Volume 1 No. 1, July 2011
International Journal of Science and Technology

http://www.ejournalofsciences.org

Rapid Progress of Transmission Bit Rates for Multi Users for Cost Planning of Passive Optical Network (PON) Standards

[1]El-Sayed A. El-Badawy, [2]Abd El–Naser A. Mohammed, [3]Ahmed Nabih Zaki Rashed
[1]Elect. Eng. Department, Faculty of Engineering, Alexandria University, Alexandria 21544, EGYPT,
Senior Member IEEE, Member of the Optical Society of America (OSA)
[2, 3] Electronics and Electrical Communication Engineering Department,
Faculty of Electronic Engineering, Menouf 32951, Menoufia University, EGYPT

ABSTRACT

In the present paper, we have planned the deployment of passive, active and splitting optical devices employed in passive optical network (PON) standards such as giga-passive optical networks (GPON), broadband passive optical network (BPON) and Ethernet passive optical network (EPON) has been modeled and investigated over wide range of the affecting parameters. The utilization of the transport capacity was analyzed on the Internet protocol (IP) traffic's point of view, illustrating how large portion of the links' capacity is actually used for carrying maximum number of subscribers' IP traffic. The transmission transport efficiency and utilization of the transport capacity were estimated using space division multiplexing (SDM) technique to evaluate costs of the passive optical networks transport concepts to build an optical access communication network for a known subscriber or user population. Moreover, the number of supported data channels, number of supported users and subscriber or user bit rates were analyzed.

Keywords: *Passive optical networks (PONs), SDM, Communication protocol, Network architecture, Access optical networks.*

I. INTRODUCTION

Traditional optical network solutions based on point-to point architectures are expensive for access configurations: besides fiber deployment costs, they need maintenance for the outside plant active systems. Time division multiplexing passive optical networks (TDM-PONs) have been developed. The optical line terminal (OLT) is the main element of the network and it is usually placed in the Local Exchange. Optical Network Units (ONUs) serve as an interface to the network and are deployed on a customer’s side [1]. The very high available bandwidth of fiber is thus mostly wasted. The optical access is gaining more interest as the demand for higher and higher bandwidth is getting stronger. The major drivers for larger bandwidth are the increasing processing power of user terminals and development of services that require substantially larger bandwidth than available in present day access networks [2]. The optical access offers significantly higher bit rates and longer transport distances. The high cost has been the foremost factor that has been slowing down penetration of the optical access. Most customer premises are connected to the nearest central office with twisted copper wires and to obtain real broadband these wires need to be replaced or supplemented with fibers Installation of an entirely new infrastructure is costly to carry out. To keep the installation cost in reasonable limits, various solutions are being studied to find the most economical optical transport concepts [3]. The PON is a network, which carries data in the optical domain between the OLT and ONU or optical network terminal (ONT) and the transport path of the optical signal is passive. This implies that the optical network devices (between the transmitter and receiver) are non-powered, i.e. no electrical devices are used. The idea of PON is to use passive components, which have no requirements for power or maintenance. These components are responsible for traffic distribution to several fibers between an OLT and several ONUs. Two types of components can be used for the purpose. The optical splitter/combiner is used with TDM-PON networks. It divides the optical power, originating from the OLT, to all ONUs and combines the upstream signals coming from the ONUs into a single fiber. In wavelength division multiplexing networks, arrayed waveguide grating devices are used for the traffic distribution. In the optical fiber communication era, it is expected that broadband network provision will require thousands of optical fibers to be accommodated in a central office (CO) for the optical access network. Optical fiber is capable of delivering bandwidth-intensive integrated, voice, data and video services at distance beyond 20 km in the subscriber access network. All transmission in a PON is performed between an OLT and ONU. The OLT resides in the central office, connecting the optical access network to the metro back-bone, and the ONU is located the end-user location [4]. Optical fiber maintenance is a very important issue to be consider in a developing a high quality and reliable PON. The long feeder line in a PON is a vulnerable part of the network; when unprotected, a break of it puts the whole PON out of service. To support various optical communication network services expected in the coming years, there has been much effort to develop a fiber to the home (FTTH) passive optical network (PON). FTTH-PON offers many advantages such as high speed, large capacity, and low cost [5].

In the present study, the efficiency utilization of the transport capacity was further used to evaluate costs of the PONs transport concepts to build an optical access network for a known user population. Multiplexing, demultiplexing, and Splitting optical devices have been modeled and employed in passive optical communication networks to increase the transmission bit rate or transmission capacity of the utilization channels. Moreover we have investigated parametrically and numerically over wide range of the affecting parameters the number of supported data channels and maximum number of supported users and terminals.

