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Performance Analysis of GPON-FTTx

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Abstract

The demand for data services and necessary bandwidth have grown rapidly because of new telecommunications services like HDTV via the Internet, video on demand, etc. An increase in demand for broadband connection from private homes, companies, etc. leads to an increase in bandwidth demand in the access domain. Issues associated with copper cables being used for transmission are quite enormous, from the imperviousness of the material to electromagnetic interference (if it is not correctly installed). Another issue is the attenuation of a signal over a distance. The study evaluates the performance of using GPON (point to multipoint) as one of the standards of PON technologies to provide triple-play services for users.

1. Introduction

The existing infrastructure for access network which was originally developed for classical telephony services is mainly on the copper cable which has limited bandwidth and reaches. Some years ago, the telecommunication system was built mainly for voice with small data capabilities. The birth of digital data

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transmission over the commonly used analog transmission brought new horizons to improved data transportation over the same infrastructure as voice calls [1]. Issues associated with copper cables being used for transmission are quite enormous, from the imperviousness of the material to electromagnetic interference (if it is not correctly installed), which can cause havoc to the network. Another issue is that of signal attenuation over a distance (e.g. over a distance of 100meteres (approximately 320feets), ber optics loses just three percent of the signal while copper cables lost about 94% of the signal). Speed is also an important factor to consider in signal transmission.
Fibre Optics has undoubtedly become a signi cant technology in the information society. After the rst low-loss bers were produced in 1970, there is exponential growth and improvement in optical ber communications. There are an extension and replacement of functionality previously done by copper-based systems [2]. Fiber optics consist of three main components: optical transmitter, ber optic cable, and an optical receiver. The process involved the conversion of an electrical signal to an optical signal, the signal is then carried from the optical transmitter to the optical receiver, it reconverts the optical signal to an electrical signal. The most commonly used optical transmitter is semiconductor devices like LEDs (Light Emitting Diode) and laser diodes. As the use and demand for speed and bandwidth increases, the development of ber optic grew exponentially. There are several types of it such as OS2 ber, OM1 ber, OM2 ber, OM3 ber, OM4 ber for di erent optical applications. They are used as a medium for telecommunication and networking because it is exible and can be bundled as cables. Optical transmission system that uses modulated light to convey information from a transmitter to a companion receiver are based on the transfer of optical signals (impulses) from one geographical area to another using speed of light (3 x 108m/s), therefore optical communication works in a greater data processing speed than that of electronic circuits which can be stretched over an extremely large length [2].
Fiber optic technology uses light impulses for communication which have far greater bandwidth than the conventional copper wire network. Therefore, it removes one of the obvious limitations of a copper wire network, and it is also immune to electromagnetic interferences and it is less susceptible to signal (impulse) degradations [3]. Network operators and service providers have taken a big leap by sending optical ber from the Central O ce (CO) to Customer Termination Point (CTP), a technology known as X, where X can be building, home, curb, cabinet e.t.c. Figure (1) [4] below shows the statistics of the increase in data rate and predicted increase after some years.

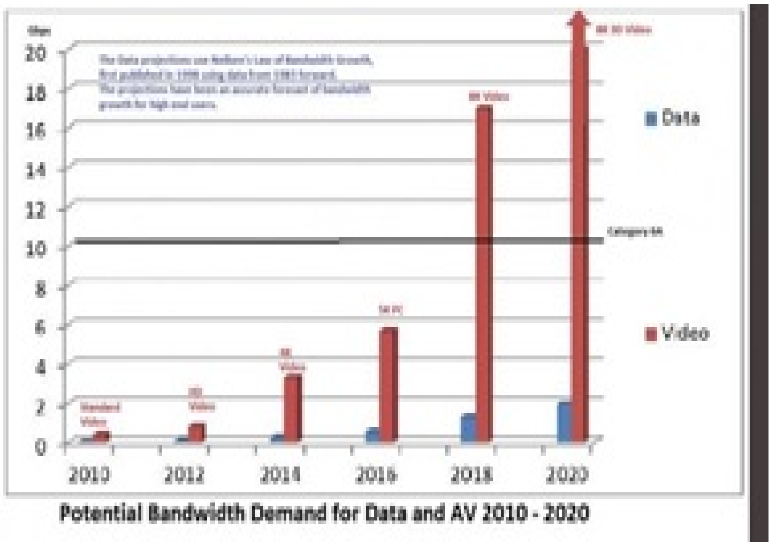

Figure 1: Showing the predicted increase in data rates.

