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OPTICAL ACCESS NETWORKS: A COMPARISON STUDY

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ABSTRACT

A comparison study of passive Optical Networks (PONs) and Active Optical Networks (AONs) had been presented. Powerful software design tool “OptiSystem” was used to perform this study. This comparison was based in terms of power consumption, communication distance, Q-factor, and bit error rate (BER) for each network system.

KEY WORDS

FTTX, PON, AON, PtP, Optical access networks

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1. INTRODUCTION

There are fast steps to improve the broadband services and increase the bandwidth of the new services, such as HDTV, broadcast TV / radio, home online games, remote medical services and next-generation 3D TV. That will be done by using network architecture which depends on optical fiber cables instead of copper cables [1-5]. Because of the fact that optical fiber has higher capacity than both coaxial cables and wireless links with lower latency and higher availability to reach longer area, optical fiber was studied to be used in broadband access networks as currently it can support data rate of more than 10 Gb/s in both upstream and downstream, also it can support the future demands by reaching 10 - 40 Gb/s with long distance and serving great number of users. That's why Fiber To the X (FTTX) is used which defined telecommunication systems that based on optical fiber [2, 3, 6, 7]. There are two networks that define the Optical access networks which gather data from the end users and forward it towards the central office and in the opposite direction data will be distributed from the central office to the end users. These networks are called Active Optical Network (AON) or Active Ethernet, and Passive Optical Network (PON) as shown in Fig.1 [2]. Active Ethernet or Active Optical Network (AON) is standardized according to IEEE 802.3 standard [8], it is used for broadband services (4/5 G for mobile network - Ultra High definition TV - Video conferencing - ..) [3, 9]. It depends on devices which are electrically powered such as routers and switches to distribute the signal [2, 10]. There is a dedicated Ethernet connection to each user that provide dedicated bandwidth of about 1 Gb/s for each user which is acceptable for the current triple play services (voice - video - data) [2, 9, 11]. Nowadays it can support applications with bandwidth of 10/40/100 Gb/s to each user and in future it can support 400 Gb/s [8] .There are two types of the AON which are based on active Ethernet switch, Point to point (PtP) and Active Star (AS). In PtP, there is a dedicated fiber link between Optical Network Terminal (ONT), Residential Gateway (RG) and the Ethernet switch of Optical Line Terminal (OLT) inside the Central Office (CO) as shown in Fig.2 (a) [9, 11]. In AS there is an Active Remote Node (RN) which is an Ethernet switch, and it is located in a cabinet or a building for connecting multiple (RGs) as shown in Fig.2 (b) [9, 11]. PONs are the principal networks for the broadband access Networks which are also fiber access network, they are called Passive networks as they don't use any active electrically powered equipment like that used in the AON (Ethernet switch), instead they only use passive components such as splitters or filters [3, 12]. Their architectures are based on main components which are an OLT, Optical Distribution Network (ODN), and Optical Network Units (ONU) as shown in Fig.3 [13]. PONs are used to provide customers with multimedia services (internet - TV - VOIP phone - internet services) with high data rate and through a network which is low cost and easy to implement [13]. The important parameters that govern the performance of the optical fiber networks are the signal to noise ratio (SNR), Q-factor, and the BER. SNR is described by the following formula [1]:

$$\text{SNR (dB)} = 10 \log (P_{out} / P_N) \quad (1)$$

SNR is the signal to noise ratio which is the ratio between the average signal power (P_{out}) to the average noise power (P_N). The Q factor measures the quality of the signal in terms of signal to noise ratio (SNR) and is given by [6]:

$$Q_{dB} = SNR + 10 \log (B_c / B_o) \quad (2)$$

Where B_c is the electrical bandwidth of the receiver filter and B_o is the optical bandwidth of the photodetector. The Bit error rate (BER) has a relation with Q factor in terms of error function (erfc) , and is defined in the following formula [6, 14]:

$$BER = \frac{1}{2}\, \text{erfc}\, (Q/\sqrt{2}) \quad (3)$$

$$\text{erfc} = \frac{2}{\pi} \int_0^x e^{-t^2}\, dt \quad (4)$$

PONs are defined and standardized by the International Telecommunications Union (ITU), the Institute of Electrical and Electronic Engineers (IEEE), and Full Service Access Network (FSAN) group to form the main architectures and the developed versions of PONs (APON - BPON - GPON - EPON) on which the commercial PONs nowadays are GPON and EPON [13]. PON technology is classified into generations, the first generation which are already deployed (APON - BPON - GPON - EPON), the first step of the next generation NG-PON1 which includes (XG-PON and XG-EPON), and the second step of the next generation NG-PON2 as shown in Fig.4 [13]. Table 1 shows the main characteristics of different types of PONs [3, 5-7, 10, 13]:

Table.1 The main characteristics of different types of PONs

Points Of Comparison	BPON	GPON	XG-PON	EPON	XG-EPON
Standard	G.983	G.984	G.987	IEEE 802.3ah	IEEE 802.3av
DS bit rate	1.24 Gb/s	1.244 Gb/s 2.5 Gb/s	10 Gb/s	1.25 Gb/s	1 Gb/s or 10 Gb/s
US bit rate	622 Mb/s	155 Mb/s 622 Mb/s 1.244 Gb/s 2.5 Gb/s	1 Gb/s, 10 Gb/s	1.25 Gb/s	10 Gb/s
DS wavelength	1490 nm	1480-1500nm 1550-1560nm (video)	1575-1580 nm	1480-1500 nm	1480-1500 nm
US wavelength	1310 nm	1300-1320 nm	1260-1280 nm	1260-1360 nm	1260-1280 nm
Distance	20 Km	60 km	20 Km	20 Km	20 km
Splitting ratio	1:32	1:64	1:256	1:16	1:32

The purpose of this paper is to provide a comprehensive comparison between AONs, and the PONs with respect to performance, ease of implementation, and cost effectiveness, using the powerful simulation tool OptiSystem. Using the proposed simulation results, we can identify in which cases PONs are preferable and in which cases AONs are preferable.

2. SIMULATION RESULTS AND ANALYSIS

Optisystem7 was used to perform a comparison between a type of AON (PtP) with dedicated BW for each user, and a type of PONs (GPON) with shared BW in terms of distance, BER and Q factor. Our requirements were to choose two networks with the same parameters as possible according to standards for appropriate comparison. Based on the Ethernet standard IEEE 802.3 , a system of AON PtP FTTH type is simulated by considering using bidirectional small form-factor pluggable transceiver (SFP), while the GPON is simulated based on ITU-T G.984 , with the following simulation parameters shown in Table.2:

Table.2 Simulation parameters for the investigated networks

Components	GPON	AON (PtP)
Bit rate	1.244 Gb/s	1.244 Gb/s
Bit sequence Generator	NRZ	NRZ
Downstream Wave length	1490 nm	1490 nm
Upstream wavelength	1310 nm	1310 nm
Downstream power	(-3, -1, 1, 3) dBm	-3 dBm
Fiber Distance	(10, 15, 20, 25, 30, 35, 40, 50) Km	
Number of ONUs	8	8
Power Splitter	1:8	-
Photodetector (Type)	PIN	PIN

There are common main components in the two networks, such as Continuous Wave Laser which acts as an Optical Source, Pseudo Random Bit Sequence Generator (PRBS) that determines the data rate, NRZ modulator which is the modulation method and MachZehnder Modulator which is used to control the amplitude of the optical wave. All of these components are under the transmitter section as shown in Fig.5. In the receiver section as shown in Fig.6, Bessel Filter is a shaping feature on which it is used to preserve the shape of the pass band signal, PIN Photodiode is used to convert optical signal into electrical signal, Low pass filter is used to cut the high Bessel frequencies, Optical Regenerator 3R is connected with BER analyzer to show the eye diagram and make performance analysis of the received signal in terms of quality and bit error rate. For the used optical fiber, we used OptiFiber program and connected it with the Optisystem to determine the attenuation (0.362 dB/ Km for 1310 nm - 0.216 dB/ Km for 1490 nm), dispersion 0.401 ps/ Km.nm for 1310 nm - 13.321 ps/ Km.nm for 1490 nm), and nonlinear refractive index (n_2) according to Kerr effect (2.607 e^{-20} m^2/W for 1310 nm - 2.51e^{-20} m^2/W for 1490 nm) in the fiber as a function of wavelength. In Fig.7, the structure of GPON has only one transmitter that launches signal towards a fiber which is connected to a passive splitter with ratio 1 : 8 used to distribute and divide the signal towards 8 ONUs. Our requirement in this simulation is to reach distance of 40 km with minimum power from (-3 dBm to 3 dBm), consequently, for GPON by using variable transmitted power for downstream (-3, -1, 1, 3) dBm to transmit signal through different fiber lengths (10, 20, 30, 40) Km, the relation between BER and fiber length is plotted in Fig.8. Knowing that the acceptable BER is 10^{-12}; it is concluded that the maximum distance that can be achieved by -3 dBm is 13 Km, by -1 dBm is 19 Km, by 1 dBm is 28 Km, and by 3 dBm is 40 Km. Simulation results show that for GPON at the maximum achieved distance of 40 Km by using transmitted power of 3 dBm, the Q factor was 6.994 and the BER was 1.3 ×