II. PASSIVE OPTICAL NETWORK LAYOUT MODEL

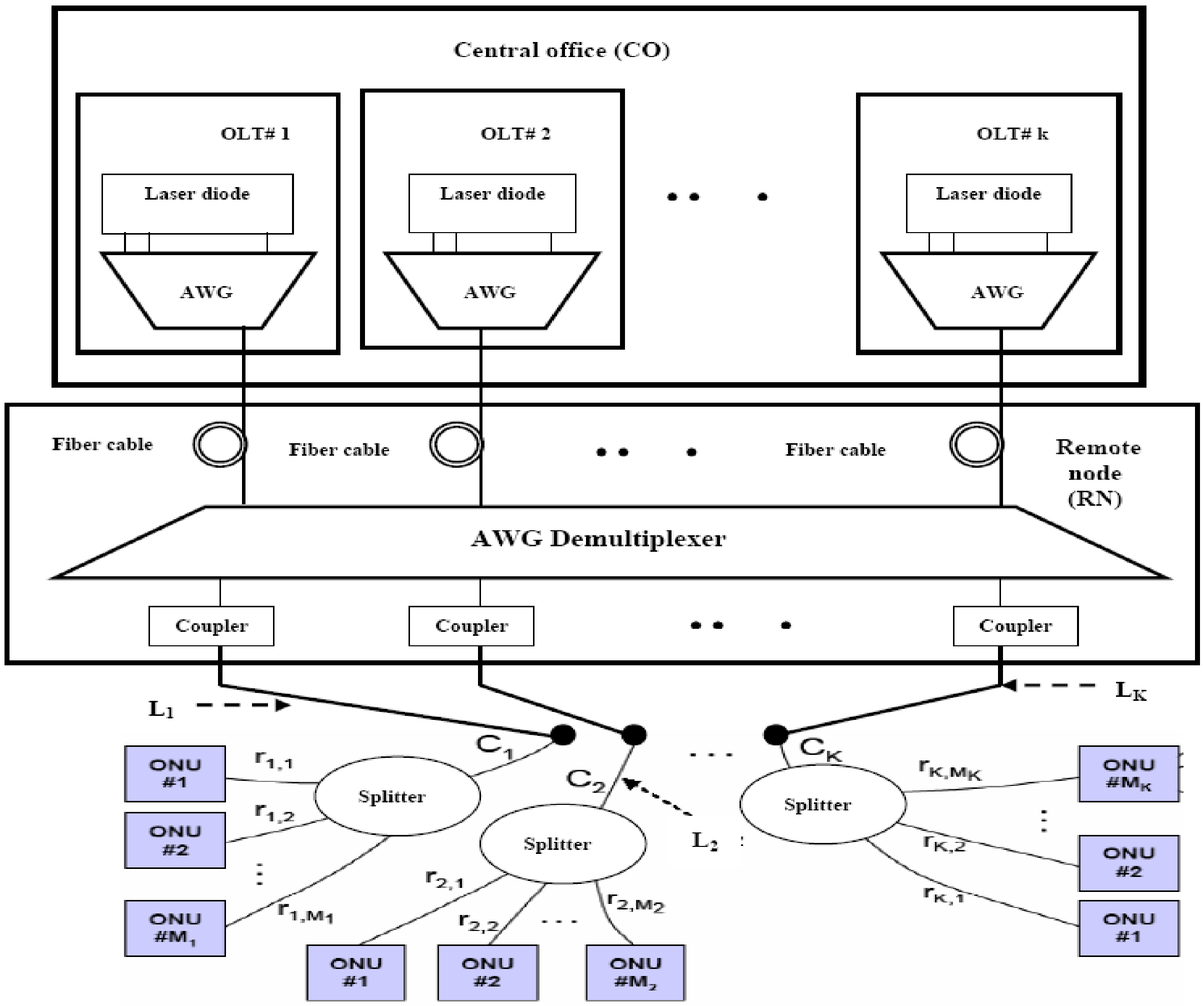

Fig. 1. Schematic view of passive optical network layout

Figure 1 illustrates a typical passive optical network layout, showing that the access network is divided into network links and each link supports a number of customers. The OLT sends all downstream information to all ONUs. The data is addressed to specific ONUs, and the unaddressed ONUs ignores the data. The ONUs could interface with each other if they are not instructed when to transmit upstream data [6]. The price of PON link is usually much higher than that of an Ethernet to the home or a 100 Mbit/sec point to point Ethernet link, but a PON link support a much larger number of end users than the two. As shown in Fig. 1, there are several independently modulated laser diodes, each emitting at a unique wavelength. Here, AWG as a multiplexer is needed to combine these optical signals from the emitters into one signal of continuous spectrum and couple it into a fiber cable. At the receiver side, arrayed waveguide grating as a demultiplexer is required to separate the combined optical signals into appropriate detection channels for signal processing. The cost of the access network has a significant contribution to the overall cost of a telecommunications network and thus it is justifiable to compare the access network cost of the various optical access techniques. The total cost is access technology dependent, but common to all techniques is that the cost depends strongly on the number of connected customers and on the offered bandwidth per customer. These two together contribute to the number of required network segments [7]. The downstream direction signals sent by the OLT arrive at the splitter's input and then the same signal reaches every ONU. The signal is attenuated but otherwise its structure and properties are the same. Although the point-to-multipoint nature of the PON in the downstream direction may create issues concerning security, complicated traffic management and bandwidth allocation algorithms are not necessary [8].

III. NETWORK MODEL ANALYSIS

As shown in Fig. 1, assume that the total transport capacity of the link L_k is C_k and utilization of the transport channel is ρ, then the total bit rate R_k available for user data in link L_k is given as the following [9]:

$$R_k = \rho C_k \tag{1}$$

The total bit rate of each link is the sum of the traffic from all ONUs connected to the L_k as:

$$R_k = \sum_{j=1}^{M_k} r_{k,j} \quad , \tag{2}$$

Where r_k is the transmission bit rate to each user, and the aggregate bit rate R_T of all the K links is as follows [10]:

$$R_T = \sum_{k=1}^{K} R_k \quad , \tag{3}$$

The number of users in the link L_k is N_k, which is the sum of users ($n_{k,j}$) connected to all ONUs in the link L_k as:

$$N_k = \sum_{j=1}^{M_k} n_{k,j} \quad , \tag{4}$$

And the aggregate number N_T of users connected to all the K links is as follows [10]:

$$N_T = \sum_{k=1}^{K} N_k \quad , \tag{5}$$

If we assume that one end user should have transport capacity of C_0 then link L_k is able support up to:

$$m_k = \frac{R_k}{C_0} \quad , \tag{6}$$

Simultaneous users and all K links support up to:

$$m_T = \sum_{k=1}^{K} m_k \quad , \tag{7}$$

Let's suppose that in the target area all links offer the same transport capacity, the size of the population is N and the broadband access take rate is γ (0<γ ≤1). Provided that the know the percentage β of the connected users that operate during a busy hour, the required links K is given From Eq. (1), and from the above assumptions, the obtained expression result as in Ref. [11]:

$$R_T = K \rho C = \gamma \beta N C_0 \quad , \tag{8}$$

Where γ is the transfer rate of users for entering the network, C is the total capacity for all users, β is the connected user percentage, N is the coverage user number of the network for connecting, and C_0 is the transport capacity of one end user. And from this we can solve the required number of links to be [11]:

$$K = \frac{\gamma \beta N C_0}{\rho C} \quad , \tag{9}$$

Each link serves γN/k customers that are connected to the ONUs of that link. When comparing the costs of different network solutions that cover the same area and customers or subscribers and use the same dimensioning parameters, relevant measures for the comparison are the number of network links, and the number of optical interfaces (i.e. ONUs and OLTs). From Eq. (9) can directly be used in evaluating the required links. It include several parameters and by varying one parameter at a time and keeping the other fixed, the study is how K develops as a function of the selected parameter. Provided that the average number of the optical interfaces in a network link is M_{ot}, then the total number M_T of the interfaces is given by [12, 13]:

$$M_T = M_{ot} K \quad , \tag{10}$$

Parameters that affect the network performance are the data rate and the splitting ratio (S) of the network link. The total number of users (N_k) is determined by the number of remote nodes and the splitting ratio in the network link [14]. Based on MATLAB curve fitting program, the fitting of the relationship between the network equipment cost (C_E) as a function of total number of optical terminals M_T for different PON standards is estimated based on the practical operating data of Refs. [12, 15, 16]:

$$C_{EE} = 3.45x10^4 M_T - 1.745x10^3 M_T^2 + 10.85x10^5 M_T^3 \ \$ \tag{11}$$

$$C_{EG} = 1.935x10^3 M_T + 0.396x10^4 M_T^2 - 6.632x10^5 M_T^3 \ \$ \tag{12}$$

$$C_{EB} = 9.975x10^5 M_T - 1.324x10^3 M_T^2 + 8.875x10^4 M_T^3 \ \$ \tag{13}$$

Also based on MATLAB curve fitting program, the relationship between user cost (C_U) as a function of total number of optical terminal, M_T for different PON standards is estimated based on the data of Refs. [12, 15]:

