Passive Optical Network: A Fibre to the 'X' Approach.

Okeke R.O[#1], Idigo V.E[*2], Akemi M. O[^3], Ogbuokebe S. K[-4]

[#] *Electrical/Electronic Engineering Department, University of Port Harcourt Choba, River State, Nigeria*

[*] *Electronic and Computer Engineering Department, Nnamdi Azikiwe University Awka, Anambra state, Nigeria*

[^] *Electrical/Electronic Engineering Department, University of Port Harcourt,* **Choba, River State, Nigeria.**

[-] *National Space Research and Development Agency (NASRDA),Abuja.*

[1] remigius.okeke@uniport.edu.ng
[2] vicugoo@yahoo.com
[3] oyinzmoses@gmail.com
[4] ogbuokebekc@gmail.com

Abstract*— With the rapidly increasing bandwidth demand mainly driven by the development of advanced broadband multimedia application, such as video-on-demand (VoD), interactive high-definition digital television (HDTV) and video conference, new access network solutions that provide high capacity are highly needed to satisfy these emerging services. In a largely populated and technologically exposed institution such the University of Port Harcourt, this demand is truly great. The Passive Optical Network (PON), which utilizes the Fibre Optic Technology, is a suitable solution to this problem. Hence this is geared towards the design and simulation of a Passive Optical Network for the University's campus district. This Campus based Local Area Network consists of the Various Faculty buildings, the Senate building which is the central administrative building, and was centralized at the Information and Communication Technology Center (ICTC), which served as the Central Office of the network. The Wavelength Division Multiplexing (WDM) technique was utilized because of its dedicated bandwidth for each subscriber and more flexible bandwidth management. The validation was carried out on a virtual computation environment called OptiSystem©.

Keywords — ***Q-Factor, PON, SMF, BER, Fibre Optics, WDM, HDTV, VoD, DSL.***

1. Introduction

In the world today, it is clearly seen that there is an ever increasing growth in Internet traffic and data demand, and this trend is expected to continue. Many experts are saying that driving force behind this trend can be attributed to the continuous improvement and development in personal computers, Internet and telecommunication technologies (Jiajia Chen, 2009). Many of our activities these days are mostly online and involve a frequent use of many bandwidth demanding applications.

According to one such expert (Min Zhu, 2013), new or improved access network solutions that provide high capacity will be needed to satisfy the emerging network services and multimedia, due to the rapidly increasing bandwidth demand. This need is mainly driven by the development of advanced multimedia application, such as video-on-demand (VoD), interactive high-definition digital television (HDTV) and video conference.

Given the cost-sensitivity of access networks, the copper wire based access network technologies, such as digital subscriber line (DSL) and Wireless Broadband Technology, are currently the main access network solutions. However, they are not considered as future-proof solutions, because these copper wire based infrastructures have been approaching their own fundamental speed limitation, and wireless communication are reaching their bandwidth capacity limit.

Therefore, networks with high capacity are needed in order to satisfy the tremendous growth in bandwidth demands, both in terms of the increased number of users and continual emergence of new online applications. It is a popular opinion, that Optical fibre communication is the key technology to realize these high capacity network infrastructures.

In this paper, we look at designing a Passive Optical Network that would serve as the framework of the Local Area Network of the Abuja Campus of the University of Port Harcourt. The University of Port Harcourt is an academic community with a teeming population with a proportional demand for online services, and bandwidth-intensive applications, such as interactive video and multimedia services. This makes the Passive Optical Network the best architecture for building an access network for the community.

Furthermore, it is viewed that wavelength division multiplexing passive optical network (WDM-PON) is a promising candidate to realize the type of optical access networks needed for the school network, due to its dedicated bandwidth for each subscriber and more flexible bandwidth management. This work is therefore geared towards this proposition.

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2.0 METHODOLOGY

The University of Port Harcourt, Abuja campus serves as the case study of this work. The work flow of this project methodology is given in figure 1.

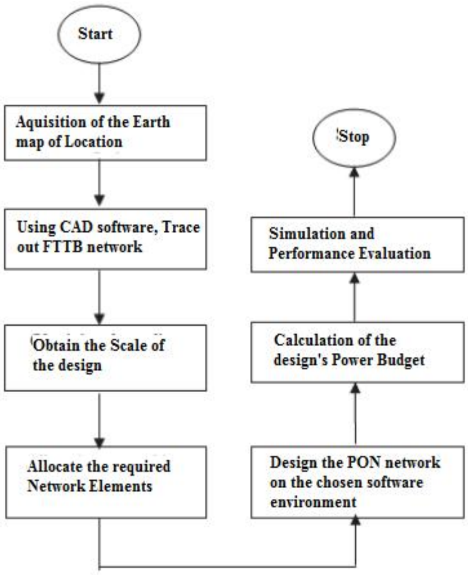

Fig 1: Methodology Flowchart algorithm

In order to accomplish this project, the following processes were carried out in accordance to the project flowchart shown in Figure 1:

First, a Physical Layout analysis was carried out. The 2-Dimensional Earth Imagery of the study location was acquired. Then using Computer Aided Design (CAD) software, the required FTTx solution was designed over the map layout. In this project, 'X' becomes building, hence, FTTB (Fibre to the building). This is done first in order to get the required information necessary for proper allocation of each of the optical communication components in use (for instance, the number of splits in the splitter required), the length of optical fibre required, expected fibre losses and so on.

