EFFECTIVENESS OF GIGABIT PASSIVE OPTICAL NETWORK (GPON) TECHNOLOGY TOWARDS BROADBAND ENHANCEMENT IN HOMES

[1]SAMUEL NDUESO JOHN, [2]ETINOSA NOMA-OSAGHAE, [3]KENNEDY OKOKPUJIE, [4]ANDU OLUWATOMISIN, [5]CHINONSO OKEREKE, [6]CHARLES U. NDUJIUBA, [7]GODFREY ONYIAGHA

[1]Nigeria Defence Academy, Kaduna, Nigeria
[2,3,4,5]Covenant University, Ota, Nigeria
[5,6]Air Force Institute of Technology, Kaduna, Nigeria
E-mail: [1]samuel.john@nda.edu.ng, [2]etinosa.noma-osaghae@covenantuniversity,
[3]kennedy.okokpujie@covenantuniversity.edu.ng, [4]chinonso.okereke@covenantuniversity.edu.ng,
[6]charles.ndujiuba@afit.edu.ng, [7]godfrey.onyiagha@afit.edu.ng

Abstract - Customarily, the longest transmission length of a PON system is 60km or less and its maximum splitting ratio is 1:64 as characterized in ITU-T and IEEE standards. Recently, network providers have shown a lot of interest in PONs with transmission lengths greater than 60km and splitting ratios larger than the earlier stated value. The aim is to substantially reduce the number of central locations, simplify the overall network structure, decrease capital and operating expenses and increase the quality of service (QoS) for real-time traffic. There are no Q-factor and BER analysis beyond the characteristic 60km length for erbium doped fiber amplifier assisted GPON in the existing literature. In this study, an erbium doped fiber amplifier assisted Gigabit Passive Optical Network (GPON) for Fiber-to-the-Home (FTTH) with a splitting ratio of 1:4 was simulated using OptiSystem and its performance over long distances in 20km intervals compared to its counterpart without the aid of optical amplifiers. A Q-factor of 6.1308 and a minimum BER rate of 4.17981 × 10-10 were achieved at a distance of 200km with the aid of the erbium doped fiber amplifier.

Keywords - Bandwidth Enhancement, Bit Error Rate (BER),Broadband Access, Fiber-to-the-Home (FTTH), Gigabit Passive Optical Network (GPON), Quality Factor (Q-factor), Quality of Service (QoS).

I. INTRODUCTION

The advantages of using optical fibers include: higher bandwidth, extended transmission distances from central locations to the client, reduced electromagnetic interference, increased security, and reduced signal degradation. In addition, the use of PON technology eliminates the need for repeaters resulting in lower Capital Expenses (CAPEX), reduced power consumption, minimal use of space, and fewer points of failure. PON Technology enables a single optical fiber to serve multiple premises (point to multipoint) with the aid of an unpowered optical splitter.

FTTH is regarded to be the best option for access networks as internet and broadband applications evolves. It is acknowledged worldwide as an excellent solution for access network. FTTH is regarded as the quickest and most secure way to access the internet. Mobile communication compared to FTTH is much slower particularly when several users in the same area are sharing the available network. Satellite communication is likewise slower than FTTH as they involve a delay which clogs telephone conversations and other interactive exercises. Digital Subscriber Line (DSL) is also slower because it uses copper wire. For instance, downloading High Definition (HD) quality videos might take hours most especially if multiple users are on the network at the same time. With FFTH, ultra-fast internet access can be delivered to homes using optical fiber as a medium for transmission. In 2003, the G.984.x standard was introduced by International Telecommunication Union– Telecommunication Standardization Sector (ITU-T) to characterize the GPON system. GPON is a Passive Optical Network (PON) that works at a downstream rate of 2.488Gbps and an upstream rate of 1.244Gbps. The next-generation FTTH system structure is helped by this technology as it provides full services, Quality of Service (QoS), robust network, high efficiency and other advantages. GPON is also considered as one of the excellent choices for broadband access.

Customarily, the longest transmission length of a PON system is 60km or less and its maximum splitting ratio is 1:64 as characterized in ITU-T and IEEE standards. Recently, network providers have shown a lot of interest in PONs with transmission lengths greater than 60km and splitting ratios larger than 64 to substantially reduce the number of central locations, simplify the overall network system structure, decrease capital and operating expenses significantly and increase the quality of service (QoS) for real-time traffic (e.g. video-on-demand).