$$C_{UE} = 2.75M_T - 3.98M_T^2 + 7.35M_T^3 \quad \$ \qquad (14)$$

$$C_{UG} = 1.95M_T + 0.85M_T^2 - 0.72M_T^3 \quad \$ \qquad (15)$$

$$C_{UB} = 8.45M_T - 3.55M_T^2 + 5.48M_T^3 \quad \$ \qquad (16)$$

Using the data of Ref. [16], and based on MATLAB curve fitting program, the relationship between user cost (C_U) as a function of both user bit rate (R_T) and splitting ratios (S) for different PON standards is estimated as follows:

$$C_{UE} = 1.08R_T S^{-1} - 1.76R_T^2 S^{-2} + 5.63R_T^3 S^{-3} \ \$ \qquad (17)$$

$$C_{UG} = 3.75R_T S^{-1} + 0.92R_T^2 S^{-2} - 1.28R_T^3 S^{-3} \ \$ \qquad (18)$$

$$C_{UB} = 6.73R_T S^{-1} - 2.37R_T^2 S^{-2} + 0.94R_T^3 S^{-3} \ \$ \qquad (19)$$

The total bit rate per subscriber or user (R_T) can be expressed in terms of number of calls (n_A), number of TV programs (m_V), number of quantization levels (Q), and the modulating frequencies of both audio (F_{mA}) and video (F_{mV}) signals as the following expression [17]:

$$R_{T(Audio)} = 2\left[n_A Q_A F_{mA}\right], \qquad (20)$$

$$R_{T(Video)} = 2\left[n_V Q_V F_{mV}\right], \qquad (21)$$

Where Q_A is the number of quantization levels for audio signal, and Q_V is the number of quantization levels for video signal or TV program.

IV. SIMULATION RESULTS AND PERFORMANCE EVALUATION

The following numerical data of the set of assumed controlling parameters of our suggested network model are employed to obtain the best performance of the passive optical networks (PONs) as the following:

Number of links: L_k with k ={1, 2, 3, ……………..…, 8}, 0.5 ≤ transport channel utilization, $\rho_{Downstream} \leq 0.95$, and 0.5 ≤ transport channel utilization, $\rho_{Upstream} \leq 0.92$, and 100 ≤ number of supported user, $N_k \leq 1000$, optical line terminal (OLT) cost= $ 900, OTN cost=$ 100, modulating frequency of audio signal (f_{mA}) = 4 KHz, modulating frequency of the video signal (f_{mV}) = 8 MHz, 4 ≤ number of quantization levels, Q ≤ 64 and 100 Mbit/sec ≤ user bit rate, R_T ≤ 800 Mbit/sec. Installation cost at the end users premises also plays an important role when implementing new services. To keep the networking costs on a reasonable level, the future network components should be cheap, long lasting and easy to install. Based on the series of the equations analysis which support the results of the Figs (2-16), the following features are assured:

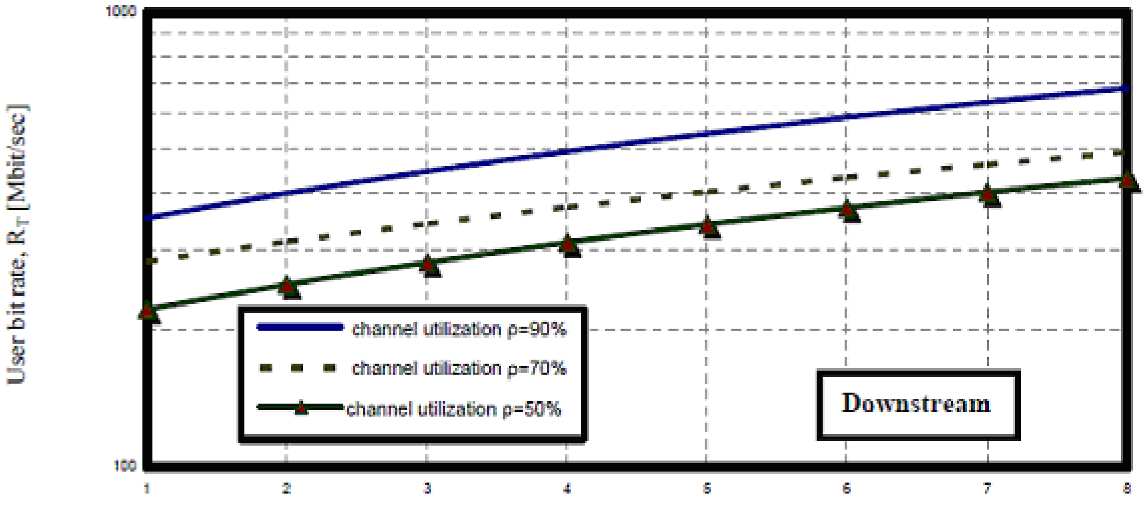

Fig. 2. Variations of user or subscriber bit rate with the number of links in at the assumed set of parameters.

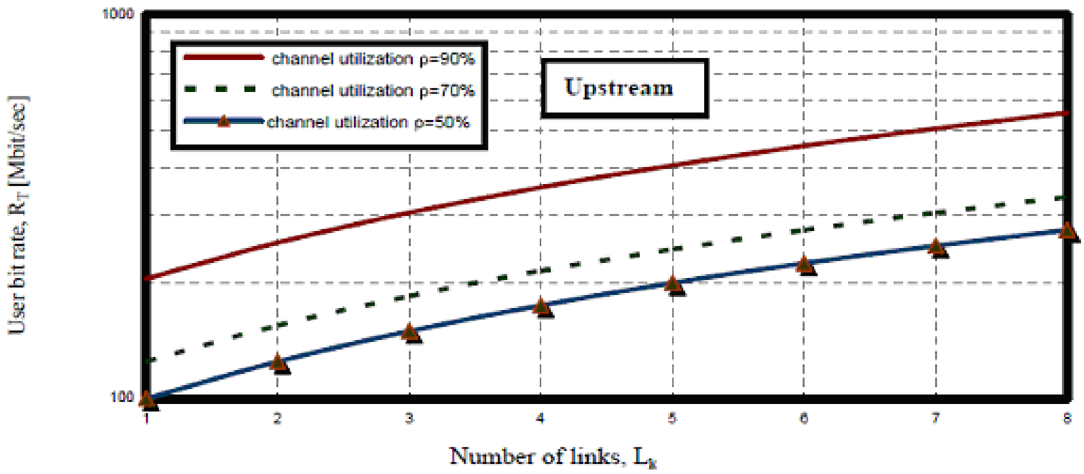

Fig. 3. Variations of user or subscriber bit rate with the number of links in the fiber cable core at the assumed set of parameters.