10^{-12} as shown in the eye diagram of Fig.9. Fig.10 shows the structure of the investigated AON PtP that consists of a central office / OLT which contained a transmitter followed by fork with 8 branches to simulate that the central office contains 8 transmitters, so that each ONU is connected to a fiber with dedicated transmitter. The simulation results show that the AON structure can easily achieve distance of 40 Km for all 8 ONUs using 8 transmitters with only -3 dBm transmitted power and provide a Q factor of 10.23 and BER of $7.07 \times 10^{-25}$for each user as shown in Fig.11. It can be concluded that AON has better Q factor and lower BER than GPON at 40 Km, as a result of the existence of dedicated bandwidth and dedicated fiber for each user, However it suffers from high power consumption as the power consumption used for 8 transmitters in AON to transmit total power of 6.03 dBm (-3 dBm×8) of course is more than the power consumption of GPON which uses only one transmitter with maximum power of 3 dBm to reach distance of 40 Km. Simulation results also show that by increasing the fiber link length to 50 Km there is no acceptable results for GPON as the Q factor and BER are 4.16, and1.52×10^{-5}, respectively as shown in Fig.12. However AON reached 50 Km with Q factor of 7.704 and BER of 6.57×10^{-15} as shown in Fig.13. Table 3 and Table 4 summarize the conclusion from the proposed comparison between the investigated networks obtained from the simulation results.

Table 3 Summary results of the proposed simulation networks.

	PON					AON	
Power (dBm)	-3	-1	1	3	3	-3	
Maximum distance (Km)	13	19	28	40	50	40	50
BER	10^{-12}				1.52×10^{-5}	7.07×10^{-25}	6.57×10^{-15}

Table 4 Conclusion of the comparison between the investigated networks

Points Of Comparison	PON	Active Ethernet / AON
Equipment	Not electrically powered (switch - Filter)	Electrically powered (Switch - Router)
Topology	Point to multipoint	Point to point
Power consumption	Low	High
Bandwidth	Shared	Dedicated for each user
Capacity for each subscriber	Low	High
Secure	Less	More
Upgrade	Difficult	Simple
Distance to reach	Short	Far
Cost	Low	High
Simplicity	Simple	Complex

3. Description of any Case Study

According to our results and the previous comparison between AON and PON in terms of advantages and limitations of each one of them as shown in Table 4, Choosing between these two types of optical networks will depend on the customer's need, requirements, and resources. Such as what kind of services are going to be delivered over the optical network, the overall network topology, the required distances, the level of security, the available transmitted power, the required number of subscribers / end users, and finally the cost.

4. CONCLUSION

The simulation results of the proposed study shows that the advantages of AONs over PONs are higher capacity as each user has a dedicated BW (not shared), longer communication distance, and more secure than PON. Because of the absence of active components, PON has advantages over AON such as reduced cost, simpler maintenance, low power consumption, and reduced size because of using only one shared fiber. The proposed simulation results showed that for reaching distance of 40 km using specific transmitted power from -3 dBm to 3 dBm, it is better to use PON than AON if our first priority is for the power consumption and the cost. However if we want to transmit data for longer distance (50 Km), AON will be used as the BER at the end users for PON is 1.52×10^{-5} which is not acceptable but for AON the BER is 6.57×10^{-15}.

