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Performance Analysis of Unidirectional and Bidirectional Broadband Passive Optical Networks

Rini T. Jacob
PG Scholar,
Opto Electronics and Communication Systems,
Dept. of Electronics and Communication Engg,
TKM Institute of Technology,
Kollam, Kerala, India.

Vidya Raj
Asst.Professor,
Dept. of Electronics and Communication Engg.,
TKM Institute of Technology, Kollam, Kerala, India

***Abstract* — Access networks are developed for reducing the congestion occurred due to high bandwidth demand. Active Optical Network (AON), the first fiber based network, caused less reliability and high cost. Thus AON is replaced by Passive Optical Network (PON), which is a point to multipoint optical fiber access network. It uses passive components to enable the optical fiber to serve multiple users. There are different PON standards with variable data rates. The unidirectional and bidirectional Broadband Passive Optical Networks (BPON) for varying fiber length are simulated and their performances are analyzed based on the Quality factor (Q-factor) and the Bit Error Rate (BER) using OptiSystem 12.0 software. In the analysis, the performance of the unidirectional system is having high Q-factor and low BER compared to that of bidirectional BPON system.**

Keywords — *Access Networks, Bit Error Rate, Broadband Passive Optical Network, Passive Optical Network, Quality factor.*

I. INTRODUCTION

The advancement in the communication systems has increased the need for large bandwidth to send more data at higher speed. The subscribers demand high speed network for voice and media-rich services. This demands the networks of higher capacities at lower costs. When a data is transferred over the network, a reliable end packet delivery is one of basic requirement of both the user and the network, but there are many major causes that can result packet loss, such as congestion over the network. The access methods based on the optical fiber is the ultimate solution in delivering different services to the customer premises.

The access network connects the service provider Central Offices (COs) to the subscribers. An access network is the part of a communication network which connects the subscribers to their immediate service provider. Active Optical Network (AON), the first based access network has been characterized by a single fiber which carries all traffic to a Remote Node (RN) mainly electrically powered switching equipment that is placed close to the end users from the central office. The Active Optical Network (AON) has the distance and the bandwidth limitations. Later the active node is replaced with a passive component leading to the development of Passive Optical Network (PON).

A Passive Optical Network (PON) is a fiber-optic access network architecture that brings fiber cabling and signals to the home using a point-to-multipoint scheme that enables a single optical fiber to serve multiple premises by means of passive components. A PON consists of an Optical Line Terminal (OLT) at the service provider's central office and a number of Optical Network Units (ONUs) near end users. It is a shared network, in that the OLT sends a single stream of downstream traffic that is seen by all ONUs. Each ONU only reads the content of those packets that are addressed to it. There are different types of PON standards, which mainly differ from each other in terms of their data rates.

Broadband Passive Optical Networks (BPON)

Broadband PON (BPON), as defined in ITU-T G.983 series, is an improvement of the ATM Passive Optical Networks (APON) system. BPON offers numerous broadband services including ATM, Ethernet access and video distribution. The basic BPON architecture follows the standard PON layout with a maximum transmission distance of 20 km between the OLT and an ONT (or an ONU). The downstream 1490 nm voice and data traffic is transmitted using time-division multiplexing (TDM) of the ATM cells and the upstream 1310 nm voice and data traffic (in the form of ATM cells) is transmitted by means of a time-division multiple access (TDMA) protocol. BPON employs wavelength division multiplexing (WDM) for downstream transmission of voice, data and video. BPON has two key advantages, first it provides a third wavelength for video services, and second it is a stable standard that re-uses ATM infrastructures.

II. SYSTEM DESIGN

A. *Unidirectional BPON*

The unidirectional BPON is the PON with the downstream transmission. The block diagram for unidirectional BPON with 2 users is shown in the Fig.1. The OLT is the transmitter block, which consists of a User

Defined Bit Sequence Generator, NRZ Pulse Generator, a Continuous Wave Laser and Mach-Zehnder Modulator. The receiver block forms the ONU, which includes APD photodetector, low pass Bessel filter, 3R regenerator and BER analyzer.

The unidirectional BPON has been simulated using the wavelength 1490 nm for different fiber lengths. With the help of the User Defined Bit Sequence Generator the data signal is generated at a data rate of 622.08 Mbps corresponding to BPON.