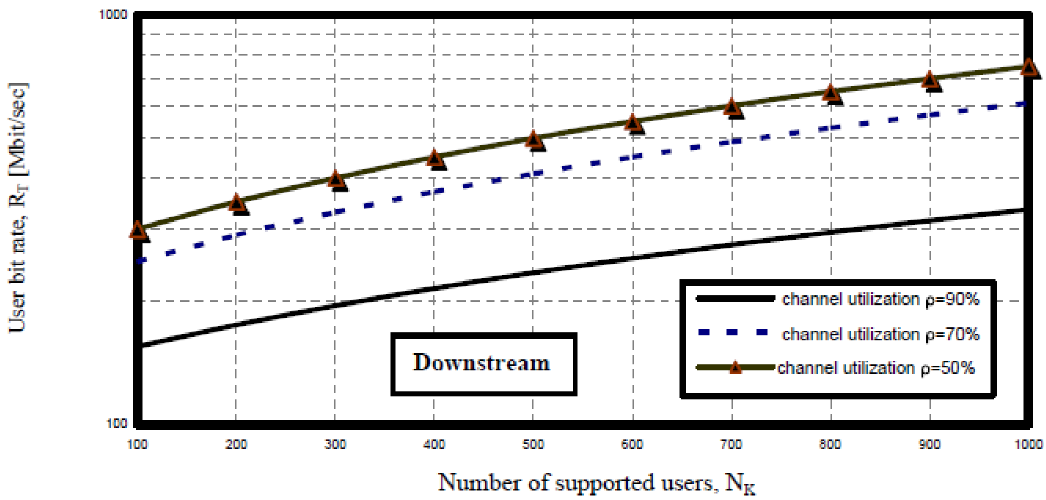

Fig. 4. Variations of the user or subscriber bit rate with the number of supported users for each link at the assumed set of parameters.

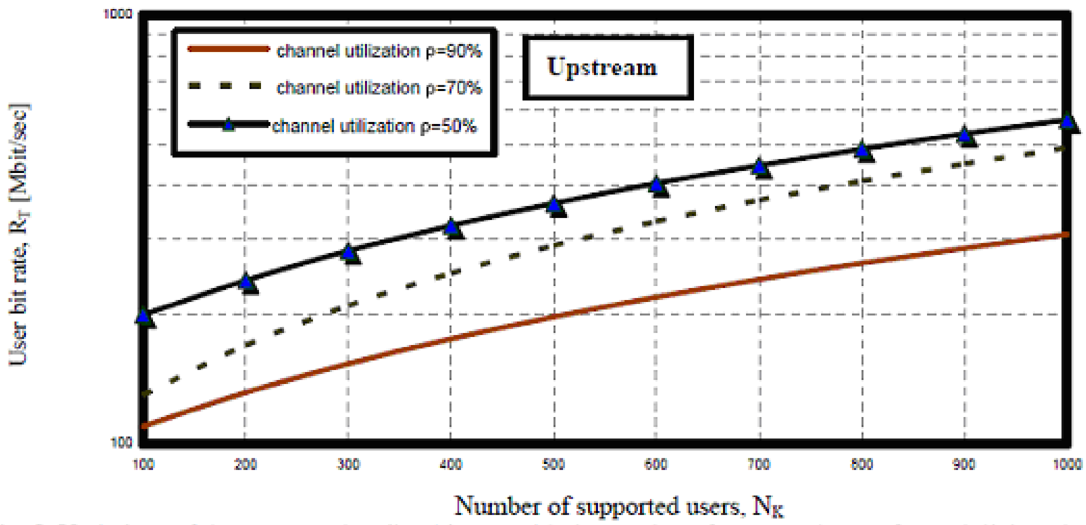

Fig. 5. Variations of the user or subscriber bit rate with the number of supported users for each link at the assumed set of parameters.

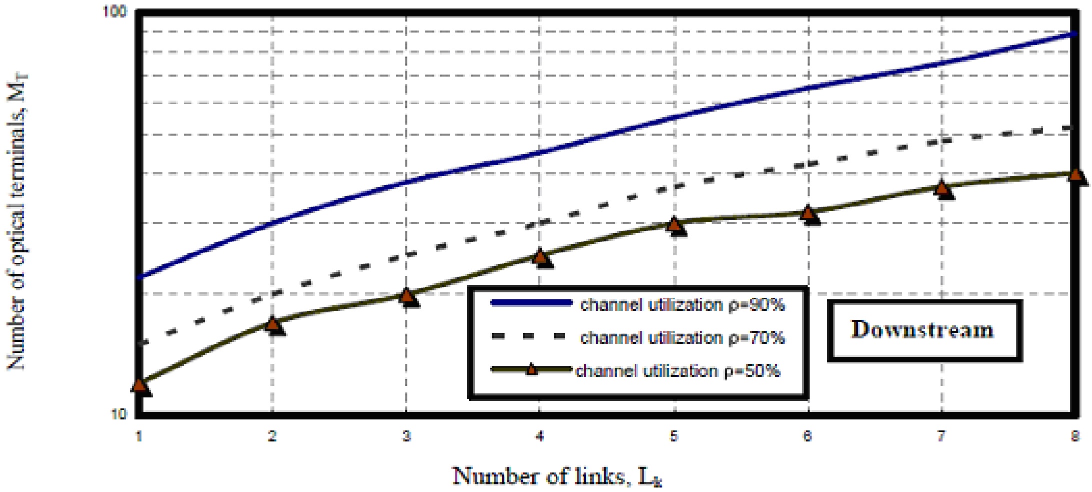

Fig. 6. Variations of number of optical terminals with the number of links at the assumed set of parameters.

