Performance Evaluation of Symmetric and Asymmetric XG Passive Optical Networks

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Abstract – *The passive optical network refers to the optical network that configured without using any electrical components. XG-Passive optical Network (PON) is the first generation of the future optical network which is widely demanded for transmitting massive information. The paper aims to study the performance of XG-PON using different types of fiber optics and also to evaluate the performance of symmetric and asymmetric XG-PON. In this paper two model designs of XG-PON are shown. The first model uses a single direction fiber and the other uses a bidirectional optic fiber. The two models are used to evaluate the performance of XG-PON for both single direction optical line and bidirectional optical line. The paper discusses the basic structure and performance of symmetric and asymmetric XG-PON. The performance evaluations scope includes the measuring values of the bit error rate BER and the quality factor. The obtained results reveal that when using the same parameters, the resulted bit error rate of the bidirectional design is (1.2087×10-13). The obtained results show that the bidirectional design reflects better performance than single directional design and also proves that asymmetric XG-PON performance is better than the symmetric one.*

Keywords: *Fiber optic, XG-PON, BER, Bi-directional transmission, OLT*

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I. Introduction

The optical network is getting more interest due to their high bandwidth, and increasing the bandwidth is required to increase the processing power consumption in the networks' terminals. This problem makes passive networks to be a good choice in many applications [1]. The cost of using passive components is lower compared to the active components because it lowers the cost of maintenance and does not require power. The increase in the internet demand also helps to use optical networks widely. Broadband optical network designs that use fiber connections are classified into two categories, active and passive optical networks. Each design offers advantages to separate data and redirect it to its intended route and guarantee its arrival to the desired user. Either passive or active optical networks can be selected based on the application that needed to be served by the desired optical networks [2]. Passive optical networks (PONs) are optimum in terms of power consumption and widely used in the applications that do not require long transmission distance and serves low capacity. Passive refers to networks which do not contain any active element or which are considered as unpowered devices [3]. There are two configurations of PON standards. Symmetric standard where the upstream and the downstream of the data direction operate in the same bit rate [4]. The other available standard of PON is asymmetric standard where both upstream and downstream have different bit rate. In this paper the symmetric system refers to operating bit rate of 10 Gbps in both directions. In this paper two implementation designs of XG- PON are used in order to investigate their performance through different scenarios. The first scenario provides an implementation of XG-PON using single transmission fiber and the other scenario designated based on the use of bidirectional fiber. This paper illustrates the required components in each design. The significance of this paper is on the performance study of XG-PON in different structures by using different types of optical fibers. It also evaluates the performance of the symmetric and asymmetric XG-PON.

II. Survey of Related Works

There are a lot of implementations efforts published in different topics of passive optical networks. All these papers are different because most of them only provide a design and the others discuss the performance of the PONs. Kashif [5] discussed the basic design principles and the configuration of GPON Network using the Cisco ME4600 OLT and ONT/ONU. Juan [6] studied in his master thesis on the design and planning of the passive optical network. The thesis studied the elements of the PON and unlike our paper the thesis did not study the bidirectional and the single direction fiber. Dmitri L. [7] explained in his master thesis the use of Field Programmable Gate Array (FPGA) in implementing optical network unit. Satish S. [8] discussed in his paper the evolution of the passive optical networks where the paper concludes that the passive optical networks are better than active networks because it has lower cost. Min Z. [9] studied in his master thesis the wavelength division multiplexing passive optical networks(WDM-PON). The thesis overviews three technologies of (WDM-PON). Baziana [10] discussed the control strategies of transmission data package to avoid collision in star network**.**

Nahla [11] presented a bidirectional model design of WCDM-PON and evaluate the performance based on the BER and the quality factor. Baziana [12] studied the strategy of transmission in the ring configuration. Israr et al. [13] evaluated the performance for Giga passive optical network GPON in terms of modulation format where the paper calculated the quality factor and the bit error rate in 2 and 2.5 Gbps. Jerome et al. [14] in their paper presented a design of XG-PON module using the ns-3 network simulator. The paper discussed the design principles and evaluates the performance. Ahmed et al. [15] discussed the TDM-PON and the requirement of cloud radio access. The paper also evaluated an optimized mechanism of dynamic bandwidth allocation and network structure. The proposed work in our paper focus on studying the performance of XG-PON based on the types of transmission. The paper also investigates the performance of symmetric and asymmetric XG-PON.

III. Evolution of PON

Since 1990s PON have been rapidly developed into various standards. The standard of the PON series created by the International Telecommunications Union (ITU) has been known as APON standard. APON provides long-haul packet transmission based on the Asynchronous Transfer Mode (ATM) which has not been used recently, the second created version of PON called the broadband PON, or BPON. This version was created as ITU-T G.983, providing standard for 622 Mbits/s downstream and 155 Mbits/s upstream. The Gigabit passive optical network is an improved version of the BPON which aimed to support the bandwidth of business services. The bit rate is a major factor in the evolution of PON networks. Modern version of GPON with bit rate of 10-Gigabit is called XGPON, or 10G-PON. This generation of passive optical networks is designed due to the increased demand for video transmission and the widely spread TV services. Thus there is a strong need to increase the capacity of the data rates through the passive optical networks to enable it to serves the massive data of high-definition video [14].