The high cost of connecting each subscriber to the CO is one of the obstacles to provisioning of the ber optic services directly to residences and small businesses even though the ber provides a means to cater for the explosive growth in demand for more bandwidth and higher speed services, longer reaches and also problem of using di erent media equipment requiring extensive maintenance. A high number of point-to-point (P2P) connections will require numerous active components and a great deal of ber optics cable and therefore would have prohibitive installation and maintenance costs. The FTTx (Fiber to the \x") using GPON (Gigabit Passive Optical Network) architecture which involves the use and deployment of an entirely passive point-to-multipoint (P2MP) topology in the building while potentially keeping the copper and wireless premises networks or providing the ber to the subscribers promises a nearly unlimited bandwidth that can be used for nowadays services and applications and that of the future. The gigabit passive optical network (GPON) is an outcome of the full-service access network (FSAN) alliance and is speci ed in the ITU-T G.984x series of recommendations, it provides larger splitting ratios, higher-up and downstream data rates, longer reach, security and improved privacy through the use of the AES (Advanced Encryption Standard) algorithm, and a new GEM (GPON encapsulation method) to carry synchronous voice and data services such as Ethernet in a bandwidth-e cient manner. A GPON is made up of an optical line terminal (OLT) at the central o ce (CO) and optical Network Units (ONU) for the local users of the network ([5] & [6]).
As the demand on data services and necessary bandwidth have grown rapidly because of new telecommunications services like HDTV via internet, video on

demand, increase in resolution of data have increased demand on broadband connection from private homes, companies, to the service provider, the services of the xed and the mobile networks steadily acquire higher speed and availability which leads to an increasing bandwidth demand in access domain. Optical networks now convert from optical to electronic form every time it needs to be routed or switched, and also changing the copper cables piece by piece does not allow for its full potential. Thus, to realize the full potential of optical technology, it is necessary to build optical network using the technology of ber to the premises using Passive Optical Network (PON) ([1] & [2]).

1.1. Related Works. Authors in the article [7] presented the downstream transmission performance of 1.25 Gb/s GPON bit rate using Optisystem, the simulated model factored in all Optical Distribution Network (ODN) class and considered the worst-case scenarios of the design constraints. Results emphasized that GPON is an ideal technology and cost-e ective solution for large-scale FTTH applications. Article by [8] presented an evaluation and comparison of FTTH GEPON link design for 56 subscribers at 20 km reach at 2 Gb/s bit rate. The simulated model implemented a 1:56 splitter PON and a boosting ampli er to reduce BER. However, the model reported a BER that increases when the data rate or transmission distance is increased. [9] in their work provided a systematic design and eld implementations of type B protected GPON FTTH access network serving 1000 users to emphasize the practical implementation of a GPON based FTTH access network.

Authors in the article [10] evaluated the performance of advance optical modulation formats (CSRZ, DRZ & MDRZ) in terms of the eye diagram, Q-factor, and BER in 2 & 2.5 Gb/s GPON system. The evaluation and comparison in this paper are based on the transmission distance and data rate. Simulations were done in Optisystem. The results showed that one of the modulation formats (MDRZ) o ers less dispersion and less BER for long-distance transmission. In the article [11], performance evaluation of a 10-Gigabit-Capable PON (XG-PON) with a splitting ratio of 1:64 was studied. The simulation was done in Optisystem and it was discovered that the model is implementation-suitable for providing broadband services. Authors in the article [12] designed an error-free gigabit PTMP communication network with the help of Fiber Bragg's Grating (FBG) in Optisystem software environment. Results showed that, with the integration of FBG, the problem of ISI was reduced to minimal.