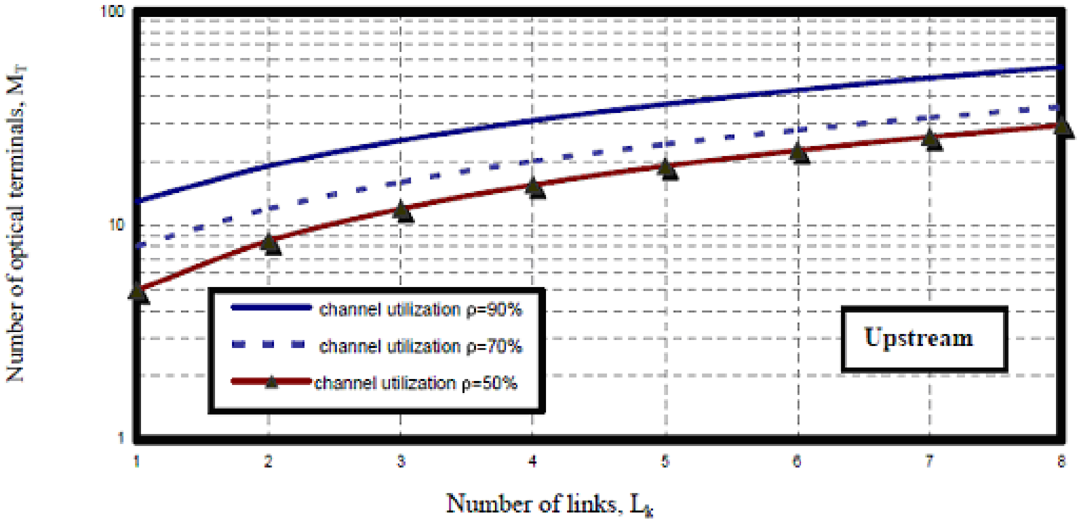

Fig. 7. Variations of number of optical terminals with the number of links at the assumed set of parameters.

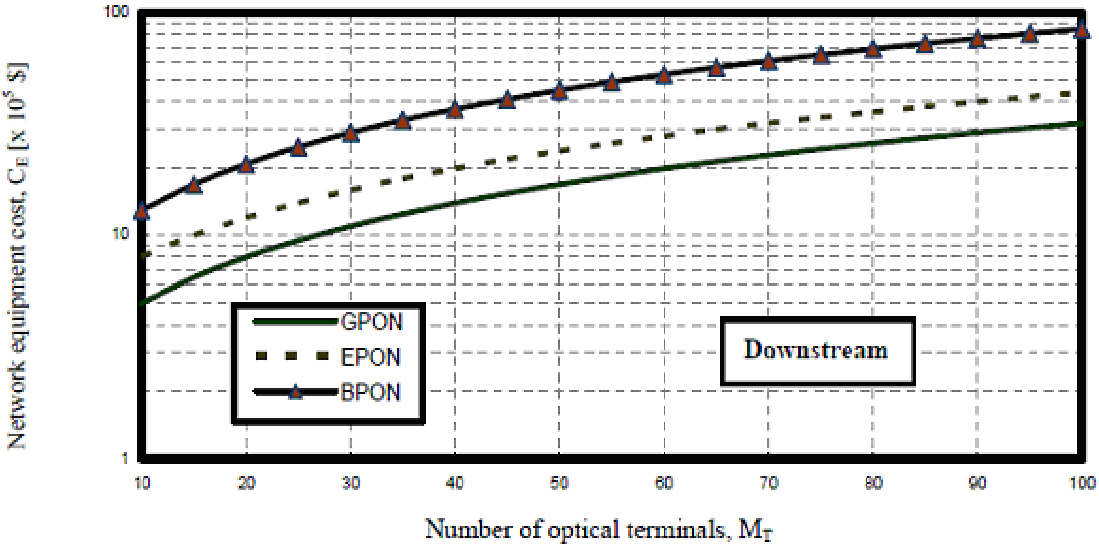

Fig. 8. Variations of network equipment cost with number of optical terminals at the assumed set of parameters.

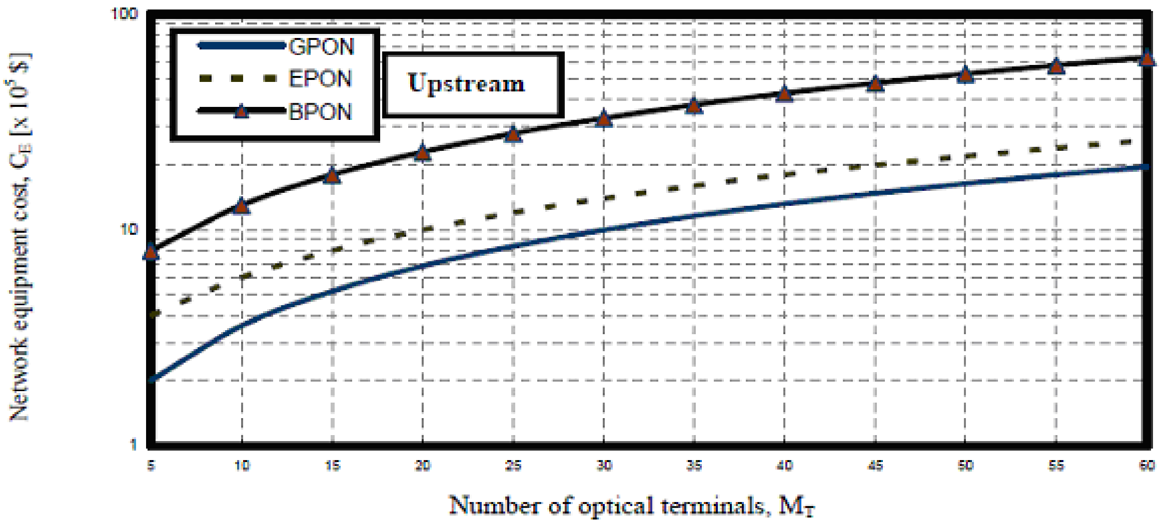

Fig. 9. Variations of network equipment cost with number of optical terminals at the assumed set of parameters.

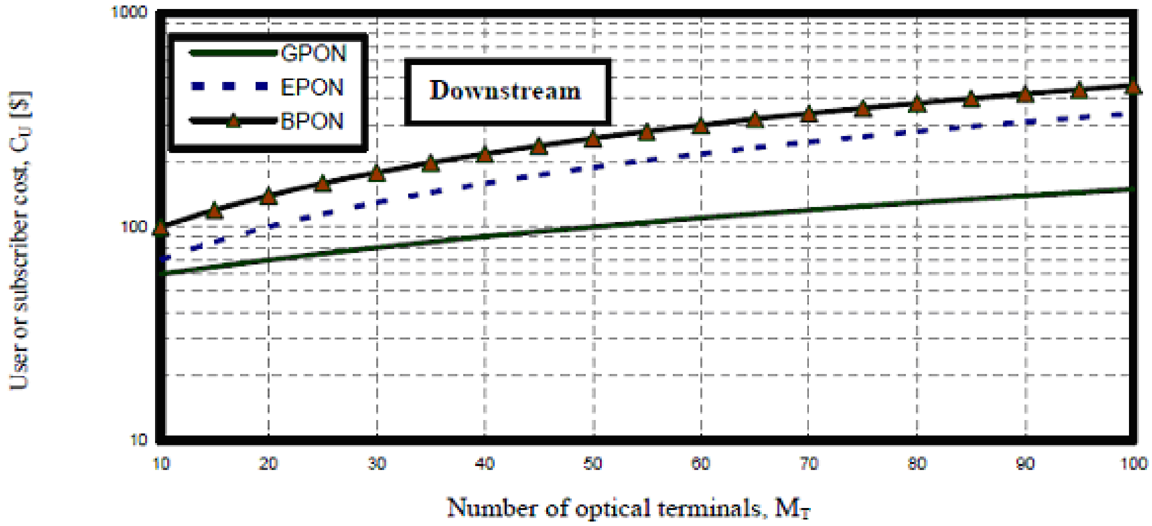

Fig. 10. Variations of user cost with number of optical terminals at the assumed set of parameters.