Fig.1 illustrates the major configuration for PONs. As shown in Fig. 1, the number of required splitters and split levels depends on the type of facility which intends to use it and the system type of PON. Usually the splitters ratio is taken around 1:32 or 1:64, but in large designs it could be higher.

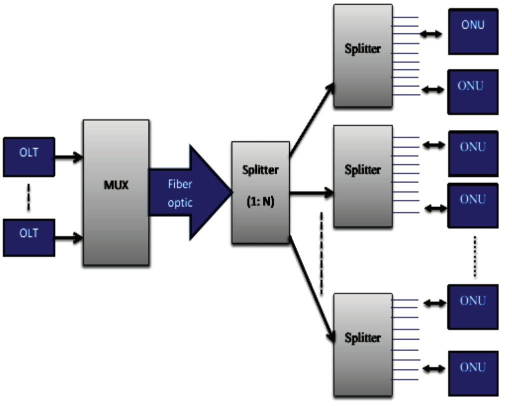

Fig.1. Basic Configuration of PON

IV. Methodology

The quality factor or called as Q-factor is an important factor used to evaluate the optical network, Q-factor is a mirror of energy loss in the system [16] and it can be defined by:

$$Q = (\mu_1 - \mu_0) / (\sigma_1 - \sigma_0) \quad (1)$$

where:

μ_1 and μ_2 : represent the average value of the receiving signal when a logical 1 or 0 is transmitted.

σ_1 and σ_0 : are the standard deviations corresponding to logic 1 and logic 0, respectively.

Bit error rate determines the efficiency of the transmitter because it indicates the number of bits which have error to the total received bits, where it should not be less than 10^{-9} [17]-[18]. In this paper two designs of XG-PON have been devised depending on the type of the optical fiber, as shown in the block diagram in Fig. 2 which represents a single direction. The block diagram shown in Fig. 3 provides the bidirectional optical network.

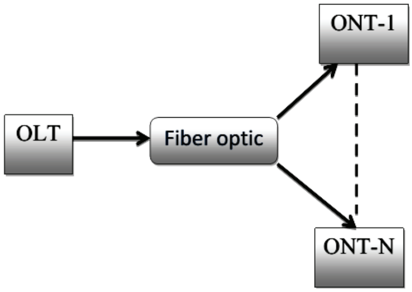

Fig. 2. Simple transmission scheme

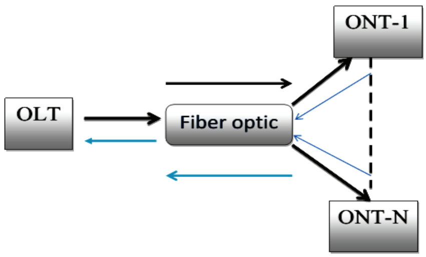

Fig. 3. Bidirectional scheme

The proposed bidirectional model design of XG- PON in this paper is done by using OptiSystem simulation software. The design model is shown in Fig.4.

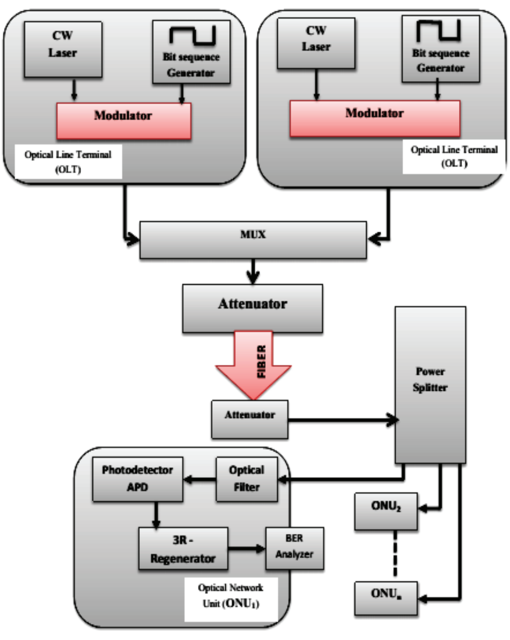

Fig. 4. Simulation Model

It illustrates the structure to connect two optical light terminal (OLT) to a various number of optical networks units ONUs. This design can be distinguished through three parts:

- Optical line terminal (OLT)
- Optical Distribution Network (ODN)
- Optical Network Terminal (ONT)

The main purpose of OLT unit as shown in Fig. 5 is to serve the function of controlling the flow of information across the ODN either to receive from the ODN such as in the downstream or in reverse direction such as in the upstream. ONT serves the receiver sides which usually consist of optical filter, photo detector device such as avalanche photodiode AVD and regenerator stage. Bi-directional fiber is used to provide connection between OLT to various ONUs. The design used a wavelength of 1575 nm for downstream from OLT to ONUs and 1270 nm for upstream from ONUs to OLT. Optical amplifier with 3dB gain has been used for increasing the transmission distance.