Authors [13] argued that Digital GPON communication uses various encoding schemes for successful communication. The results were evaluated in the form of Q factor and BER, and the results proved the e ciency of the proposed work. The authors in [14] achieved in Optisystem the aim of optimizing network and reducing the cost of ber optic component in a protected GPON FTTH access network model, thus, emphasizing the importance of GPON architecture in FTTH design.

A systematic approach to designing and analyzing FTTH using Optisystem was presented in [15]. The results emphasized the fact that Optisystem can be used to design and con rm the feasibility of a link before the actual rollout process. Using Optisystem, a simulation model of the GPON standard of FTTH to deliver a reliable connection to 64 subscribers over a distance of 50km was proposed by [16]. The results showed that optical ampli ers extended the reach of GPON beyond the 20km mark to achieve a high-performance working system.

[17] proposed two BI-DBA (CBDBA and GBDBA) mechanisms for GPON. The results showed that the GBDA mechanism outperformed the CBDBA but the T-CONT2 packet delay when the proportion of the T-CONT is increasing which as a result of GBDBA allocating resources based on the bandwidth requirements of each ONU thereby retaining global fairness. The limitation here is that the CBDBA reported the bu er REPORT twice in a cycle time which causes a double guard time problem and eventually reduces the performance of the system.

[18] analyzed di erent cases for multiple wavelengths for data, speech, and video, and it was discovered that using directly modulated laser and optical MUX (instead of signal combiner (EDFA) 1490 nm wavelength for Data+Voice and 1550 nm for Video) is the best for lengthy range triple play connectivity in terms of performance. Quad play (SDH, voice, video, and information) from a single device is feasible.

The work of [19] demonstrated the coexistence of XGSPON and GPON in the same FTTH optical network (ODN) allocation. The ndings showed that XGS-PON and GPON that coexist can operate successfully.

A traveling-wave semiconductor optical ampli er (TSOA) with a square root module (SRM) to analyze the e ciency of 10 GPON for 50 km bidirectional ber connection was used in [20]. The proposed work was used 1550 and 1300 nm wavelength for downlink and uplink transmission respectively. It was noted that when using the TSOA-SRM mix in the architecture, there was an increase in the bit error rate, quality factor and SNR for information rates up to 10Gbps with 64 downlink users and 40 uplink users. Further enhancement in SNR helped in achieving the expanded GPON.

2. Methodology

Implementation of bidirectional transmission of GPON that uses Time-division multiplexing (TDM) on a single ber that can be used for downstream and upstream data would be shown. The simulation would be carried out in the Optisystem software environment. The performance of the GPON simulated network model would be tested as well as the benchmark for the BER and improve the quality factor of the network. Optisystem software is a powerful optical network design tool that enables the user to plan, simulate optical communication systems from component to system level, test and optimize the simulated model. It is used to design several applications such as PON, WDM/TDM (Wavelength Division Multiplexing/Time Division Multiplexing), OCDMA (Optical Code-Division Multiple-Access System), SONET/SDH (Synchronous Optical Networking/Synchronous Digital Hierarchy), link budget calculations and transmitter, channel, ampli er, and receiver design. Optisystem software has useful tools like parameter sweep and optimization. Parameter sweep lets users input range of values for one component parameter or more to test the output against the range specify output peaks and values related to that input. Nested Sweep allows the designer to perform multidimensional analysis to get better values. While Optimization is used to set any component parameter to value required to maximize, minimize or set the output to the target value.

Optical devices are quite costly which makes it di cult for network designers to test the related network (optical communication network) in real life. However, Optisystem software which has relatively high accuracy is being used.

2.1. Network Design and Setup. The simulation scenario of the GPON is shown in Fig. 2. Optical circulator, 1x32 bidirectional passive optical splitter, one transmitter and one receiver at the OLT distributed to 32 ONUs. Pseudo-Random Bit Sequence (PRBS) Generator produces the data signal sequence at the transmitter, then Non-Return to Zero (NRZ) generator produces a sequence of non-return to zero pulses coded by a digital input signal. Continuous laser wave (CW) produces an ongoing optical wave signal; the laser is pumped continually to emit constant light.