FIGURES

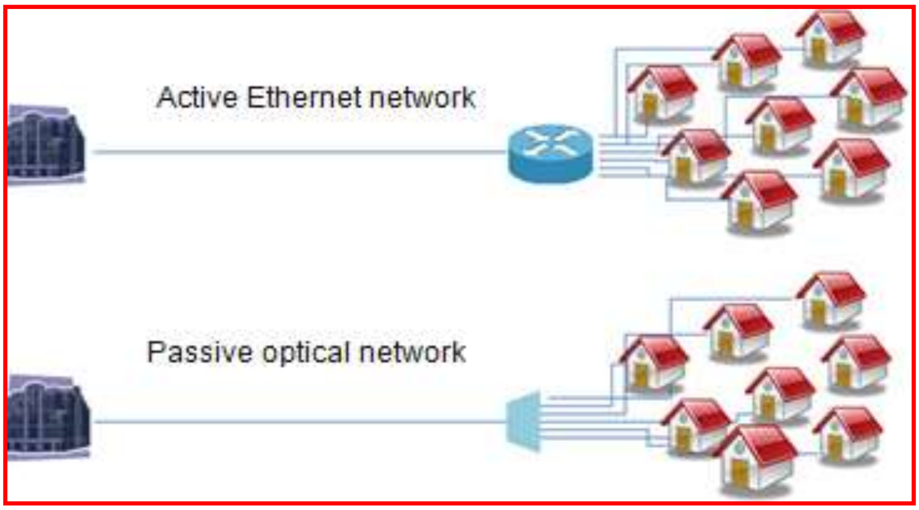

Fig.1. Active Ethernet and Passive Optical Network [2].

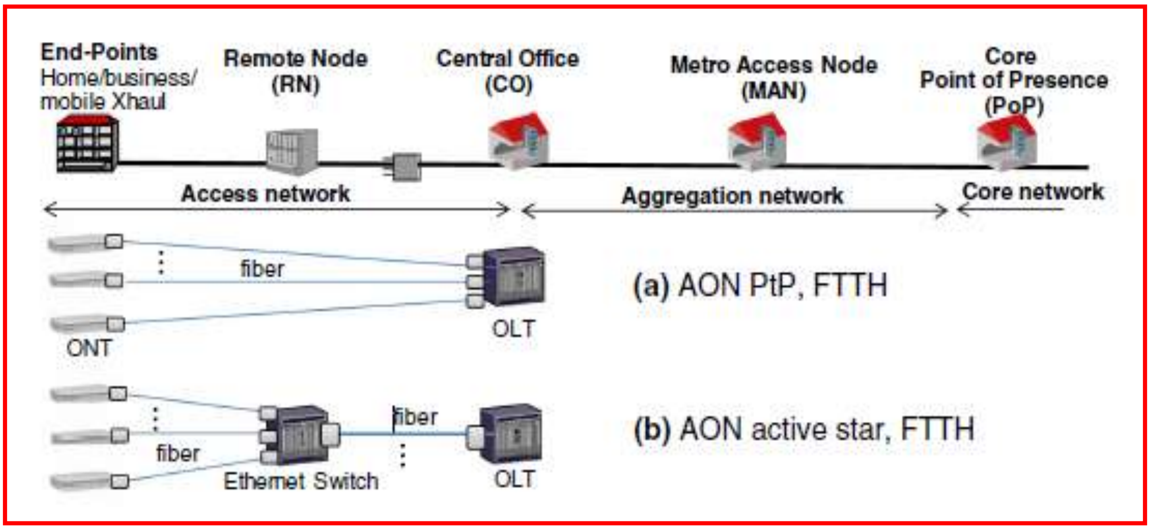

Fig. 2. a) AON P2P; b) AON active star [11].

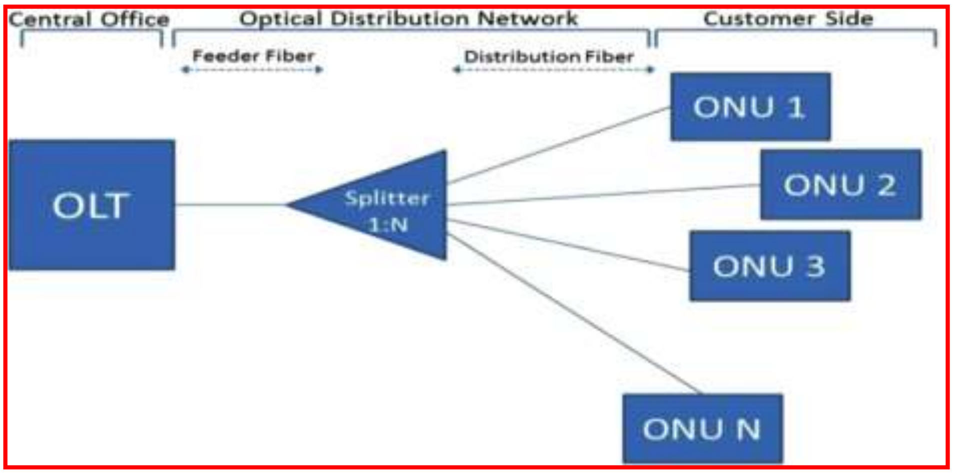

Fig.3.PON's Architecture [13].