The next step is the design of the network on the virtual computation environment (Optisystem) and finally the Power budget calculations for the designed network. Then, the results are analyzed to verify the designed systems performance and feasibility.

A. The Physical Layout Design

The location that has been chosen for this project is the Abuja campus, University of Port Harcourt. The central office (that is the network service provider point) is assumed situated at the Information & Communication Technology Centre (ICTC). Since this is a prototype research, specific buildings have been chosen as the Optical Node units for this prototype network. These buildings are: Senate building, Donald Ekong Library Building, Ophrima Building, Faculty of Engineering Complex, Petroleum & Gas Engineering Department buildings, School of Basic Studies Building and Department of Philosophy. The Earth Map with an identification of these buildings can be seen in figure 2.

Having identified the chosen locations, the next step was to determine the distance of these locations from the core network. This is done so that the position of the optical splitters can be planned in the most effective way such that the distance of each End-User node to the splitter is optimized. The distance measurements was done using a GPS application known as Earth Map, and the distance is not done using the great circle method (which is the shortest distance between two points on the earth surface), but by measuring the streets and roads that connect the locations. Round up approximations should be made to create distance allowances for the fibre length. Table 1 shows the distance of the Optical Node Unit (ONU) locations from the central office.

Table 1: Distance measurements for ONUs from Central Office

S/No	ONU Locations	Measured Distance of ONUs from the Central Office (meters)	Approximation of the measured Distance (meters)
1	Senate Building	878	900
2	Donald Ekong Library Building	672	700
3	Ophrima Building	748	800
4	Gas Engineering Building	893	900
5	Faculty of Engineering Complex	978	1000
6	Petroleum & Gas Engineering Department building (PTDF)	752	800
7	School of Basic Studies Building	600	600

8	Department of Philosophy	288	300
TOTAL SPAN LENGTH			6000

Now that the positions of the ONUs have been identified and their individual distances have been noted, an optimal position for optical splitting can be obtained. The essence of this is to reduce the amount of optical fibre cables that would be needed.

Fig 3 gives the detailed FTTB network design and network element (NE) showing the actual network

Fig 2: Earth Map of Abuja Campus showing the chosen locations

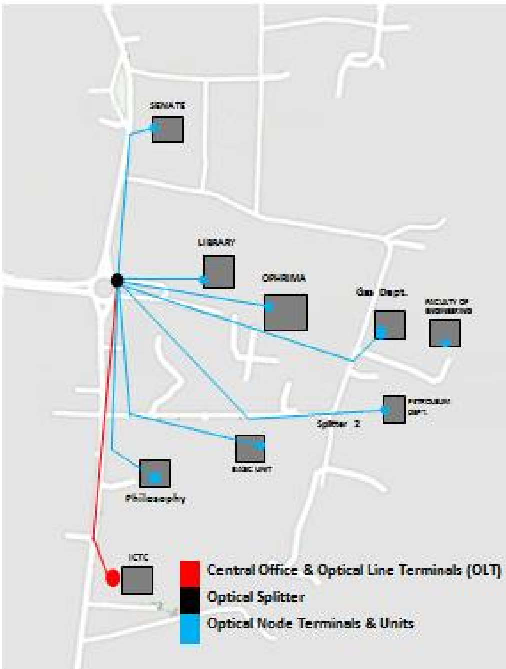

Fig 3: FTTB layout for the specified network location.

of fibre between the network elements and the ports that terminates each fibre cable at the splitter locations, the points the ONU terminate and the Optical line terminal (OLT). The distance between each ONU to its corresponding Splitter is obtained and the span length from the closure to the data centre having the OLT is also obtained.

From figure 3, the main network elements could be drafted as thus. The red point is the Central Office of the Optical Network, the red line serves as

the Fibre Backbone link. The black point serves as the Closure point, that is the first-level splitting of the fibre optic network and the green point is the second-level splitting. The blue points are the multi-service terminals or second-level splitter locations.
Now that the splitter location and other network element positions have been chosen, the span length for each position with respect to the splitter locations must also be measured. This was done using the GPS software previously mentioned. Table 2 shows the fibre lengths for each location.

Table2: Distance measurements for ONUs from Central Office

S/No	ONU Locations	Measured Distance of ONUs from the Central Office (meters)
1	Senate Building	400
2	Donald Ekong Library Building	200
3	Ophrima Building	280
4	Gas Engineering Building	600
5	Faculty of Engineering Complex	600
6	Petroleum & Gas Engineering Department building (PTDF)	500
7	School of Basic Studies Building	500
8	Department of Philosophy	300
TOTAL		3,380

Other important measurement is the distance of splitter from the Central Office which is 510m. The total span length of fibre cable (both central office and ONU) is now 3890m. It can be seen that the positioning of splitters has dropped the cable requirement to nearly half its original measure.
Now that Network element positions and cable span length have been acquired, the next phase of the work, which is the software based design of the Network can be started.

B. Power Budget Analysis

This analysis is concerned with the network layout and network design showing the fibre optic cable route and the associated losses due to the splitting of optical signals by the splitter, the connector losses and the splice losses (for splicing activities, which entail the joining of more fibre optic cables especially at closure points in the network).

