail received both Bachelor Degree in Electrical & Electronic Engineering and Master in Electrical Engineering from the Universiti Tenaga Nasional in 2008 and 2013 respectively. She is currently a PhD candidate at Universiti Teknologi Malaysia. Her current research activity is mainly focused on energy efficiency for optical access network. Other research interests include efficient dynamic bandwidth assignment and performance evaluation of access network.

Sevia M. Idrus received her Phd in 2004 from the University of Warwick in optical communication engineering. She is a professor and currently deputy dean of Faculty of Electrical Engineering Universiti Teknologi Malaysia. Her main research interests are optical communication system and engineering management. She is actively involved number of international research collaboration projects and has delivered keynote and invited speeches to many international conferences and seminars.

Rizwan Aslam Butt received his Bachelor degree in Electronic Engineering, Master in Computer science and Masters in Telecom- munication Engineering from NED Univer- sity of Engineering and Technology Pakistan in 2006, 2011 and 2013, respectively. He received his Ph.D. degree in Electrical Engi- neering from Universiti Teknologi Malaysia in 2018. He has also served as Operation Engineer in Pakistan Telecommunication Company Ltd. from 2006 to 2010. He is working as a lecturer at Telecommunication Engineering Department of NED University of Engineering and Technology Pak- istan from 2010 to till date. His research interests include Optical and Communication networks. He has authored more than seven journals and several conference papers.