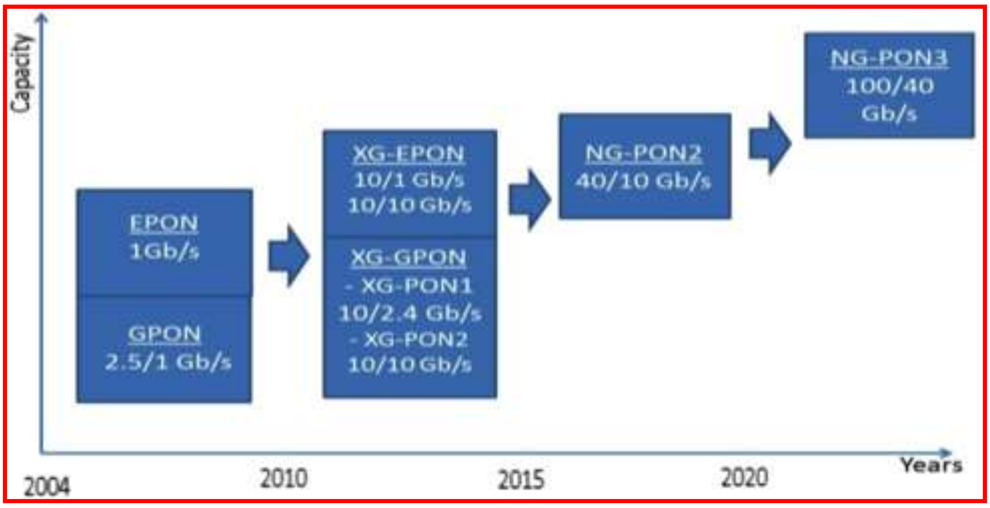

Fig.4. Generations of PONs [13].

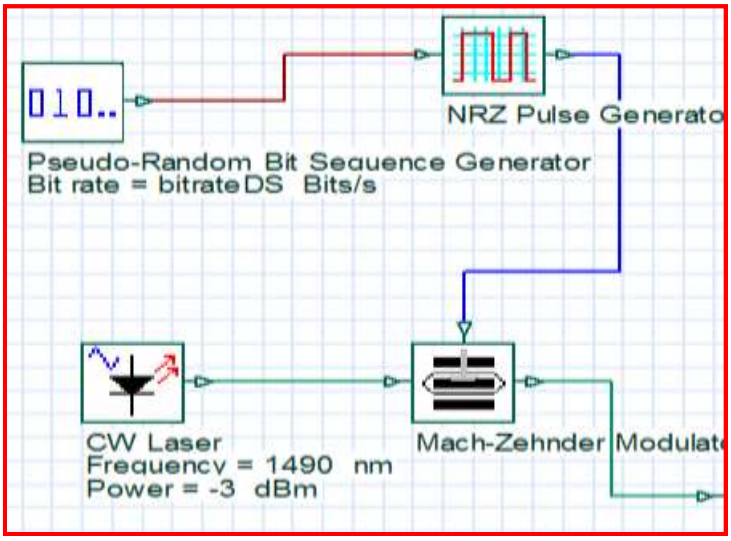

Fig.5. Structure of the transmitter.

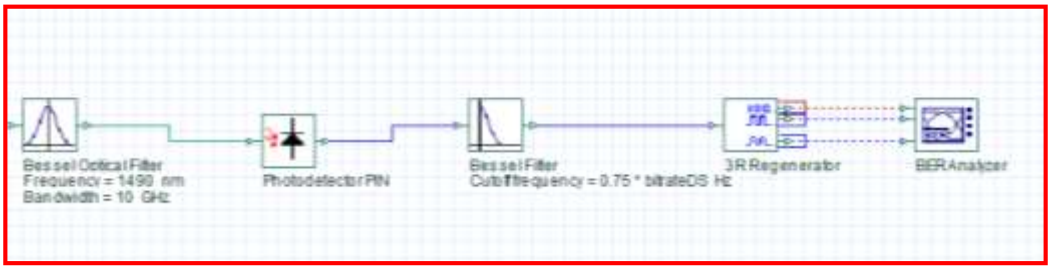

Fig.6. Structure of the receiver.