Following the Layout design, the following measurements for cable length are obtained:

(i) OLT to Splitter - 510m
(ii) Optical Fibre Cable (for the distance between split point and the individual ONUs) For both uplink and down-link configuration-
(iii) ONU1 (Senate Building)- 400m
(iv) ONU2 (Library)- 200m
(v) ONU3 (Ophrima)- 280m
(vi) ONU4 (Gas Engineering)-600m
(vii) ONU5 (Faculty of Engineering)-600m
(viii) ONU6 (Petroleum Engineering Building)-500m
(ix) ONU7 (Basic Unit)- 500m
(x) ONU8 (Philosophy Department)-300m

Total of 3380m of fibre cable length, for both upstream and downstream directions.

From the relation in equation 1
PT-PR = (TFL +TCL +TSL + TSiL + PM)…… (1)
Where
PT = OLT transmit Power
PR = Receiver Sensitivity of ONU
TFL = Total fibre loss
TCL = Total Connector loss
TSL = Total Splitter loss
TSiL = Total Splice loss
PM = Margin

The fibre optic losses are calculated as follows :
TFL = cable distance ×loss (dB per km);
Note, the following assumptions were made:
(i) The type of fibre used is a single mode fibre cable; therefore attenuation coefficient is 0.3dB/Km
(ii) Ideal insertion loss for connector = 0.5dB
(iii) Ideal Splice loss = 0.1 (1 splicing assumed)
(iv) Insertion loss for splitter used = 4.1dB
(v) Class B optics with max loss of 25dB adopted
(vi) OLT Transmit power PT of -3dBm assumed

TFL = ((3.380 + 0.510) × 0.3 = 1.167 dB
There are connectors in the following areas:
1 connector at the OLT
2 connectors at the Splitter
8 connectors for ONUs
Hence, a total of 11 connectors
TCL = Number of Connectors × Connector Loss
TCL = 11 x 0.5 = 5.5dB
TSL = 1 x 4.1 = 4.1dB
TSiL = 1x 0.1 = 0.1 dB

Total FTTx Network Loss = (TFNL) = 25dB
TFNL = TFL + TCL + TSiL + TSL + PM …. (2)
TFNL = 1.167 +5.5 + 4.1 + 0.1 + PM
TFNL = (10.867 + PM) dB
PM = 25 – 10.867 = 14.133dB
Transmitting power (PT) is set to -3dBm, and for a good safety margin, the power margin is set at

14.133dB. Power Margin is simply the allowable amount of power that must be available after subtracting attenuation and link losses. To calculate the receiver sensitivity (PR), the mathematical relationship of equation 1 was used:
PT-PR = (TFL +TCL +TSL + TSiL + PM)

The corresponding values are inputted into the relationship:
-3 – PR = 1.167 + 5.5 + 4.1 +0.1 + 14.133

PR = -28dBm

This means that the receiver should provide sensitivity better than -28dB.

I. OPTICAL SIMULATION

The simulation was carried out in OptiSystem environment. The Network is divided into a Down-stream and Up-stream system transmissions.

For the Down-Stream Network, the central office consists of transmitter units corresponding to the number of receivers at the Optical Node Units (ONU), this number is therefore 8 since this project consist of only 8 node points.

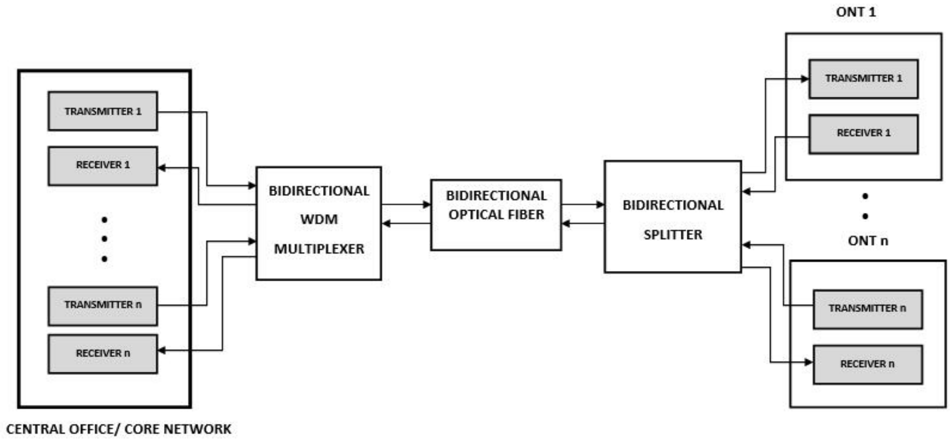

Fig 4: General block diagram for bidirectional PON

Each of these receivers is passed through a Wavelength Division Multiplexing (WDM) Multiplexer. The multiplexer in turn is connected to a single mode bidirectional optical fibre cable. A WDM enabled Demultiplexer served in place of a splitter for this project, due to the fact that the distances between Central Office and any of the ONUs are below 1km. The receiver units are then connected to the Demultiplexer to complete the Down-stream network.

The Up-stream network is similar to that of the Down-stream network in terms of the network elements and even the cable distances. The difference is the direction of transmission which is now from the ONUs to the Central Office. Transmitter Units from the ONUs are connected to receiver units at the Central Office using the same configuration as the Down-stream. The General block diagram is shown in Fig 4.

A. Transmitter Section

The transmitter consists of four sections. The first section is data source, which produces a Pseudo Random Binary Sequence (PRBS) that represents the information to be transmitted. The second section is Non-Return-to-Zero (NRZ) pulse generator. It converts the binary data into electrical pulses. The third section of an optical transmitter is a light source that might be a Light Emitting Diode (LED), a Vertical Cavity Surface Emitting Laser (VCSEL), or a Light Amplification by Stimulated Emission of Radiation (LASER) diode. Block diagram of transmitter is shown in Figure 5. These sources use wavelengths in the infrared band, specifically 850nm, 1300nm and 1550nm. The last section is the Mach-Zehnder Modulator (MZM). It is an external modulator used to vary the intensity of the light source from the laser according to the output of the NRZ pulse generator. The figure 5 gives the block diagram of the transmitter unit.