The output of the NRZ pulse generator and CW laser goes to Mach-Zehnder Modulator (MZM) to convert the electrical signal to an optical signal. At the receiver, the optical signal was converted to an electrical signal using Avalanche Photodiode (APD), then the signal was ltered by a low pass Bessel lter to regenerate the desired signal. A BER analyzer was used for data analysis.

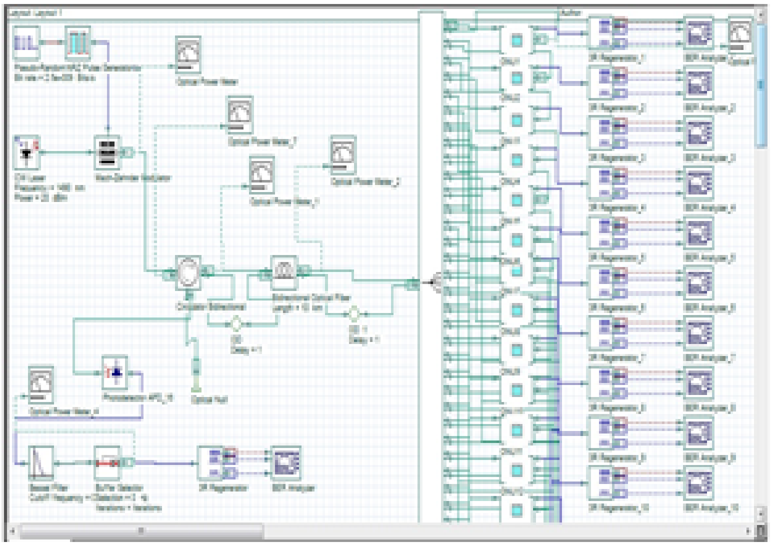

Figure 2: Simulation Scenario of the GPON.

The description of the components used in the simulation process is illustrated in Table 1 and Table 2.

Table 1. Descriptions of Components used in Simulation

Block Unit	Block Number
PRBS Generator NRZ Pulse Generator	Generates PRBS according to di erent mode operation Generates NRZ coded signal
CW Laser	Generates a continuous wave optical signal
M Z M	Converts electrical signal to an optical signal
Circulator Bidirectional	Separates upstream and downstream signals
Optical Null	Creates a zero optical signal
Optical Delay	Adds delay to make the bidirectional signals pass at the same time
Bidirectional Optical	Fiber Allows optical signals to travel in both directions at the same time
1xN Splitter Bidirectional	Splits the signal into the required number of signal streams $(N = 32)$ to transmit it to ONUs
APD Photodetector	Convert an optical signal to an electrical signal
Low pass Bessel Filter	Filters the signal with a Bessel frequency transfer function
Dynamic Y-Select	Used in upstream due to TDMA mechanism

Table 2. Descriptions of Components used in Simulation

Block Unit	Block Number
Buffer Selector	Selects the signal data associated with a specified iteration in a series of iterations
3R Regenerator	Regenerates the optical signal
BER Analyzer	Measures system performance based on the pre- and post-propagation signal
Optical Power Meter	Measures the optical power in different ports

In the downstream direction, the signal traveled from the OLT transmitter and passed through bidirectional SMF then split via 1x32-bidirectional splitter and received by the 32 ONUs receivers. The transmitter consists of PRBS that was set to 2.5Gbps, which is the downstream data rate of the GPON. The data was coded via NRZ. The optical modulation comprises of LD and MZM, which operates on the GPON's working wavelength to prepare the electrical signal for bidirectional fiber transmission. MZM has three ports, where the first port is for electrical modulation type, the second is the CW laser input while the third is for the output of the optical signal.
The extinction ratio of the MZM was set to 30 dB. This characterizes the ratio of the two optical power levels created by the optical source.
Extinction-Ratio (ER) is given as:

$$ER = \frac{P_0}{P_1} \tag{1}$$

where P_0 is the optical power level generated when LD is on, and P_1 is the optical power level generated when LD is off. The bidirectional channel consists of a circulator to separate downstream from upstream traffic and a one-unit optical delay to ensure correct circulation timing. Optical circulator insertion losses characterize the loss of signal power resulting from the optical fiber insertion set to zero dB. Insertion Losses (IL) is given by:

$$IL = 10 \log \frac{P_t}{P_r} \mathrm{dB} \tag{2}$$

where P_t is the transmitted power to the load before insertion, and P_r is the power received by the load after insertion. Return losses characterize the ratio of the light reflected from a device under the test to the light launched into that device. It was set to 65 dB. Return Losses (RL) is therefore