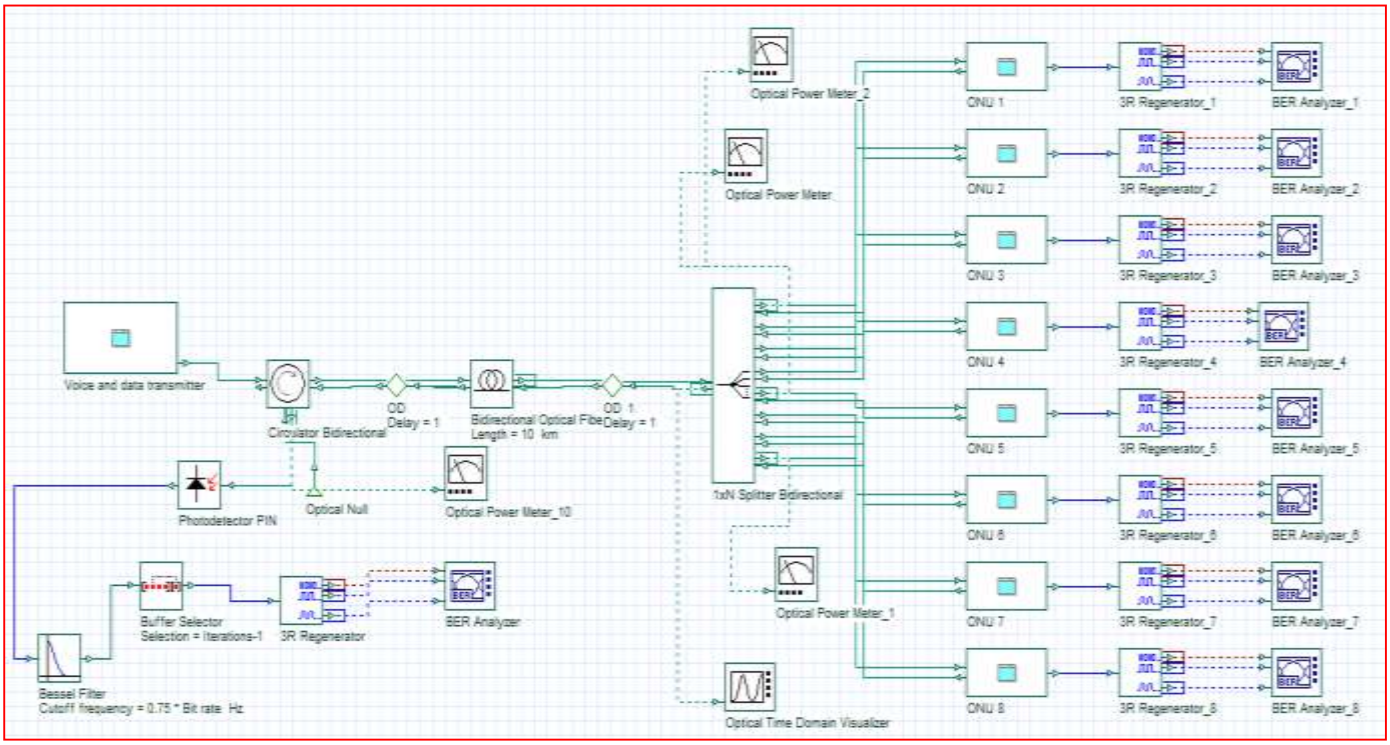

Fig.7. Structure of the investigated GPON

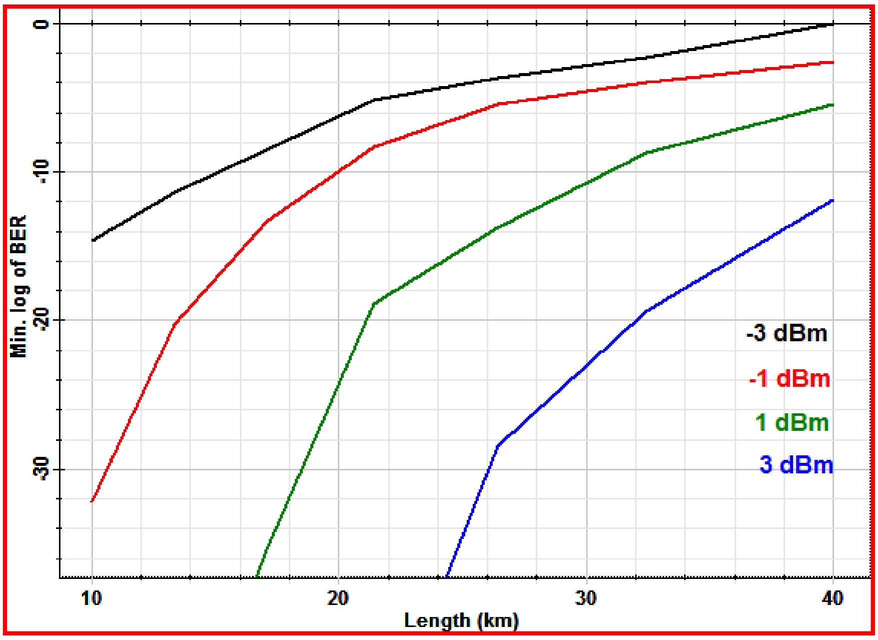

Fig.8. BER versus fiber length for PON case with using different power sources.