For a more cost-effective solution, an alternative architecture was proposed for optical networks and it is known as the long-reach optical access network. An optical technology strength lies is its ability to simplify the network by adding several layers of the network and to displace electronics. Passive optical splitters are located close to end-users and are used to connect these users to the main fiber. The current standardized PONs have a maximum length of 60 km with splits ranging from 1:4 to 1:64 for Ethernet-PON (EPON), Broadband-PON (BPON), or Gigabit-PON (GPON) respectively.

One of the issues with having access to broadband is distance. For instance, the distance between a central location and where broadband is needed could run into hundreds of kilometers. The normal PON cannot carry data with high integrity for that distance without optical amplifiers. Optical amplifiers are introduced into the network to efficiently increase the transmission length whilst ensuring that the distribution section closest to the customer remains passive. Over the years, various long-reach optical access network architectures have been developed. Initially, Time Division Multiplexing (TDM) was used. Later on, Wavelength Division Multiplexing (WDM) systems was introduced [8]. A lot of researches are still being carried out on the development of long-reach GPON systems.

The aim of this study is to increase the transmission length of a GPON network whilst enhancing the performance of the network. A Gigabit Passive Optical Network (GPON) was simulated in a fictitious environment using erbium doped fiber amplifiers. The performance of the simulated network was evaluated using two critical metrics, the Quality factor (Q-factor) and the Bit Error Rate (BER). Optical amplifiers were used to enhance the simulated network and its performance was weighed against the same simulated network without the aid of optical amplifiers. An OptiSystem network simulator software developed by Optiwave was used to simulate the proposed optical network. The simulation features the Gigabit Passive Optical Network transmission from the Optical Line Terminal (OLT) through the optical splitter to the Optical Network Unit (ONU) in homes.

The introductory part of this paper highlights the importance of broadband enhancement and gives a brief introduction into Passive Optical Networks. It also discusses the aim of the study, its objectives and the methodology employed. Section two reviews related works. Section three develops and shows more light on the study's methodology. It discusses the process involved in simulating and developing the tools to be used in the study. reveals, states and describes the design and methodology of the system to be developed. The result of the study is discussed in section four. A conclusion is made along with recommendations for future work. Acknowledgements are made and the paper is closed with a list of references.

II. RELATED WORKS ON GPON

Attaouia et al [1] conducted a research on the use of erbium doped fiber amplifier for the downstream of GPON with a split ratio of 1:128 and a transmission length of 80km compared to the 60km standard. They compared the various figures gotten from parameters like Q factor and minimum bit error rate for both 60km and 80km and discovered that with increasing fiber length, Q factor decreases and gives a better performance.

Srinath [2] designed a 2.5Gbps GPON model with a 50km fiber length for both single and multiple users. After simulation it was discovered that the most suitable wavelength for optimum performance is 1490nm while for multiple users it was 1550nm.

Aldhaibani et al [3] developed a hybrid GPON by integration both wave division multiplexing and time division multiplexing to form a single passive network which can support up to 64 users by implementing radio over fiber technique. This system increases data rate at reduces cost.

Kumar [4] presented a simulative investigation of a purely - passive Gigabit Passive Optical Network (GPON) at high transmission rate of 2.5 Gbps over a distance of 60km with compatible reach extender. The simulation was carried out with and without a square root module and distributed Raman amplification. It was concluded that signal power, Signal-to-Noise Ratio (SNR) and Q factor was improved using the SM module.

Verma [5] discovered that using uniform fiber Brag grating to vary the user defined bit sequence and length in an optical fiber communication system, improved the Q-factor and minimum Bit Error Rate (BER). During transmission through an optical fiber, parameters such as Maximum Q-factor, Minimum BER, Eye height, and Threshold were defined. These parameters characterize the proficiency of the network for various sorts of application such as live television broadcast, video streaming etc. A desired result was obtained by using user defined bit of 1010101010 as input at kilometer 70km to give a maximum Q-factor of 13.9572 and a minimum BER of 1.21174e-044 as the output.

Suzuki et al [6] showed that at a standard PON wavelength of 1310nm and 1490nm can be used to implement a PON extender box using either optical fiber amplifiers to increase the distribution length and split of a PON system. Noise created downgrades the sensitivity of the receiver as a result of optical amplification which introduces Amplified Spontaneous Emission (ASE) to the optical signal. The use of narrowband optical filter subdues the ASE noise effectively but it also restricts gain bandwidth present and places a necessity on the ONU transmitter wavelength than necessary in the current PON standard.