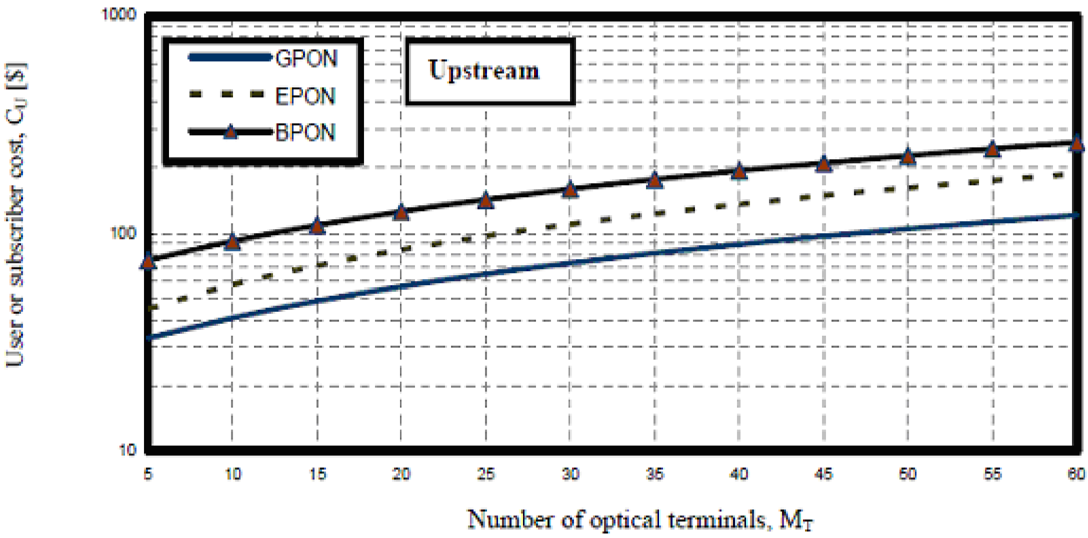

Fig. 11. Variations of user cost with number of optical terminals at the assumed set of parameters.

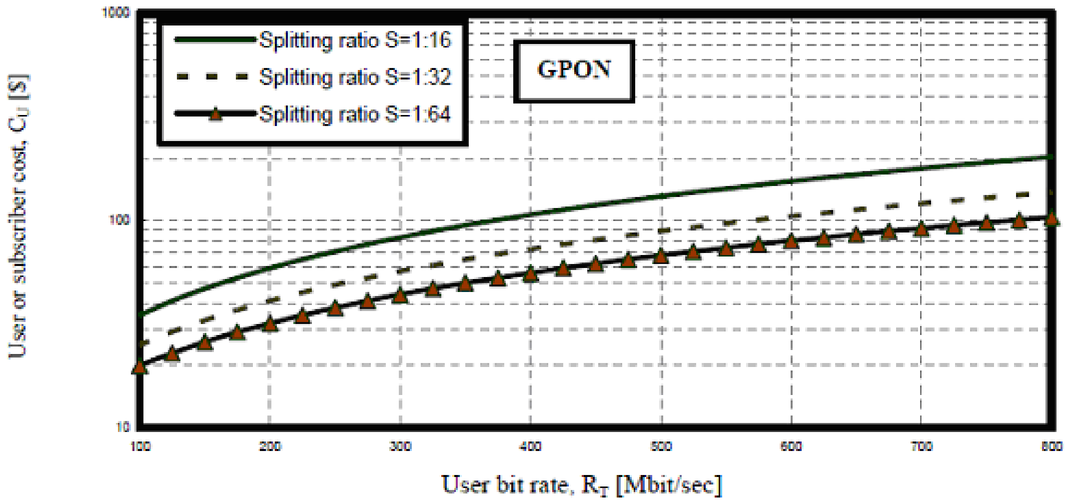

Fig. 12. Variations of user cost with user bit rate for downstream direction at the assumed set of parameters.

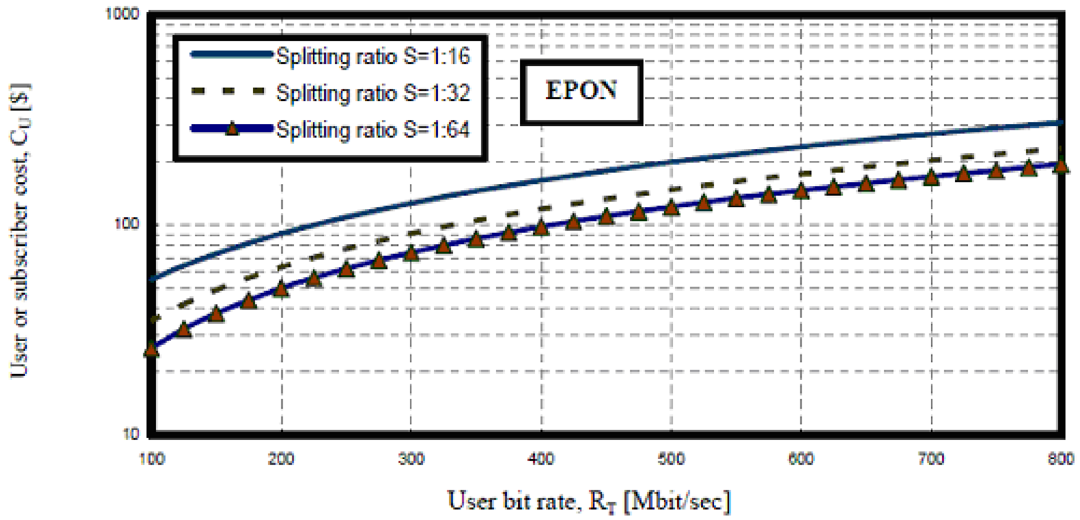

Fig. 13. Variations of user cost with user bit rate for downstream direction at the assumed set of parameters.