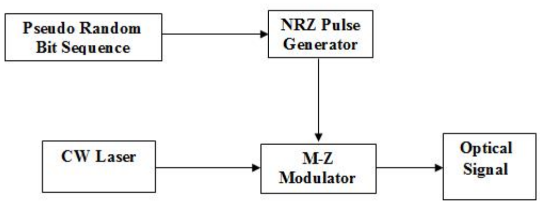

Fig 5: Network Block diagram of Transmitter section

B. Receiver Section

The first receiver element is a Positive Intrinsic Negative diode (PIN) or Avalanche Photo-detector Diode (APD), which produces an electrical current proportional to the received power level. Since the electrical current is typically very weak, a font end amplifier is added to boast it to a level that can be used by the next element. After being amplified the signal passes through a Low Pass Filter (LPF) to reduce the noise that it outside the signal bandwidth. At the end, an integrated signal processing circuit is added to analyse the delivered data.

At the receiver, Avalanche Photodiode (APD) used to convert the optical signal to electrical signal, then the signal is filtered by low pass Bessel filter to regenerate the desired signal. Bit Error Rate (BER) analyser used for data analysis. Block diagram of receiver is seen in Figure 6

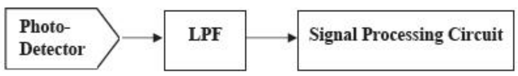

Figure 6: Network Block diagram of Receiver section

C. PON System communication analysis

In the downstream direction, the signal travelled from the Central Office (CO) to the OLT transmitter and passed through bidirectional SMF channel then split via 1x6 Demultiplexer and received to 8 ONU receivers.

In upstream direction, the optical signal directed from 8 ONUs to the OLT. The signal travelled from the transmitter at the ONU to the corresponding receiver in the OLT following a similar configuration like the downstream.

Both the CO and the ONU are built as a transceiver since bidirectional communication involves both upstream and downstream transmission.

The transmitter unit consists of PRBS that was set to 2.5Gbps, which is the downstream data rate of GPON then the data coded via NRZ. CW Laser power was set to 3 dBm to test the performance of

the network and the line width that characterizes the width of the frequency interval of the total emission area was set to 10 MHz.

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 efficiency (n). The signal filtered by low pass Bessel filter that have a cut-off frequency of 0.75×bitrate and there is a loss in power due to filtering. These three signals connected directly to the BER Analyser to analyse the performance.

Figures 7 and 8 give the transmitter and receiver units respectively.

The Bidirectional channel consists of the Bidirectional Optical Fibre and EDFAs (Erbium Doped Fibre Amplifier). Insertion losses of the WDM multiplexer characterize the loss of signal power resulting from the insertion of the optical fibre was set to zero dB.

Return losses characterize the ratio of the light reflected back from a device under test to the light launched in to that device was set to 65 dB.

Figure 9 gives the block diagram of simulation design for the channel, and Figure 10 gives the complete network.