Ghafoor et al [7] proposed a network which has contributed greatly to the reduction of cost and power amplifiers for Raman amplification. The proposed network consisted of a symmetric 100 Gbps bidirectional WDM PON with a length of 80km bolstered by Raman amplification. The routinely overlooked wavelength region of E-band of 1450nm was used for utilizing pre-amplified data modulated Raman pumps.

III. METHODOLOGY

A GPON has a downstream potential of 2.5Gbps and an upstream potential of 1.244Gbps which is known as the ITU G.984 standard. The network consists of an OLT, optical splitter and ONUs located in homes. Table 1 shows the GPON model configuration used in the study. In general, every communication system comprises of a transmitter, channel and a receiver.

COMPONENT	VALUE
PBRS Generator	2.5 Gbps
CW Laser Diode	Power = 10dB
Mech-Zehnder Modulator	Extension Ratio = 30dB
Fiber Optic	Length = 20 – 200 km Attenuation = 0.2dB/km
Erbium Doped Fiber Amplifier (EDFA)	Gain = 20dB Noise figure = 4dB
Splitter	1× 4
Low pass Bessel Filter	Cutoff frequency = 0.75 * Symbol rate Hz

TABLE 1: The GPON Model Configuration

The OLT represents the transmitter and it contains Pseudo random bit sequence generator, pulse generator, light source and a modulator as shown by the block diagram in Figure 1. The channel via which the optical signal is transmitted is the optical cable. The optical splitter receives the signal and splits the fiber optic light into several parts at a certain ratio. It allows a single PON interface to be shared among multiple subscribers (it could be 1:2,1:4,1:8,1:16 or 1:32). The optical splitter used do not require power and that is why the network is known as a passive network. The ONU functions as an optical receiver and it consists of a photodiode and a filter. The ONU receives the signal in homes and transmits the data to various devices such as television, personal computers, etc.

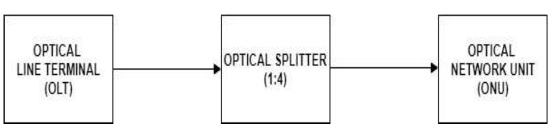

FIGURE 1: Functional Block Diagram of a GPON Network

A. Optical Line Terminal (OLT) Parameters

1) **Pseudo-Random Bit Sequence Generator (PRBS):** it generates a binary sequence known Pseudo Random Binary Sequence (PRBS). The bit rate chosen was 2.5×10^9.
2) **None-Return to Zero (NRZ) Pulse Generator:** it is used to convert the input digital signals from the PRBS to electrical signals. It generates electrical pulses.
3) **None-Return to Zero (NRZ) Pulse Generator:** it is used to convert the input digital signals from the PRBS to electrical signals. It generates electrical pulses.
4) **Continuous Wave (CW) Laser:** it is a laser that continuously pumps and an optical signal. The frequency was set to 193.1dB.
5) **Mach-Zehnder (MZ) Modulator Analytical:** A Mach-Zehnder modulator was used for modulating the amplitude of an optical wave.

B. The Optical Fiber

The length of the optical fiber was varied from 20km to 200km and experimental results got was recorded and analyzed.

C. Optical Splitter

An optical splitter divides the input optical signal into a required number of output optical signals. The split ratio used was 1:4, which means that one input signal was split into 4 output optical signal.

D. Optical Network Unit (ONU) Design

The ONU comprises of a photodiode and a flow pass filter

1) **Photodiode PIN:** This component does the conversion of optical signals to electrical current. As the electrical signal format in OptiSystem is unit-less, it is assumed that the load impedance used to calculate the current = 1 ohm (i.e. current equals voltage). To match the current results from OptiSystem with measurement data from an actual test measurement it is required to correct the current or voltage measurement based on the test equipment load impedance (typically 50 ohm).
2) **Low Pass Bessel Filter:** it is analog filter that preserves the wave shape of a filtered signal. A cutoff frequency of 0.75 times the symbol rate in Hertz was selected.

E. Optical Amplification

Optical amplification is a process whereby a fiber optic device is used to augment an optical signal directly without the need to convert it to an electrical signal at the beginning. When transmitting signals over long distances (>100 km), it is important to compensate for attenuation losses within the fiber. At first sending data over long distances was accomplished with the use of an Optoelectronic Module (OE) which consists of an optical receiver, a regeneration and equalization system, and an optical transmitter. But the conversion from optical to electrical signals and vice versa limited this arrangement. Hence different forms of optical amplifiers have been introduced to replace the use of Optoelectronic Module (OE). Factors to consider when choosing an amplifier includes; input and output power measured in dB, gain, noise and response to changes. Picking the right amplifier is dependent on the requirement of the fiber optic model and since the design is for the home, the optical amplifier used in this study is the Erbium Doped Fiber Amplifiers (EDFA). There are three methods of amplification which are pre-amplification, inline amplification, and post amplification. In this paper, post amplification was adopted because it is considered to be one of the best methods of amplification.