(3)
$$RL = 10 \log \frac{P_i}{P_r} dB$$

where P_i is the incident power and, P_r is the re ected power.
The power measured after the circulator did not change. The ber cable has a reference wavelength of 1490 nm, dispersion value and dispersion slope value were set to standard values of 16.75 ps nm-1km-1 and 0.075 ps nm-2 km-1 respectively. Attenuation loss set to 0.2 dB/km. For example, when optical ber length was 10km and LD power was zero dBm, the output power measured by using the optical power meter after MZM was (P= -3.218dBm), the loss in power was due to the modulation.
After the bidirectional ber, the loss in power was (0.2 dB/km Ö 10 km = 2dB) and the power measured by the optical meter was (-3.218-2 = -5.218 dBm). The power before splitter was (-5.218 dBm = 300.720*10-6 W) and after splitter, by calculations, became (300.720*10-6 /32 = 9.3975*106 = -20.269 dBm) which was the same value as measured by the optical power meter.
The signal went through a 1x32-bidirectional splitter with zero dB value for insertion losses and 65 dB for return losses. The receiver consists of an APD with responsivity set to 10 A/W. Responsivity (Rd) measures the electrical output per optical input and can be expressed in terms of a fundamental quantity called the quantum e ciency (n) [21].

(4)
$$Rd = \frac{n_q}{h_v}$$

Dark current was set to 10 nA (the leakage of current that ows when a bias voltage is applied). The signal ltered by low pass Bessel lter that had a cut-o frequency of 0.75Öbitrate and there was a loss in power due to ltering.
After receiving and ltering the signal, the 3R regenerator was connected. 3R regenerator has three output ports, the rst output port is the bit sequence, the second one is a reference signal and the last one is the output signal. These three signals were connected directly to the BER Analyzer to analyze the performance.
The rst scenario (Variable Power with Fixed Wavelength and Fiber Length) tested the performance by taking di erent values of LD power of OLT from 0.5 to 2.5 dBm with 100 km length and 1490 nm wavelength to show how the performance of the system was a ected by increasing the power. In the second scenario (Variable Fiber Length with Fixed Power and wavelength), the LD power of OLT was set to zero dBm with random values of ber length from 10 to 100km to show at which length the system has a good performance.

In the scenario (Variable Wavelength with Fixed power and Fiber Length) was considered different values of the operating wavelength used for downstream direction (1470-1530) nm at 100 km of the fiber length for all wavelengths and fixed power of CW laser of OLT (zero dBm) to test the performance.
In the upstream direction, the optical signal was directed from 32 ONUs to OLT. The signal traveled from the transmitter at the ONU to the receiver in the OLT and passed through a 1x32bidirectional splitter that combined signals and then passed the signals through bidirectional fiber to the OLT receiver.
The transmitter consists of PRBS that was set to 1.25Gbps, which is the upstream data rate. The data coded is via the NRZ pulse generator.
The optical modulation consists of LD and MZM. It works at a range of GPON upstream operating wavelength to prepare the electrical signal to transport through the bidirectional fiber. LD power in OLT was set to different values and the value of CW laser in ONUs was set to zero. The excitation ratio of the MZM was set to 30 dB.
In the case of upstream, it has more than one transmitter operating in harmony, considering the TDMA. Therefore, it used two-cascaded Dynamic Y-select. For each one of Dynamic Y-select, the time interval (switching time) defined to have the following values. For the first Dynamic Y-select:

$$\text{SwitchingTime} = \text{TimeSlot} \quad \frac{1}{\text{Bitrate}} \quad \frac{\text{Sequencelength}}{32} \tag{5}$$