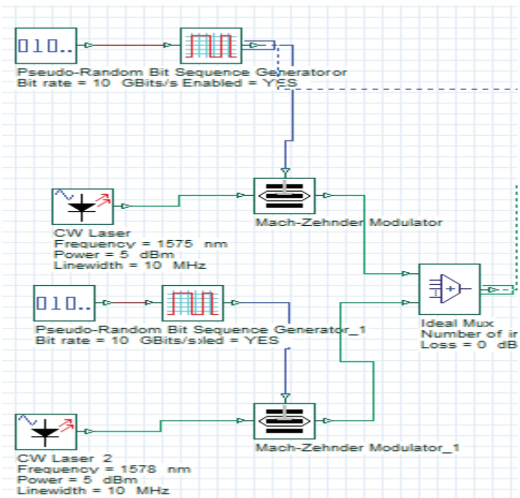

Fig. 5. Optical Line Transmission

The optical distribution networks as shown in Fig. 6 refers to connectors, fiber and power splitters.The two attenuators shown in Fig. 4 are placed to represents the equivilant loss due to connectors and splice connections.

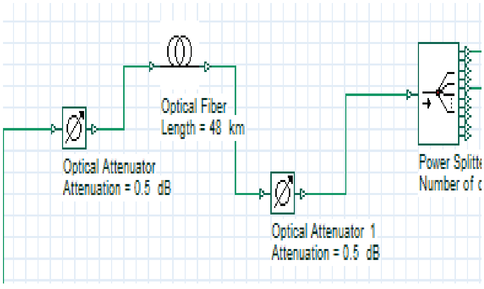

Fig. 6. Optical Distribution Unit

A. Simple and bidirectional XG-PON

The purpose of this analysis is to demonstrate the relation between the fiber length and the bit error rate in both types of fiber optic. The results in Table I show the values of BER which have been calculated for various length. The obtained results in Table I demonstrate the performance of passive optical network for simple transmission and bi-directional in term of BER factor.

TABLE I
PERFORMANCE OF SINGLE & BIDIRECTIONAL XG-PON

Type of Optical Network	Length (km)	Bit Error Rate (BER)
Single direction fiber	20	2.6633×10^{-19}
	30	6.5573×10^{-11}
	40	1.6850×10^{-5}
BiDirectional fiber	20	3.9383×10^{-29}
	30	1.2087×10^{-13}
	40	5.5244×10^{-7}

As shown in Table I, the results show that the bi-direction fiber provides better performance than the single-direction fiber for all length of fiber. It also shows that for both types of the fiber optic cable, the bit error rate decreased by increasing the length. The BER became less than the acceptable value (10^{-9}) when the length increased to more than 40km for both types. The design of the bi-directional fiber is more complicated than the single direction circuit.

B. Performance of Symmetric XG-PON

The performance investigation for symmetric XG-PON is shown in Table II. The results include the BER and the Q factor measured in various distance. The results indicate that the BER increased with the increase in the distance. The Q-factor decrease with the increase in distance.

TABLE II
PERFORMANCE VS DISTANCE FOR SYMMETRIC XG-PON

Length (Km)	BER	Q-factor
10	1.3840×10^{-2}	10.7977
20	1.5359×10^{-16}	8.1475
30	2.06×10^{-12}	6.9295
40	1.6361×10^{-6}	4.6500

The results show that the Q-factor value is in direct proportional with the BER value.

C. Performance of Asymmetric XG-PON

Similarly, the investigation on the performance of asymmetric XG-PON has been done in terms of BER and Q-factor and the results are given in Table III.

TABLE III
PERFORMANCE VS DISTANCE FOR ASYMMETRIC BR

Performance Parameter	Length (Km)	Bit Rate (BR) G Bit/s	
		10/5	10/2.5
BER	20	3.9383×10^{-29}	6.2488×10^{-33}
	30	1.2087×10^{-13}	4.6653×10^{-18}
Q-factor	20	11.1296	11.8806
	30	7.3159	8.7542

The results show that the use of asymmetric bit rate has improved the BER and the Q-factor. The overall results show that the optimum length of the fiber is less than 30 km because in this range the BER value of the communication system is within the acceptable range. The results also show that the bidirectional fiber has better performance because it has BER of 1.2087×10^{-13} than the single direction fiber which has BER of 6.5573×10^{-11}.

V. Conclusion

In this paper the structure of bidirectional XG-PON have been illustrated and evaluated for both symmetric and asymmetric transmissions. The evaluation parameters include the BR, BER and Q factor. The model design which has been shown in this paper is examined by assuming various lengths of fiber and different bit rates. The paper has discussed the performance of single and bidirectional XG-PON in terms of BER for different distances of fiber. The paper demonstrated that asymmetric networks have better performance than the symmetric networks which appear to be a reasonable because errors are reduced when using different wavelengths for upstream and downstream transmission. The paper also investigated the design and performance of simpler transmission and bi-directional transmission, where the configuration of XG-PON using bi-directional transmission requires additional components and it provides better performance.

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