The Figure 2 shows the sequence of step follows to simulate and evaluate the GPON FTTH network.

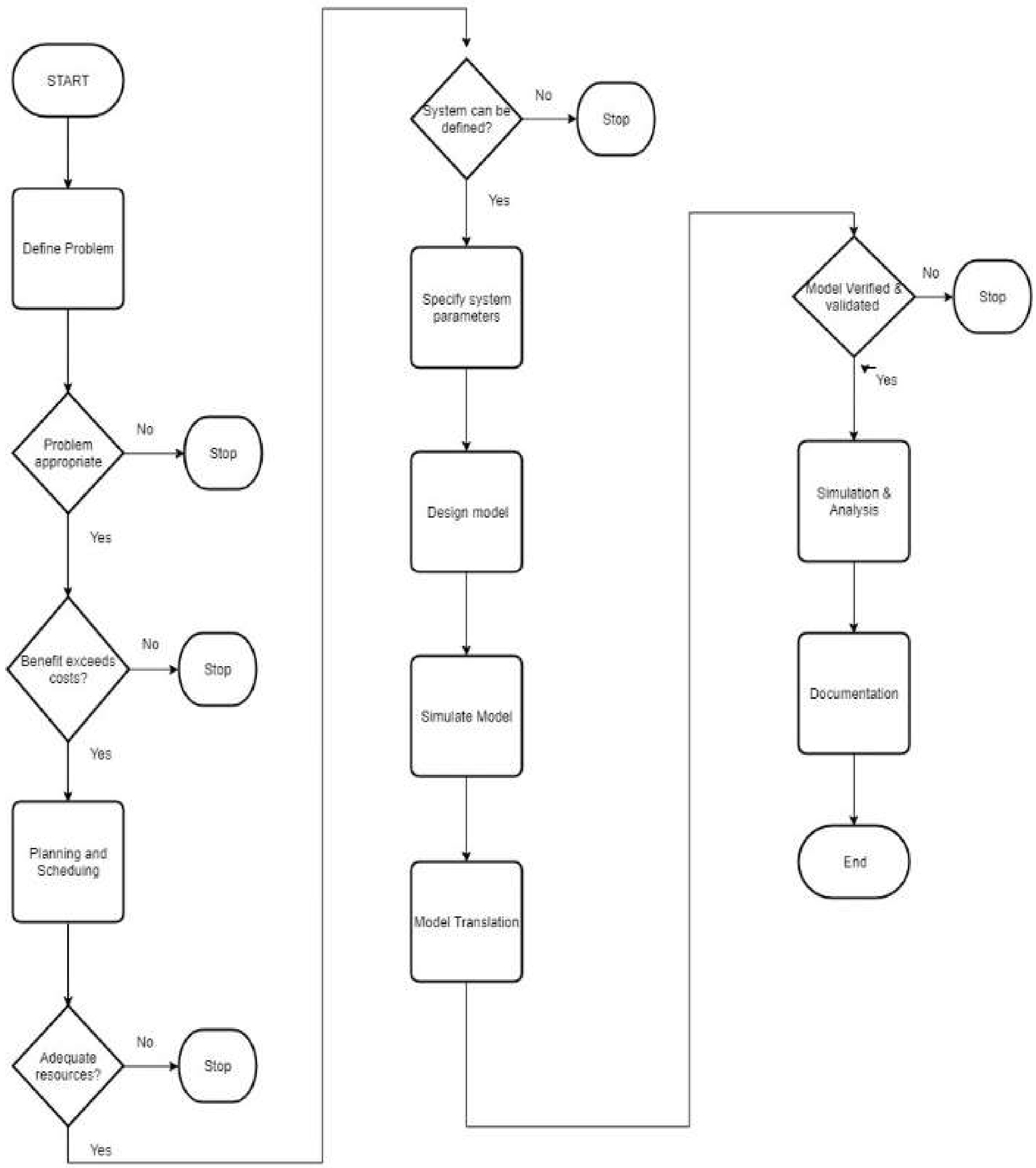

Figure 2: Flow Chart of GPON Model

F. Simulated GPON FTTH Model

Two GPON models were simulated. The model of GPON FTTH was without the use of amplifiers as shown in Figure 3 while the second model was with the use of Erbium Doped Fiber Amplifiers (EDFA) as shown in Figure 4. The optical distribution network was varied from 20km to 200km. Both models were simulated, evaluated and compared to ascertain the network reach using the OptiSystem Network Simulator.