For the second Dynamic Y-select:

$$\text{SwitchingTime} = \text{TimeSlot} \quad \frac{1}{\text{Bitrate}} \quad \frac{\text{Sequencelength}}{32} + \frac{\text{Timewindow}}{32} \tag{6}$$

The number 32 refers to 32 ONUs. The TimeSlot parameter for each ONU was defined at the beginning and assigned zero value to the first ONU, 1 to the second ONU, and so on until 31 value was assigned to 32nd ONU. There is no overlap in time between the signals transmitted by the multiple ONUs. The concept was clarified on ONU1 and ONU32 by implementing in equations (5) and (6) the following parameters: Time window = 51.2ns, Sequence length=128 Bits and Global Bit rate = 2.5 Gbps.
Firstly, for ONU1, TimeSlot =zero, Switching time for first Dynamic Y-select = zero ns and switching time for second Dynamic Y-select = 1.6 ns. First Dynamic Y-select will pass the input signal to the output from 0 ns to the end of the time window, while second Dynamic Y-select will allow passing the signal from the switching time of the first Dynamic Y-select to the switching time of the second Dynamic Y-select. This means that the signal will pass to the output from zero ns to 1.6 ns and the rest will be zero. Lastly, for ONU32, TimeSlot =31, Switching time for the first Dynamic Y-select = 49.6 ns and switching time

for the second Dynamic Y-select = 51.2 ns. The rst Dynamic Y-select will pass the input signal to the output from 49.6 ns to the end of the time window, while the second Dynamic Y-select will allow passing the signal from switching time of rst Dynamic Y-select to the switching time of the second Dynamic Y-select. This means the signal will pass to the output from 49.6 ns to 51.2 ns and the rest will be zero. This proved that the signals transmitted by the various ONUs don't overlap in time. After the two Dynamic Y-selects, signals were combined by a 1x32-bidirectional splitter with zero dB insertion losses value and 65 dB for return losses. Thereafter, the signals passed through the bidirectional channel that consists of optical ber, circulator, and an optical delay. The upstream receiver consists of an APD with a responsivity of 10 A/W and the dark current was set to 10 nA, the signal was ltered by low pass Bessel lter with a cut-o frequency of 0.75Öbitrate. Thereafter, the signal passed through a bu er that was used for the selection of the iteration. 3R regenerator that was connected directly to the BER Analyzer was used to analyze the performance. In the upstream direction scenarios, the rst scenario (Variable Power with Fixed Wavelength and Fiber Length) was designed to test the performance by taking di erent high values LD power of OLT (0 to 30) dBm and 1310nm at 100 km.
In the second scenario (Variable Fiber Length with Fixed Power and Wavelength), LD powers in OLT were set to 15 dBm and ONUs were set to zero dBm with a wavelength of 1310 nm and di erent ber lengths.
In the third scenario (Variable Wavelength with Fixed Power and Fiber Length) was taken into consideration three distinct wavelength values from the working range used for the upstream direction (1260, 1310 and 1360 nm) at 100 km of the ber to check the performance impact of variable wavelength. The following (7) are the performance evaluation parameters BER:

$$BER = \frac{E}{N} \tag{7}$$

where E is the Errors and N is the Total Number of Bits transmitted. BER also was de ned in terms of probability of error (POE) as (8):

$$BER = \frac{1}{2}(1 \quad erf\,)\sqrt{\frac{E_b}{N_0}} \tag{8}$$

where erf is the error function, E_b is the energy in one bit and N_0 is the noise power spectral density noise power in a: 1. Hz bandwidth [22]; 2. Q Factor.
Q factor de ned according to the following formula [21]:

$$Q = \frac{I_1 \quad I_0}{{}_1 \quad {}_0} \tag{9}$$

where I_1 is a logic level \1\, I_0 is a logic level \0", $_1$ is a standard deviation of a logic level \1", $_0$ is a standard deviation of a logic level \0".