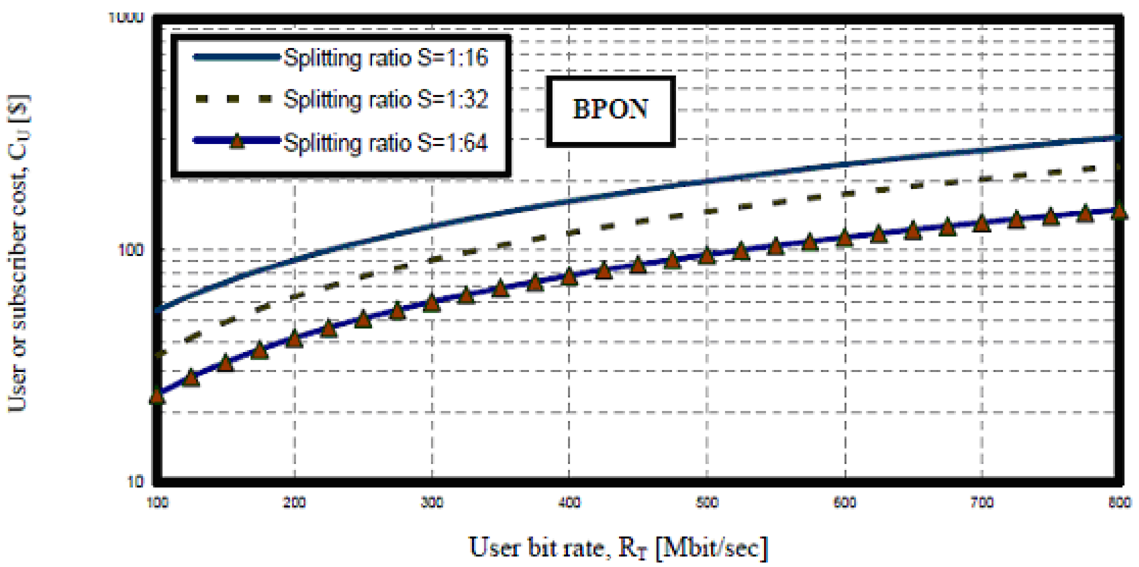

Fig. 14. Variations of user cost with user bit rate for downstream direction at the assumed set of parameters.

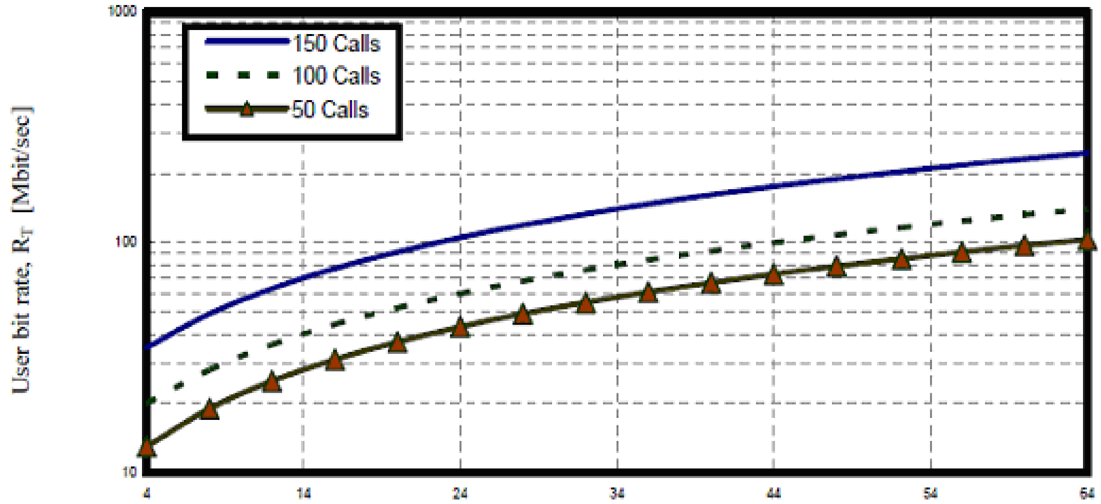

Fig. 15. Variations of user bit rate with number of quantization levels at the assumed set of parameters.

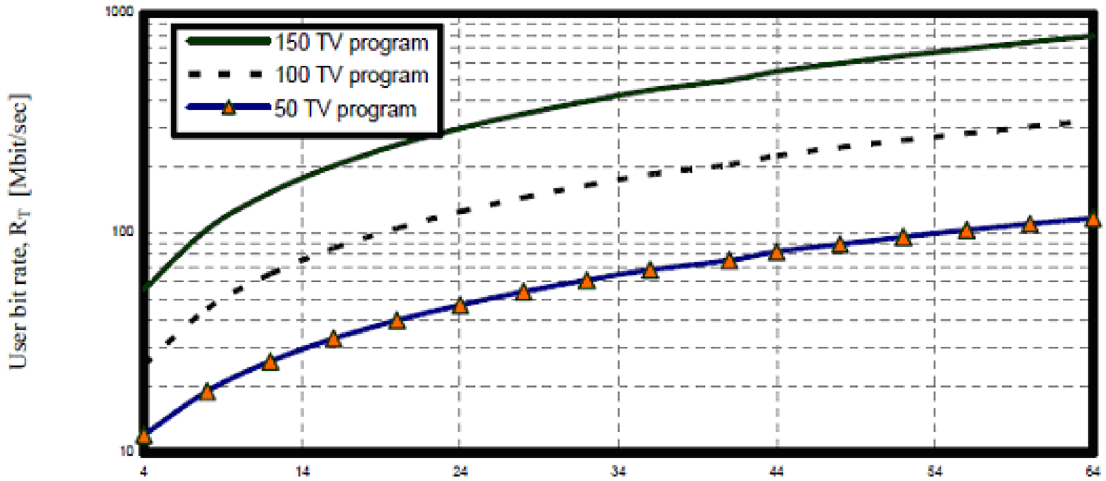

Fig. 16. Variations of user bit rate with number of quantization levels at the assumed set of parameters.

i- As shown in Figs. (2, 3), the user bit rate increases in the downstream and upstream directions with the number of links increases at constant channel utilization. Moreover as the transport channel utilization increases, the user bit rate increases in both downstream and upstream directions at the constant number of links.

ii- Figs. (4, 5) have indicated that the user bit rate decreases as the number of supported users increases in both downstream and upstream directions at constant channel utilization. As well as the transport channel utilization increases, user bit rate decreases for both downstream and upstream directions at the constant number of supported users.

iii- As shown in figs. (6, 7), the number of optical terminals (i.e. OLTs and ONUs) increases as the number of links increases in both downstream and upstream directions at constant channel utilization. Moreover as the transport channel utilization increases with number of optical terminals increases at the constant number of link.

iv- Figs. (8, 9) have demonstrated that as the number of optical terminals increases, network equipment cost also increases at both downstream and upstream directions for different PON standards.

v- As shown in figs. (10, 11), as the number of optical terminals increases, subscriber or user cost also increases at both downstream and upstream directions for different PON standards.

vi- Figs. (12-14) have indicated that as subscriber bit rate increases, user or subscriber cost also increases at the constant splitting ratio for different PON standards. Moreover as the splitting ratio increases, user or subscriber cost decreases at the constant user bit rate for different

PONs. We have observed that Giga passive optical network (GPON) offered the lowest user cost than the other PON standards.

vii- As shown in Figs. (15, 16), as the number of quantization levels increases, user bit rate also increases for both audio and video signals at the constant both number of calls and TV programs. Moreover, as the number of calls or TV programs increases, the user bit rate also increases at the constant number of quantization levels.