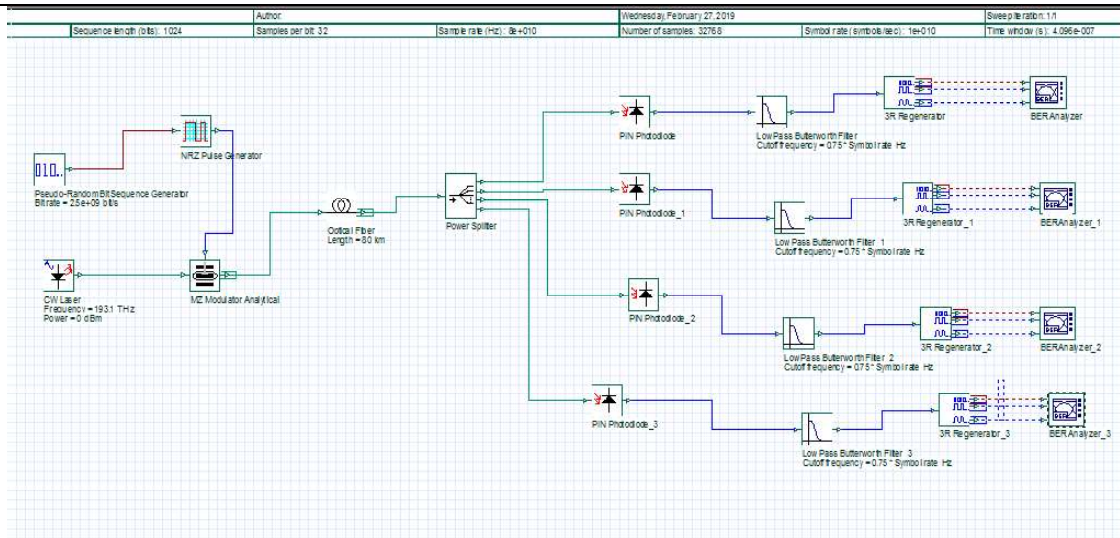

Figure 3: A GPON Network without Optical Amplifiers

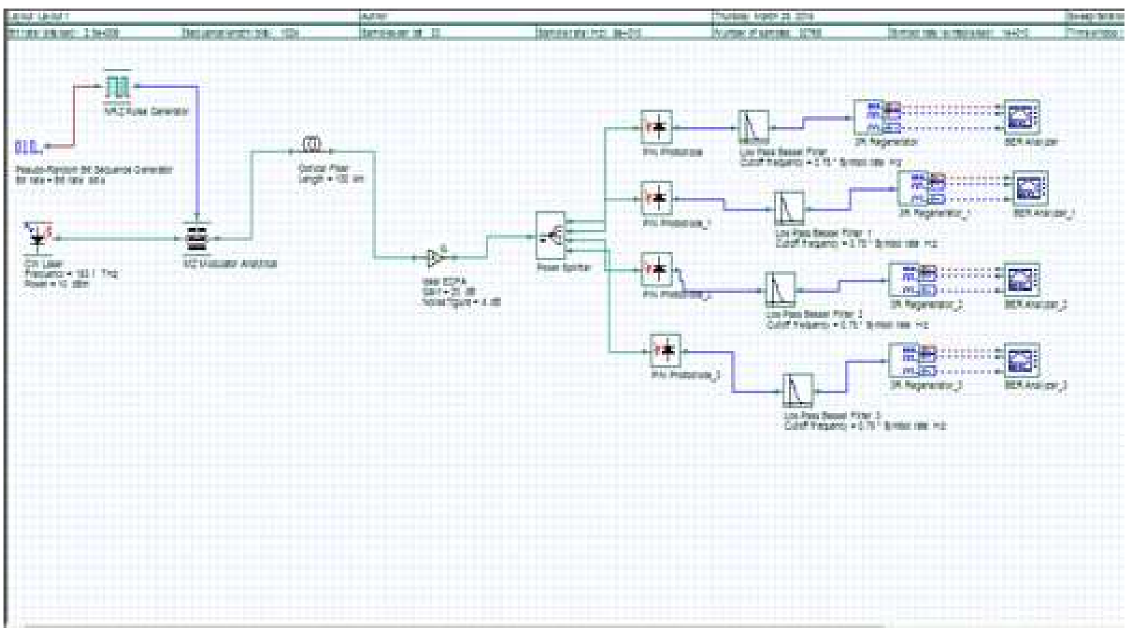

Figure 4: A GPON Network with EDFA Optical Amplifiers

IV. RESULT AND DISCUSSION

Use The two GPON models were simulated through Optical Distribution Network (ODN) transmission lengths ranging from 20km to 200km. One of the models is a pure GPON network while the other is Erbium Doped Fiber Amplifier (EDFA) assisted. The first simulation was done without the use of an erbium doped fiber amplifier and every component used was in accordance to the ITU-T standard. The parameters of the various components such as the PRBS, NRZ Pulse generator, MZ modulator, CW laser, optical wire, photodiode, low pass filter, 3R generator and BER Analyzer were set.

The 3R generator is a repeater that amplifies, reshapes and retimes. The use of 3RR generator eliminates the direct connection between the BER analyzer and the transmitter and this also, regenerates the electrical signal for the system. The BER analyzer was used to analyze the performance of the system. The result obtained was based on four parameters from the BER Analyzer. The parameters are as follows: Maximum Quality factor, Minimum BER, Eye height, Threshold and Decision Instant.

A. Maximum Quality Factor

Q factor gives the performance of the receiver. A high Q factor value indicates the presence low levels of noise in the system.

B. Minimum Bit Error Rate

The BER is the rate of error that occurs in a transmission system and it measures the transmission quality of a digital signal. It is the number of bits out of the total bits transmitted that have errors. It is the key parameter that is used in determining the performance of the system. The BER is typically expressed as ten to a negative power. For instance, a transmission might have a BER of 10 to the power of minus 10; it implies that out of 1,000,000,000 bits transmitted, one bit was in error. The BER shows how often data has to be retransmitted because of the presence of an error. It is unit-less. The formula of BER is given as:

$$BER = \frac{Errors}{Total\ Number\ of\ Bits} = \frac{E(t)}{N(t)} \quad (1)$$

The relationship between the bit error rate and the quality factor is:

$$BER = 0.5\, erfc\left(\frac{Q}{\sqrt{2}}\right) \quad (2)$$

Where,
BER = Bit Error Rate
erfc = error function
Q = Quality factor

C. Eye Height