3. Results and Discussion

3.1. Downstream link: Fiber Length and Variable Power with Fixed Wavelength

Table 3. Min BER and Max Q Factor at 1490 nm, 100 km for Varied Power Values

Power	Min BER	Max Q Factor
0	4.84464Ö10 ^{15}	7.74314
0.5	3.70731Ö10 ^{18}	8.60816
1.0	6.39055Ö10 ^{22}	9.55135
1.5	1.94371Ö10 ^{26}	10.575
2.0	6.13717Ö10 ^{32}	11.7027
2.5	7.4889Ö10 ^{39}	12.984

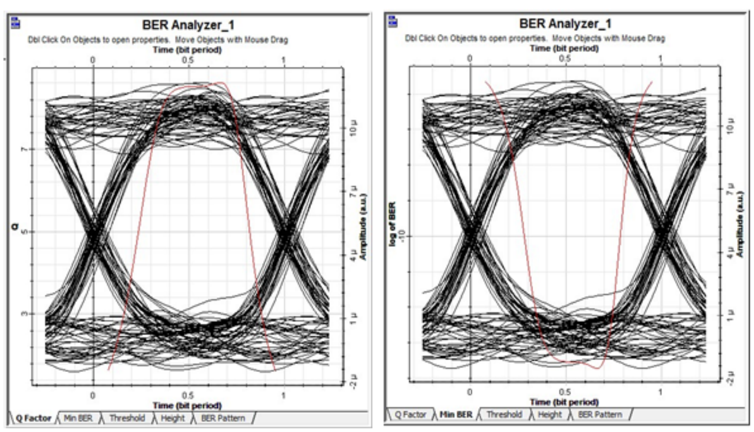

Figure 3 Figure 4

Figure 3: Max Q Factor at 0.5 dBm, 100 km and 1490 nm
Figure 4: Min BER at 0.5 dBm, 100km and 1490nm.

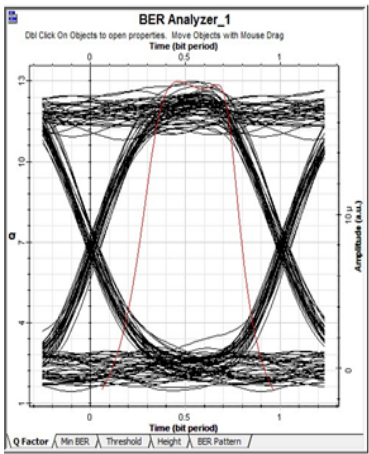

Figure 5

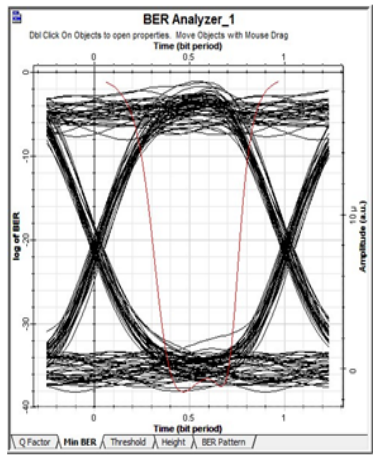

Figure 6

Figure 5: showing Max Q Factor at 2.5 dBm, 100 km and 1490 nm
Figure 6: Min BER at 2.5 dBm, 100 km and 1490 nm.

Figure 3 through 6 show the power relationship between BER and Q factors. When power was increased, both BER and Q factor had better values; High SNR resulted in less BER and more Q factor. The gures represented system performance by eye diagrams. An increase in BER values resulted in less distortion, less ISI, better synchronization, higher SNR and better eye height.

Variable Fiber Length with Fixed Power and wavelength.

Table 4. Min BER and Max Q Factor at 0 dBm, 1490 nm for Varied Length Values.