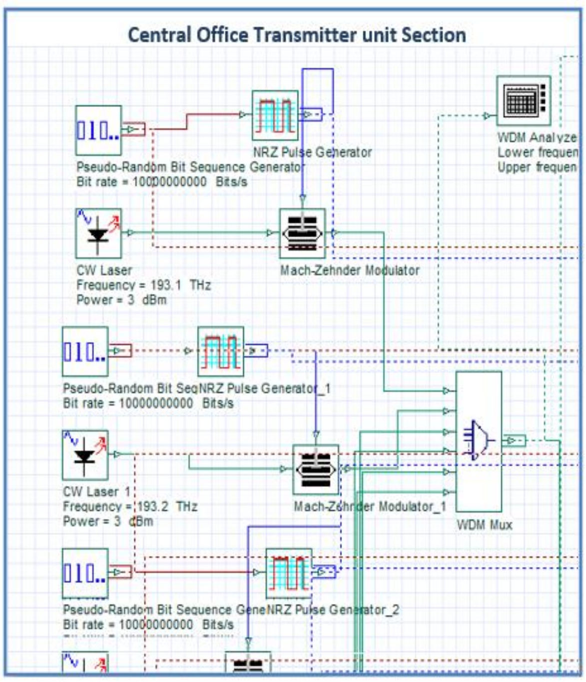

Figure 7: Transmitter Design

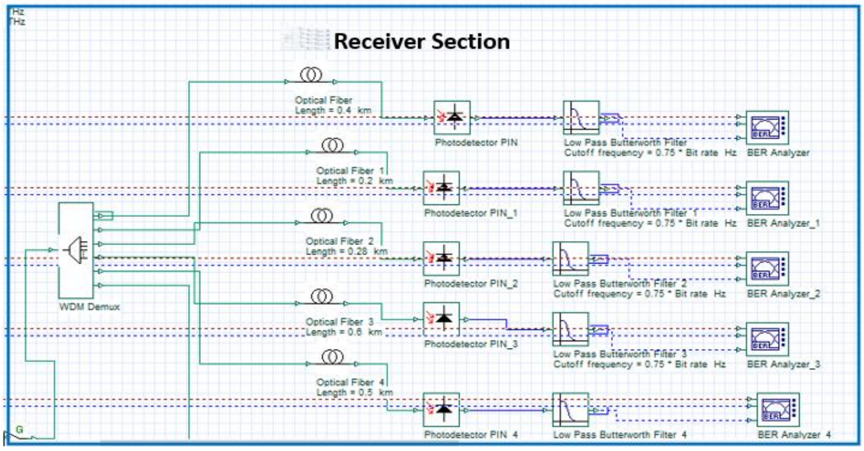

Figure 8: Receiver Design

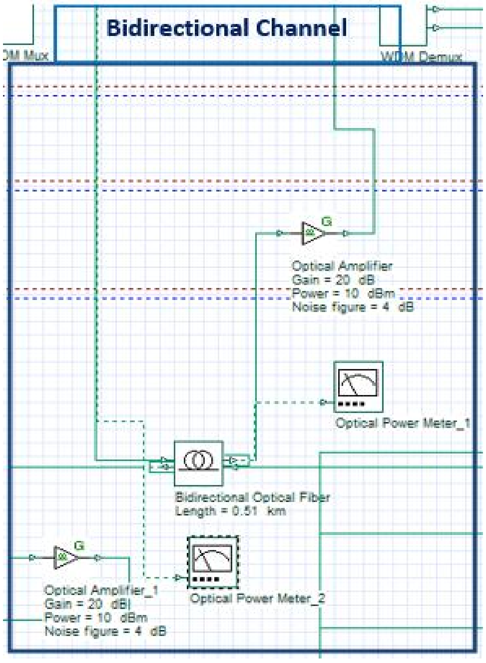

Figure 9: Bidirectional channel of the PON

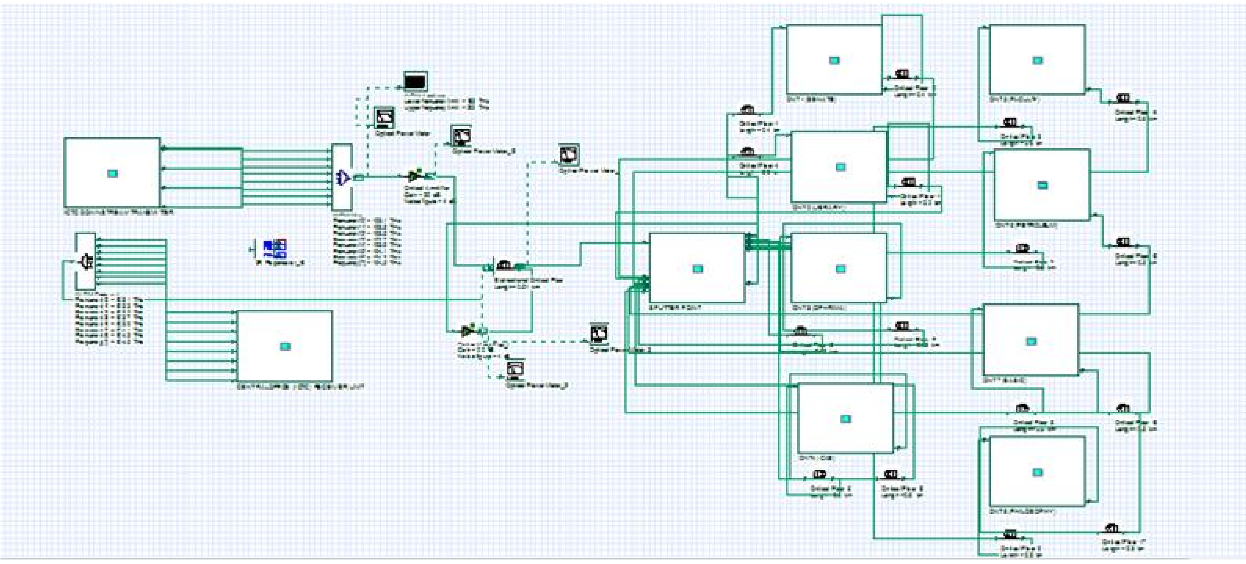
Figure 10: Complete Network

II. RESULTS

The system was analysed to verify performance using the Eye Diagram and the values obtained from the BER (Bit Error Rate) anaylisers attached to every receiver unit. Tables 3 and 4 show the BER and Q Factor for downstream and upstream transmissions respectively.

The Eye Diagrams are obtained from the Bit-Error-Rate (BER) Analyser and can be calculated along with the BER patterns. Given below as Figures 11 to 18 are the eye diagrams for all 8 of the Downstream Channels (Receiver channels at the ONU locations).