This is the distance measured from the peak of the eye to the base. It is measured in voltage. The allowed minimum height value of the eye diagram is inversely proportional to the photosensitivity. High photosensitive sensitivity requires low height value of the eye for data assessment and vice versa. The eye height estimation determines the closure due to noise.

D. Threshold

The threshold selection depends on the received signal nature. Its value is in voltage. The received signal is regarded as a mark when the signal is higher than the voltage but it is considered a space when the received signal is lower than the voltage. The setting of the decision instant is done automatically inside the receiver when the system under test is a complete system.

E. Decision Instant

The BER analyzer chooses the optimum instant with which the widest eye opening has the decision instant to calculate maximum Q-factor. The optimization of threshold and decision instant concerning error detection is very important. The decision instant is chosen when the decision is made for whether a received signal is a mark or space. It should coincide with the time at which the eye diagram has the broadest opening.
In this study, the two major parameters that were used for analysis are minimum BER and Q factor.

F. Simulation Result for GPON FTTH Model

The Q factor and BER readings were obtained by using EDFA for 10 different transmission distances. The allowable minimum BER was 10^{-10} while the minimum allowable quality factor was 6. The result in Table 3 showed higher Q factor values which are 69.418, 40.5476, 30.8929, 25.9309, 22.1173, 17.6288, 18.0798, 12.4157, 10.6104 and 6.13082 compared to the values got from the result Table 2 - 26.7547, 12.6484, 5.5726 and 0. For 20 km ODN model with EDFA, as shown in Figure 10, the Q factor of 69.418 is higher than that of the model without amplifier, Figure 8 which is 26.7547 – The higher value indicates a lower noise level. From Table 2, the distances 80km to 200km in the simulation without amplifiers proves that the long-reach GPON is not possible.

Figure 9 and Figure 11 shows the minimum BER values for the GPON simulation with and without optical amplifier. The minimum BER values indicate the model with amplifiers performs better than the model without amplifiers. For the 80km – 200km ODN result of Table 2, the BER is 1 which indicates poor performance of the signal and it is filled with noise. But after the application of amplifiers, the noise is reduced drastically at those same lengths. Better performance and a satisfactory QoS has been achieved in the proposed system at distances greater than 60km with the introduction of optical amplifiers.