Wavelength	Min BER	Max Q Factor
10	0	247.994
20	0	173.654
30	0	121.042
40	0	83.9781
60	1.99405Ö10-320	38.2505
80	7.90159Ö10-73	18.0111
100	4.84464Ö10-15	7.74314

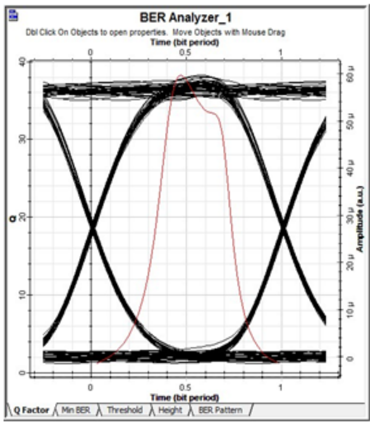

Figure 7

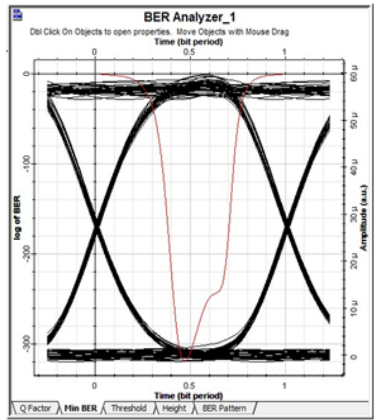

Figure 8

Figure 7: Max Q factor at 0 dBm, 61 km and 1490 nm
Figure 8: Min BER at 0 dBm, 61 km and 1490 nm.

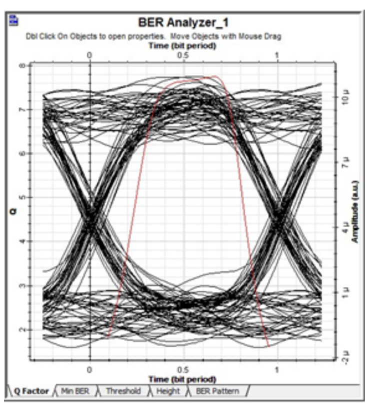

Figure 9

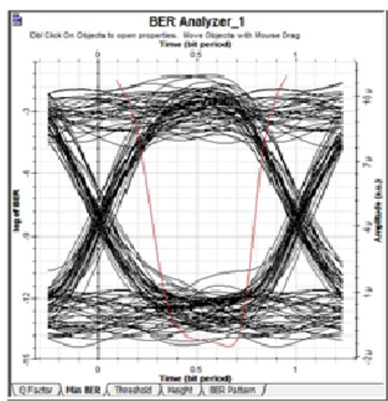

Figure 10

Figure 9: Max Q Factor at 0 dBm, 100 km and 1490 nm
Figure 10: Min BER at 0 dBm, 100 km and 1490 nm.

Table 4 shows the BER and Q factor for random distance values. At the initial stage, BER values were not a ected by distance. However, and as the distance increased, they increased, the Q factor values were a ected by the power values, they decreased when the distance was increased majorly due to losses. Fig. 7

through 10 represent system performance by eye diagrams. The performance is better at 61 km than at 100 km.

Fiber Length and Variable Wavelength with Fixed Power

Table 5. Min BER and Max Q Factor at 0 dBm, 100 km for Varied Wavelength Values.

Wavelength	Min BER	Max Q Factor
1470	1.29511Ö10-15	7.90909
1480	3.25133Ö10-15	7.79333
1490	4.84464Ö10-15	7.74314
1500	2.26262Ö10-16	8.12337
1510	4.1583Ö10-15	7.7634
1520	2.61278Ö10-16	8.10521
1530	1.613429Ö10-17	8.43755

It was observed from the results obtained (Table 5) that the BER and Q factor variation are not linear according to wavelength (frequency) variation.

3.2. Upstream Link: Variable Power with Fixed wavelength and Fiber Length

Table 6. Min BER and Max Q Factor at 1310 nm, 100 km for Varied Power (a).

Power	Min BER	Max Q Factor
0	1	0
5	1	0
10	1	0
15	0.00428369	2.62522
20	5.8669Ö10-16	8.0055
25	2.03588Ö10-121	23.4007
30	0	63.0859

Figure 11: Max Q factor at 15 dBm
Figure 12: Min BER at 15 dBm.

Figure 13: Max Q factor at 30 dBm
Figure 14: Min BER at 30 dBm.

It was observed from the results (Table 6) that the upstream majorly requires high power to function/operate. When the power was high, BER values decreased in value and there Q factor increased. The upstream was controlled by continuous