V. CONCLUSIONS

Within SDM multiplexing technique, we have indicated that the increased number of links, yields the increased transmission bit rates for the maximum number of supported users, and the increased transport channel utilization in both downstream and upstream directions. Therefore, we have planned for the network to grow in the number of RNs due to an increase in the number of users or in the network bandwidth requirements. We have demonstrated the increased number of optical terminals, the increased both network equipment and subscriber cost for each link. Also, in the same way the increased transmission bit rate per user, the increased subscriber cost achievable with increased splitting ratio for different PON standards. Our current work have assured that GPON offered the lowest network equipment and subscriber costs than the other PON standards for different applications such as home and business. We have summarized the network equipment and subscriber costs for different PON standards compared to the their equipment and subscriber costs as in Refs. [14-16] as shown in Table 1.

Table 1: Comparison of network costs in comparison with their network costs in Refs. [14-16]

	Our suggested model with network equipment and subscriber costs and possible transmission bit rates		Their network equipment and subscriber costs and possible transmission bit rates as in Refs. [14-16]	
	Downstream	Upstream	Downstream	Upstream
User bit rate	800 Mbit/sec	600 Mbit/sec	622 Mbit/sec	455 Mbit/sec
Number of users	Up to 1000 supported users		Up to 1000 supported users	
PON standards	Average network equipment and user or subscribers costs for different PON standards at both downstream and upstream directions			
	Equipment cost	User cost	Equipment cost	User cost
GPON	350000 $	250 $	500000 $	400 $
EPON	600000 $	325 $	900000 $	500 $
BPON	850000 $	425 $	950000 $	650 $

REFERENCES

[1] F. Effenberger, D. Clearly, O. Haran, G. Kramer, R. D. Li, M. Oron, and T. Pfeiffer, “An Introduction to PON Technologies,” IEEE Commun. Mag., Vol. 45, No. 3, pp. S17–S25, 2007.

[2] C.-H. Lee, S.-M. Lee, K.-M. Choi, J.-H. Moon, S.-G. Mun, K.-T.Jeong, J. H. Kim, and B. Kim, “WDM-PON Experiences in Korea,” J. Opt. Netw., Vol. 6, No. 5, pp. 451–464, 2007.

[3] Abd El-Naser A. Mohammed, Abd El-Fattah A. Saad, and Ahmed Nabih Zaki Rashed, “Characteristics of the Fabrication Materials Based Arrayed Waveguide Grating (AWG) in Passive Optical Networks (PONs),” International Journal of Material Sciences Research, Vol. 1, No. 6, pp. 89-97, June 2009.

[4] Abd El-Naser A. Mohammed, Mohammed M. E. El-Halawany, Ahmed Nabih Zaki Rashed, and Mohamoud M. Eid “Recent Applications of Optical Parametric Amplifiers in Hybrid WDM/TDM Local Area Optical Networks,” IJCSIS International Journal of Computer Science and Information Security, Vol. 3, No. 1, pp. 14-24, July 2009.

[5] J. Zhang, and N. Ansari, “Design of WDM PON With Tunable Lasers: The Upstream Scenario,” Journal of Lightw. Technol., Vol. 28, No. 2, pp. 228-236, 2010.

[6] G. C. Gupta, H. Tamai, and T. Kamijoh, “A Simple One System Solution COF-PON for Metro/Access Networks,” J. Lightwave Technol., Vol. 25, No. 1, pp. 193-200, Jan. 2007.

[7] Abd El-Naser A. Mohammed, Abd El-Fattah A. Saad, and Ahmed Nabih Zaki Rashed, “Study of the Thermal and Spectral Sensitivities of Organic-Inorganic Fabrication Materials Based Arrayed Waveguide Grating for Passive Optical Network Applications,” Journal of Engineering and Technology Research, Vol. 1, No. 5, pp. 81-90, August 2009.

[8] A. Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, G. Kramer, K. Kim, and B. Mukherjee, “Wavelength-Division-Multiplexed Passive Optical Network (WDM-PON) Technologies for Broadband Access: A

review," J. Opt. Netw., Vol. 4, No. 11, pp. 737–758, 2005.

[9] F. I. El-Nahal and R. J. Mears, "Multistage WDM Access Architecture Employing Cascaded AWGs," Opt. Fiber Technol., Vol. 15,, No. 4, pp. 181–186, 2009.

[10] S. Khan, "Heuristics-Based PON Deployment," IEEE Commun. Lett., Vol. 9, No. 9, pp. 847–849, 2005.

[11] M. Hajduczenia, B. Lakic, H. J. da Silva, and P. P. Monteiro, "Optimized Passive Optical Network Deployment," J. Opt. Netw., Vol. 6, No. 9, pp. 1079–1104, 2007.

[12] J. Li and G. Shen, "Cost Minimization Planning for Passive Optical Networks," in Nat. Fiber Optic Engineers Conf., San Diego, CA, OSA Technical Digest (CD), Washington, DC: Optical Society of America, 2008.

[13] K. Kanonakis and I. Tomkos, "Improving the Efficiency of Online Upstream Scheduling and Wavelength Assignment in Hybrid WDM/TDMA EPON Networks," IEEE Journal on Selected Areas in Communications, Vol. 28, No.6, pp. 838-848, 2010.

[14] C. Bock, J. A. Lazaro, and J. Prat, "Extension of the TDM-PON Standards to a Single Fiber Ring Access Network Featuring Resilience and Service Overlay ," J. Lightwave Technology, Vol. 25, No. 6, pp. 1416–1421, 2007.

[15] ALCATEL, Optical Networks, The International Engineering Concortium, http://www.iec.org, 2006.

[16] GPON and EPON (GE-PON) Economical Comparison, http://www.flexight-networks.com, 2006.

[17] M. L. Jones, "Optical Networking Standards," J. Lightwave Technol., Vol. 22, No. 1, pp. 275-280, Jan., 2004.

AUTHOR'S PROFILE

Dr. Ahmed Nabih Zaki Rashed was born in Menouf city, Menoufia State, Egypt country in 23 July, 1976. Received the B.Sc., M.Sc., and Ph.D. scientific degrees in the Electronics and Electrical Communications Engineering Department from Faculty of Electronic Engineering, Menoufia University in 1999, 2005, and 2010 respectively. Currently, his job carrier is a scientific lecturer in Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia university, Menouf.