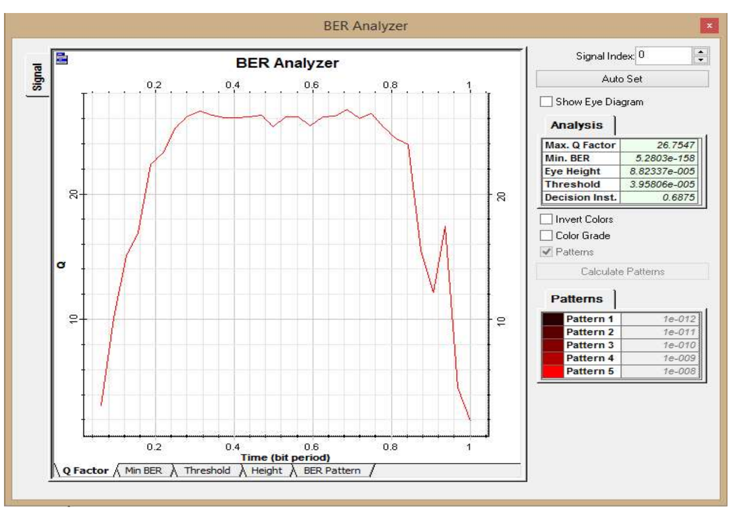

Figure 8: Q-Factor Graph for 20km ODN without Amplifier

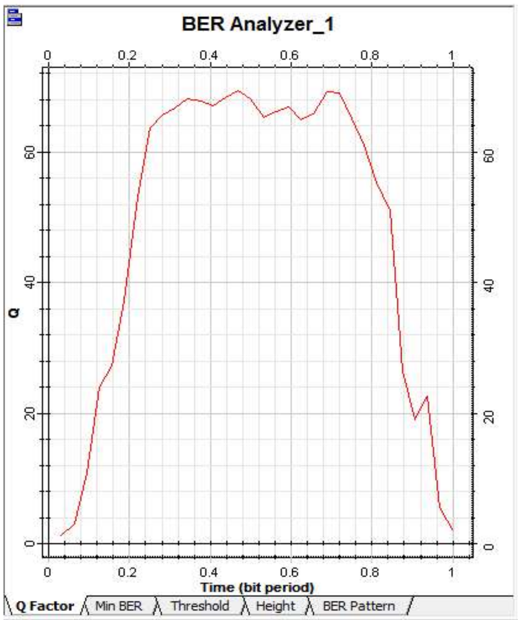

Figure 10: Q Factor Graph for 20km ODN with Amplifier

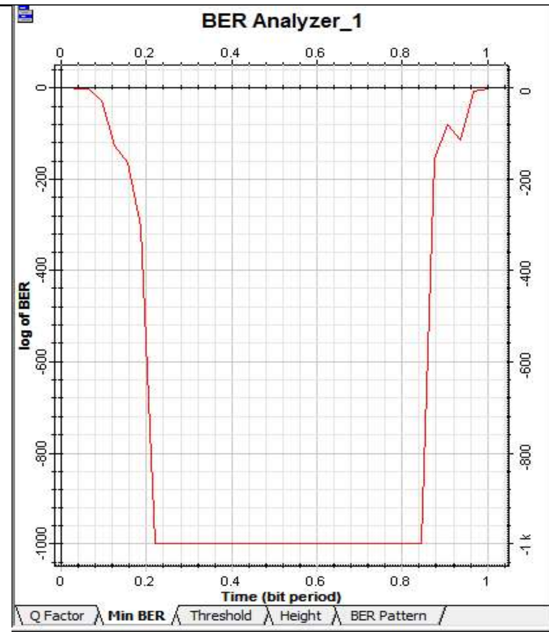

Figure 11: Minimum BER Graph for 20km ODN with Amplifier

V. CONCLUSION

One of the limits of passive optical networks is its inability to carry high integrity data beyond 60km without interference in the network. The introduction of optical amplifiers serves as booster to the network.The optical amplifier used in this study is Erbium Doped Fiber Amplifier (EDFA). Two different simulations of a GPON model were carried out; one with amplifiers and the other without amplifiers. The result, based on the two parameters (maximum Q factor and minimum BER), shows that the amplified GPON FTTH model achieved a high integrity long-reach GPON.