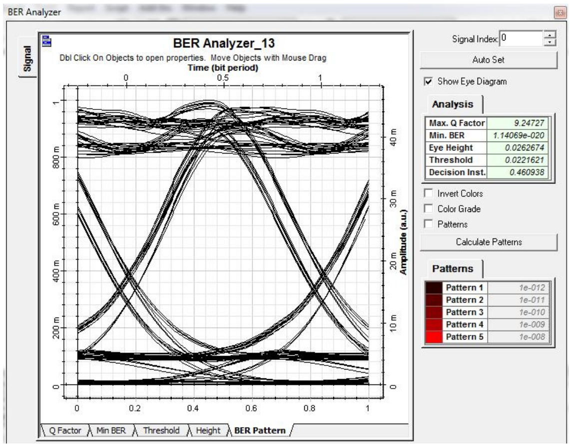

Figure 11: Channel 1Eye Diagram

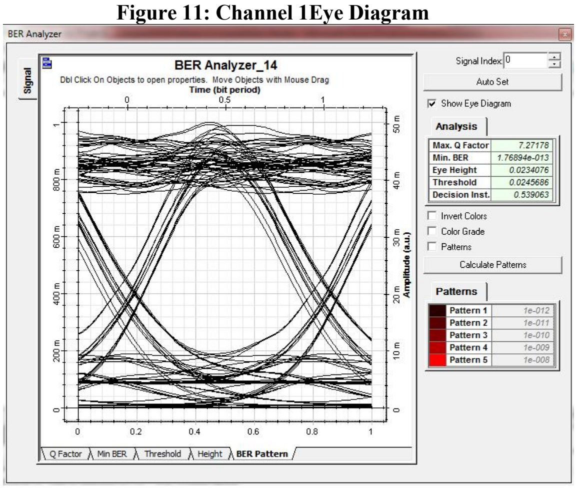

Figure 12: Channel 2 Eye Diagram

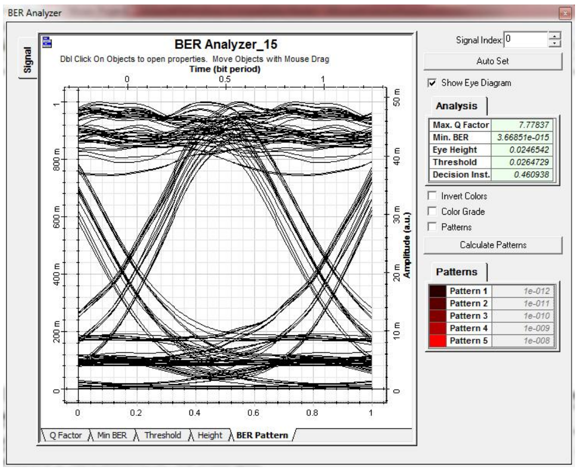

Figure 13: Channel 3 Eye Diagram

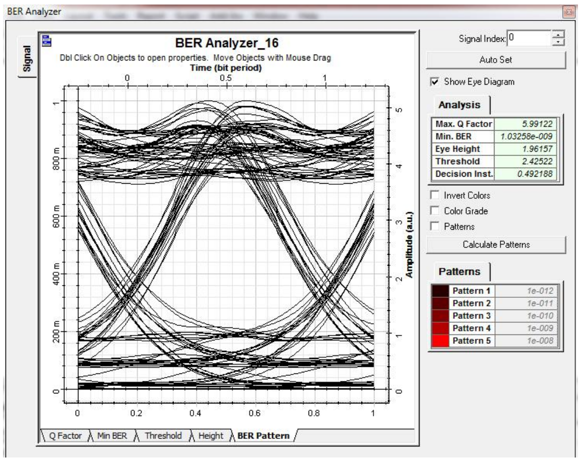

Figure 14: Channel 4 Eye Diagram

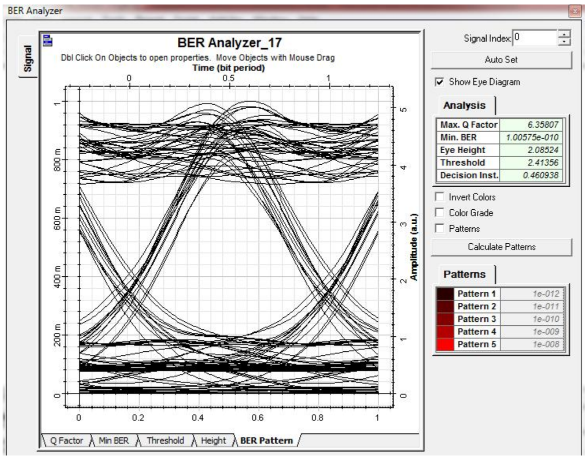

Figure 15: Channel 5 Eye Diagram

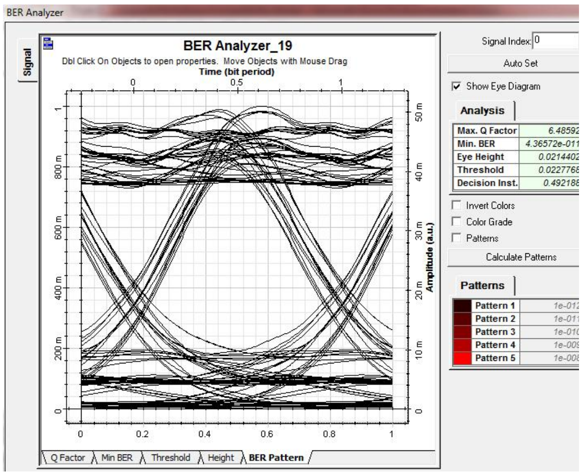

Figure 16: Channel 6 Eye Diagram

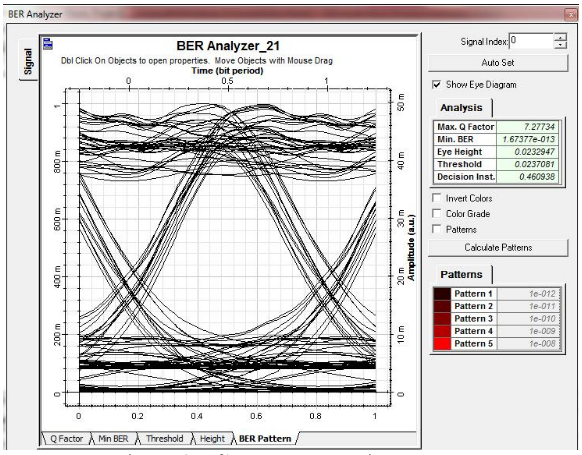

Figure 17: Channel 7 Eye Diagram

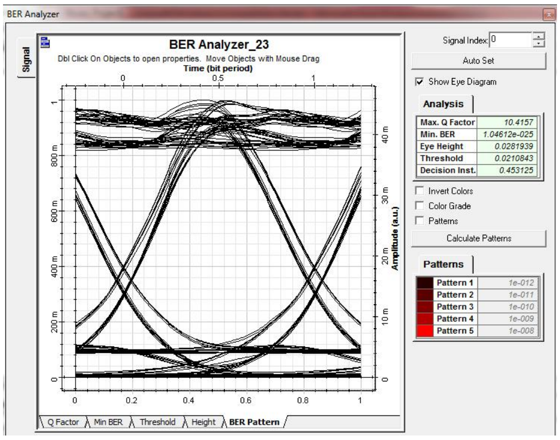

Figure 18: Channel 8 Eye Diagram

Given below from Figures 19 to 26 are the Eye Diagram results for the Upstream Channels (Receiver channels at the Central Office).