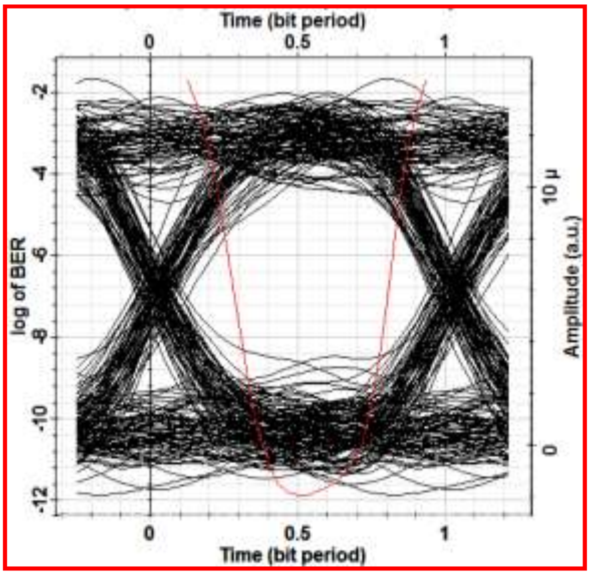

Fig.9. Eye diagram for GPON at distance 40 km using 3 dBm transmitted power

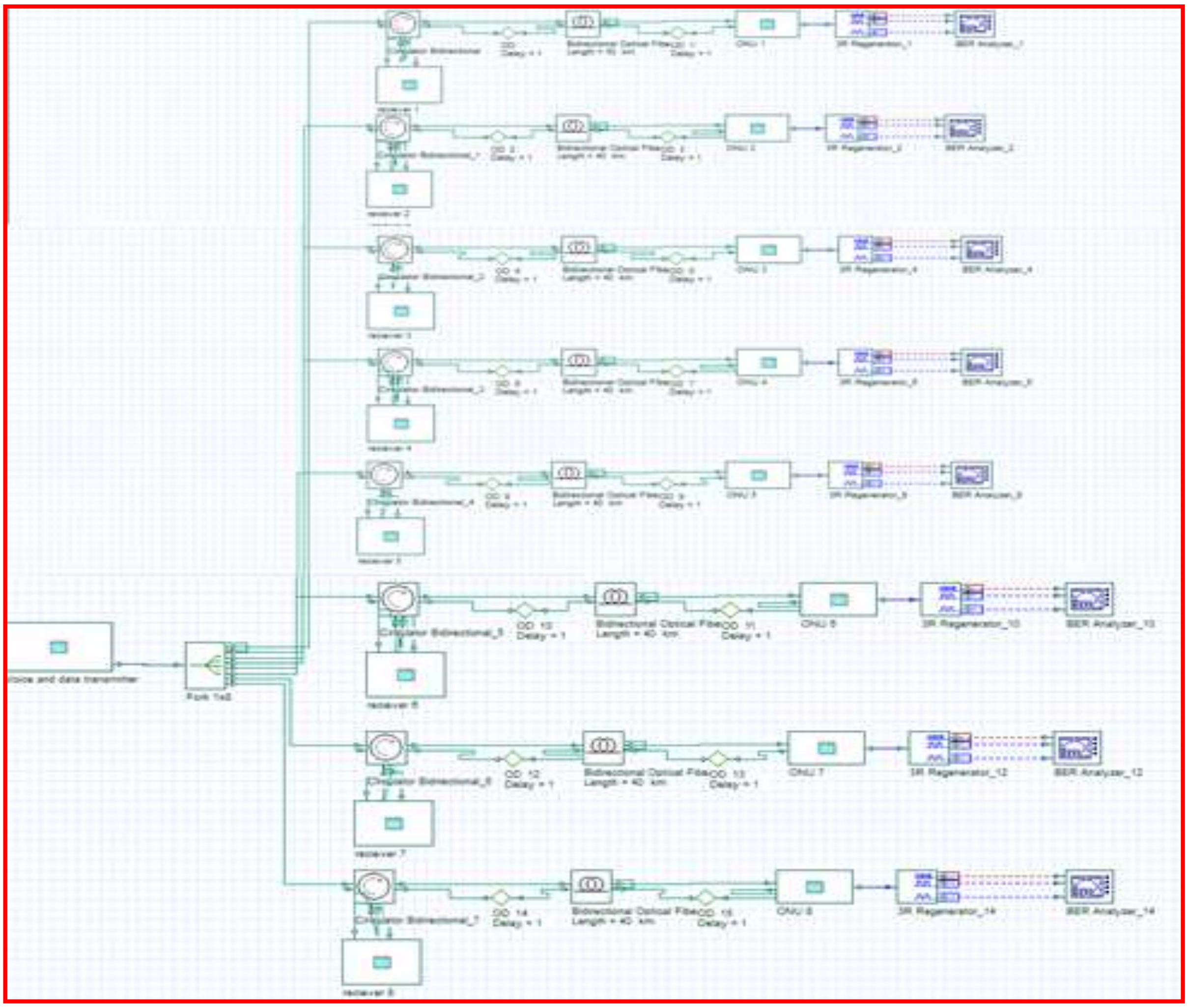

Fig.10. Structure of AON PtP.

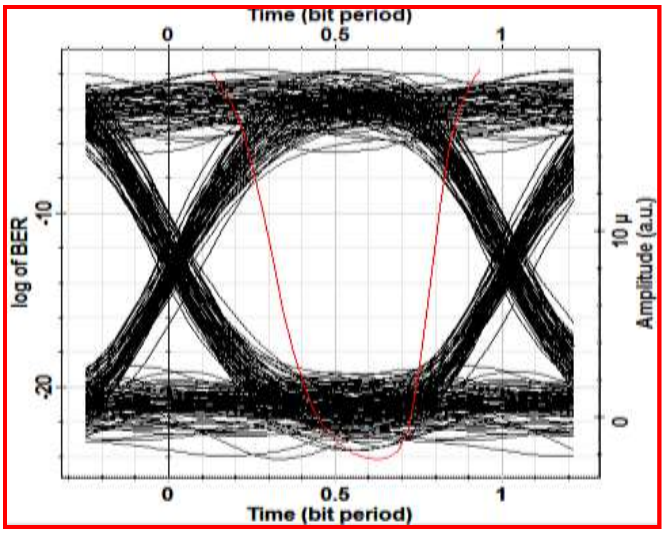

Fig.11. Eye diagram for AON PtP at distance 40 km using transmitted power of -3dBm