DISTANCE (KM)	MAXIMUM QUALIITY FACTOR	MINIMUM BIT ERROR RATE (BER)	EYE HEIGHT	THRESHOLD	DECISION INSTANT
20	26.7547	5.2803×10^{-158}	8.82337×10^{-5}	3.95806×10^{-5}	0.6875
40	12.6484	5.64092×10^{-37}	3.03095×10^{-5}	1.77943×10^{-5}	0.65625
60	5.5726	1.2492×10^{-8}	7.46752×10^{-6}	7.94753×10^{-6}	0.65625
80	0	1	0	0	0
100	0	1	0	0	0
120	0	1	0	0	0
140	0	1	0	0	0
160	0	1	0	0	0
180	0	1	0	0	0
200	0	1	0	0	0

TABLE 2: RESULT OF SIMULATION WITHOUT AMPLIFIERS

DISTANCE (KM)	MAXIMUM QUALIITY FACTOR	MINIMUM BIT ERROR RATE (BER)	EYE HEIGHT	THRESHOLD	DECISION INSTANT
20	69.418	0	0.0951372	0.000267384	0.53125
40	40.5476	0	0.036712	0.000800276	0.53125
60	30.8929	4.33366×10^{-210}	0.0142672	0.000856951	0.53125

80	25.9309	9.1357×10^{-149}	0.00557781	0.000475262	0.53125
100	22.1173	7.44175×10^{-109}	0.00216693	0.000311131	0.59375
120	17.6288	4.93024×10^{-70}	0.000855265	0.000112187	0.5625
140	17.3049	1.58307×10^{-67}	0.000326019	0.0000626519	0.5000
160	12.4157	7.41777×10^{-36}	0.000125054	0.00002.22945	0.40625
180	10.6104	1.1191×10^{-26}	0.000045814	0.0000162809	0.4375
200	6.13082	4.17981×10^{-10}	0.000012997	0.000010437	0.21875

TABLE 3: RESULT OF SIMULATION WITH ERBIUM DOPED AMPLIFIERS

FURTHER WORK

A lot of work needs to be done to reduce the noise in the GPON network.

ACKNOWLEDGEMENT

This paper is sponsored by Nigerian Defence Academy, Kaduna, Kaduna State, Nigeria.

REFERENCES

[1] Bentahar, M. Kandouci, and C. Aupetit-Berthelemot, "Analysis of GPON Downstream with 128 Users using EDFA In-Line Amplifier for Extended Reach to 80 km," American International Journal of Research in Science, Technology, Engineering & Mathematic, pp. 20-27, 2014.

[2] S. Srinath, "Performance analysis of 2.5 gbps gpon," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 1, no. 3, pp. 10148-10155, 2014.

[3] O. Aldhaibani, S. Yaakob, R. Shaddad, S. Idrus, M. A. Kadir, and A. Mohammad, "2.5 Gb/s hybrid WDM/TDM PON using radio over fiber technique," Optik-International Journal for Light and Electron Optics, vol. 124, no. 18, pp. 3678-3681, 2013.

[4] N. Kumar, "Improved performance analysis of Gigabit passive optical networks," Optik-International Journal for Light and Electron Optics, vol. 125, no. 7, pp. 1837-1840, 2014.

[5] S. Verma, A. Kakati, M. Tripathy, A. K. Singh, S. Kumar, and H. Rana, "Performance analysis of GPON network for maximum Q-FACTOR and minimum BER for various fiber length using uniform fiber Bragg's grating," in Information Technology (InCITe)-The Next Generation IT Summit on the Theme-Internet of Things: Connect your Worlds, International Conference on, 2016, pp. 247-250: IEEE.

[6] T. Tsutsumi et al., "Long-reach and high-splitting-ratio 10G-EPON system with semiconductor optical amplifier and N: 1 OSU protection," Journal of Lightwave Technology, vol. 33, no. 8, pp. 1660-1665, 2015.

[7] M. A. Farooq and S. Ghafoor, "Raman amplification by employing data modulated pump signals for bi-directional communication," Microwave and Optical Technology Letters, vol. 60, no. 3, pp. 778-784, 2018.

[8] Charles UzoanyaNdujiuba, Samuel Ndueso John: "Analysis and Applications of Nonlinearities in Optical Fibres in Wavelength Division Multiplexed Systems", International Journal of Optoelectronic Engineering (Vol.4, No.1, 2014), pg. 1-10, Elsevier, 2015, p-ISSN: 2168-5053 e-ISSN: 2168-5061, USA,

[9] http://article.sapub.org/10.5923.j.ijoe.20150501.01.html

★★★