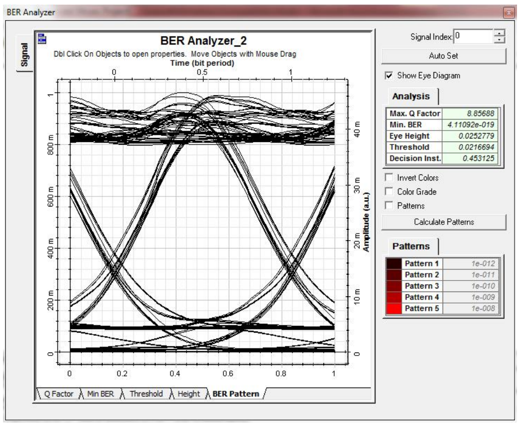

Figure 19: Channel 1 Eye Diagram

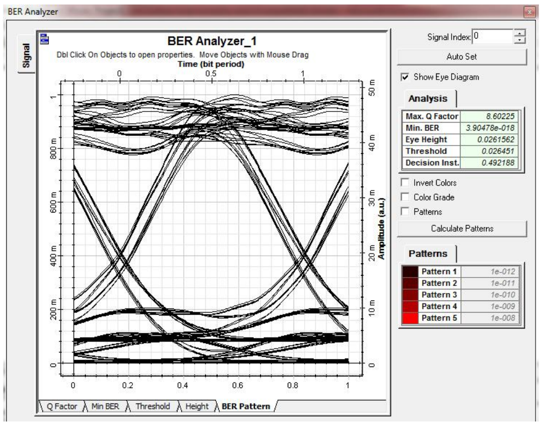

Figure 20: Channel 2 Eye Diagram

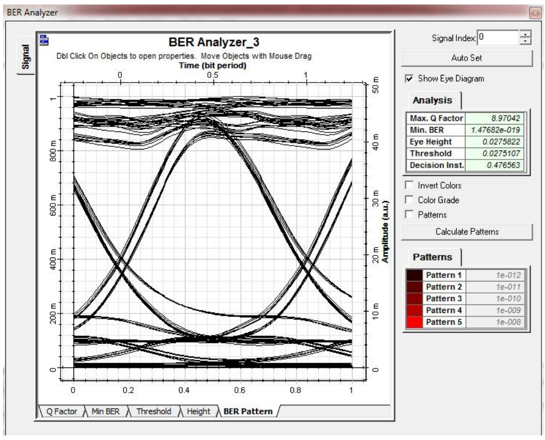

Figure 21: Channel 3 Eye Diagram

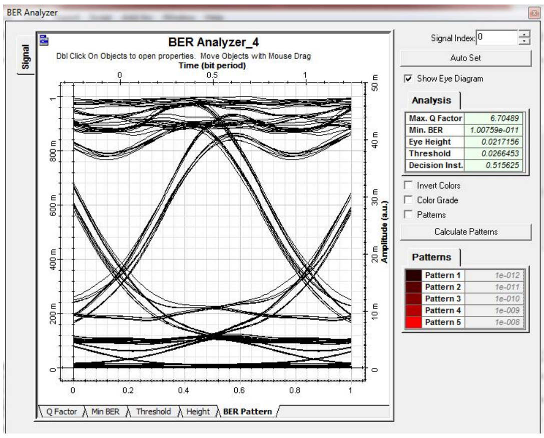

Figure 22: Channel 4 Eye Diagram

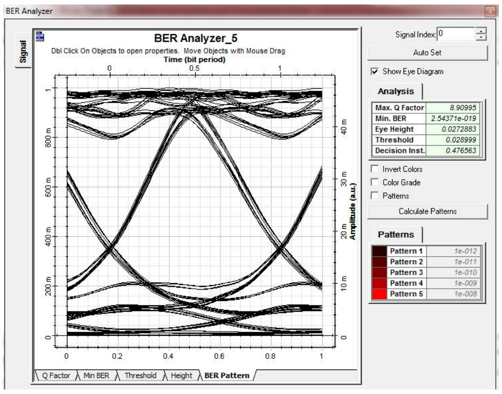

Figure 23: Channel 5 Eye Diagram

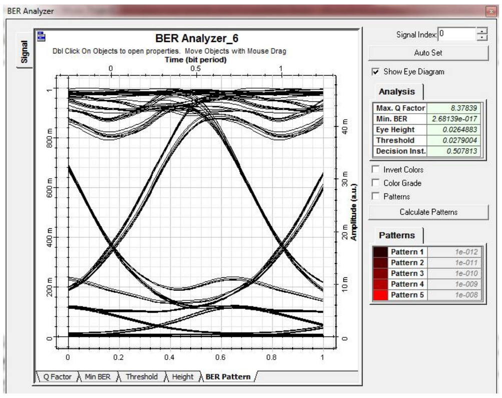

Figure 24: Channel 6 Eye Diagram

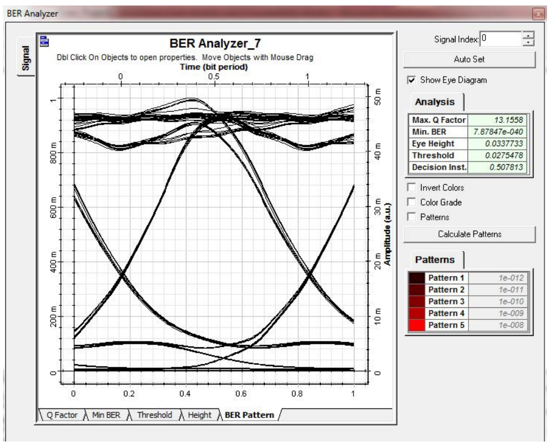

Figure 25: Channel 7 Eye Diagram

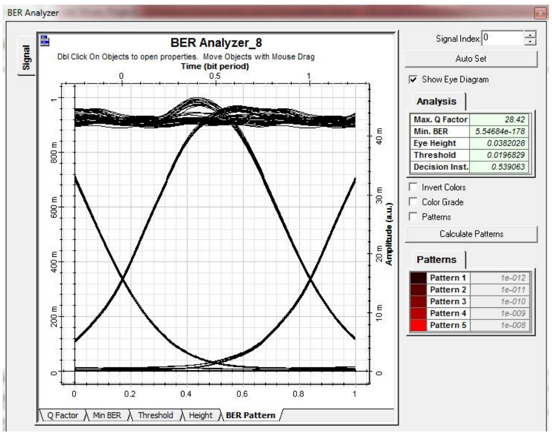

Figure 26: Channel 8 Eye Diagram

Error rates describe the number of bit errors in the number of received bits of the data in communication system due to noise, interference or distortion. In telecommunication transmission, the bit error rate (BER) is the percentage of bits that have errors relative to the total number of bits received in a transmission. For every transmission, the BER analyser will be analysing data, to ensure system integrity. The Q factor or quality factor represents the loss in energy of the signal. Maximum Q factor has less loss of energy. Q-factor is a convenient measure of overall system quality provided when two SNRs can be combined into a single quantity. In order to calculate the overall probability of bit error, it must account for both of the signal-to-noise ratios.

An Ideal BER value should be from the ranges of e-009 and above (That is n x 10-9 and above). From the results of the simulation, it can be seen that the design was successful in its operation and therefore is feasible and possible in the given location of study.

Table 3 and 4 give the Q-Factors and minimum BER values for all 8 channels for both downstream and upstream communication, along with other important values.

Table3: Downstream Results

DOWNSTREAM				