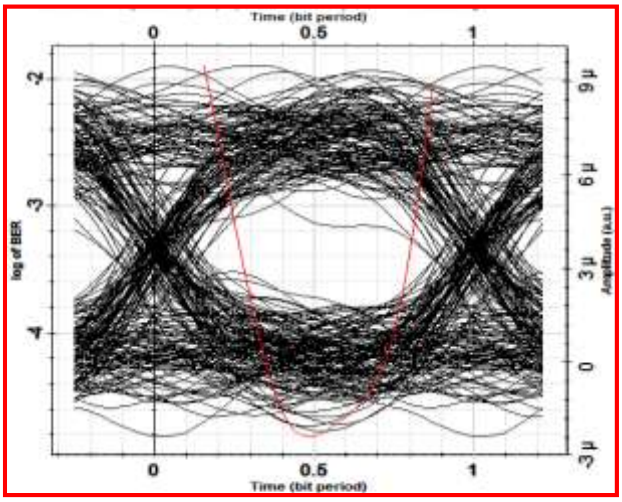

Fig.12. Eye diagram for GPON at distance 50 km using transmitted power of 3 dBm.

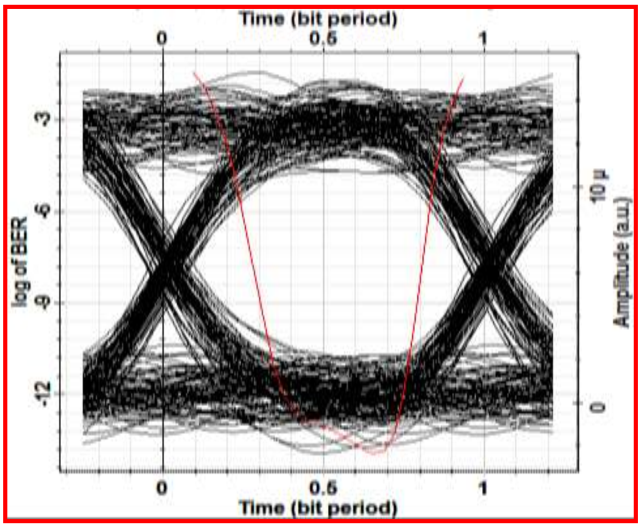

Fig.13. Eye diagram for AON PtP at distance 50 km using transmitted power of -3 dBm

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