CHANNEL	**EYE HEIGHT**	**THRESHOLD**	**Max Q-FACTOR**	**Min. BER**
1	0.0262674	0.0221621	9.24727	1.14069e-020
2	0.0234076	0.0245686	7.27178	1.76894e-013
3	0.0246542	0.0264729	7.77837	3.66851e-015
4	1.96157	2.42522	5.99122	1.03258e-009
5	2.08524	2.41356	6.35807	1.00575e-010
6	0.0214402	0.0227768	6.48592	4.36572e-011
7	0.0232947	0.0237081	7.27734	1.67377e-013
8	0.0281939	0.0210843	10.4157	1.04612e-025

Table4: Upstream Results

UPSTREAM				
CHANNEL	**EYE HEIGHT**	**THRESHOLD**	**Max Q-FACTOR**	**Min. BER**
1	0.0252779	0.0216694	8.85688	4.11092e-019
2	0.0261562	0.026451	8.60225	3.90478e-018
3	0.0275822	0.0275107	8.97042	1.47682e-019
4	0.0217156	0.0266453	6.70489	1.00759e-011
5	0.0272883	0.028999	8.90995	2.54371e-019
6	0.0264883	0.0279004	8.37839	2.68139e-017
7	0.0337733	0.0275478	13.1558	7.87847e-040
8	0.0382028	0.0196829	28.42	5.54684e-178

III. CONCLUSIONS

This project was concerned with the design and simulation of a Passive Optical Network; Using University of Port Harcourt, Abuja campus as location.

The technology employed was the Wavelength Division Multiplexing (WDM) technique, which allocates bandwidth by wavelength. This technique gives better bandwidth capacity, which is required for a network that would service a university complex. This network was designed and simulated using OptiSystem software by taking different values of transmitted power, fibre cable length and operating wavelengths with multiple scenarios. Then results evaluated based on BER, Q factor and eye pattern obtained.

The network was bidirectional and results were derived for both upstream and downstream network.

The highest BER obtained was exponential -9, best BER obtained was E-175. Q factor obtained was as high as 13.115. The result so obtained showed that the network is feasible and the performance level is satisfactory.

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