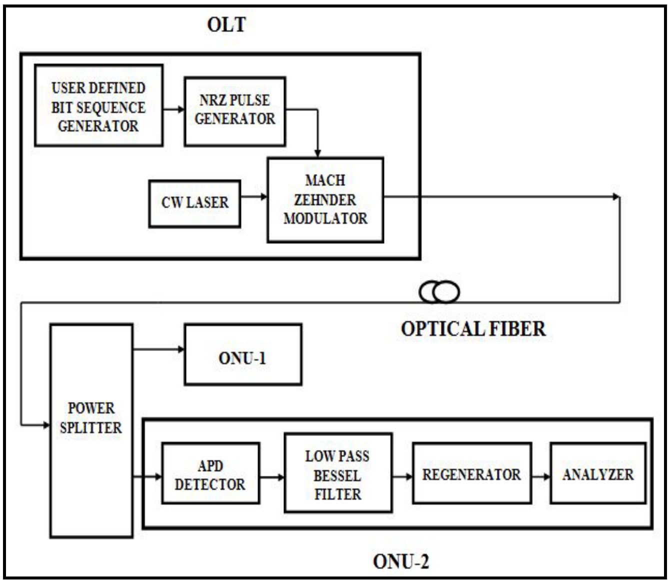


Fig. 1: Block Diagram of Unidirectional BPON with 2 Users

The generated signal is then encoded by using NRZ pulse generator. The wavelength is set as 1490 nm and the power as 0.2 dBm in the Continuous Wave (CW) laser source. Mach- Zehnder Modulator (MZM) is an optical modulator which is used to vary the intensity of the light from the CW laser according to the output of the NRZ pulse generator.

The Mach-Zehnder modulator consists of two couplers and two waveguides of equal-length. Those two waveguides form the two arms of the Mach-Zehnder modulator. The input optical signal from the laser will split in to two and passes through the arms of the MZM. The phase-shifting happens due to the electro-optic effect where the output electrical pulse from the NRZ pulse generator will vary the voltage hence varying the refractive indices of the waveguides. The output of the Mach-Zehnder modulator will be transmitted to the ONUs through the optical fiber channel. The simulation set up for unidirectional BPON is shown in the Fig. 2.

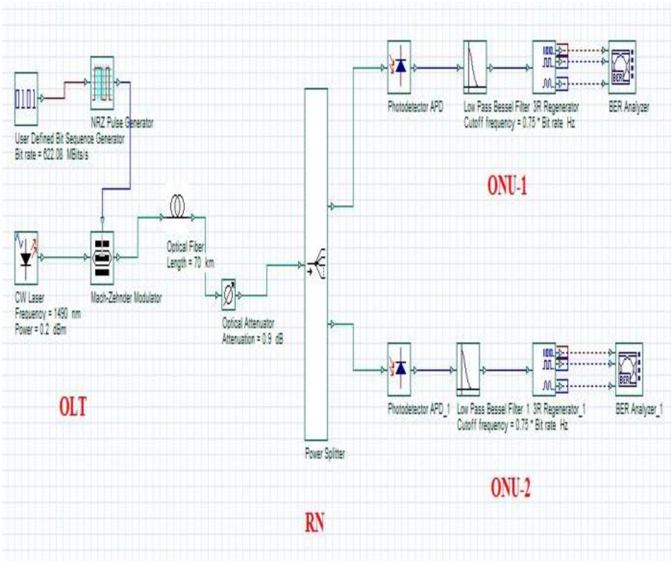


Fig. 2: Simulation Layout of Unidirectional BPON with 2 Users

The transmission channel used is the optical fiber channel with attenuation of 0.2 dB/km. An optical attenuator with a small attenuation is used to reduce the power level of the optical signal transmitting through the optical fiber. At the receiver end a power splitter is used to receive and to split the signals to the users. Each of the signals is detected by the photodetector. Photodetector is used primarily as an optical receiver to convert light into electricity. Here, the APD is used as the photo detector. The properties of APD are set as: the gain is set to 3, responsivity as 1 A/W and dark current is taken as 10 nA. The output of the APD is fed to the low pass Bessel filter centred at 0.75 x bit rate Hz frequency.

The low pass filters (LPFs) are used to filter higher frequency components. The filtered output is fed to a 3R regenerator and got the data which was initially transmitted and the output is analyzed using a BER analyzer that can be used to generate the eye diagram, which is used for the performance analysis of the system, for varying length of the optical fiber.

B. Bidirectional BPON

The bidirectional BPON is the PON with both the downstream and the upstream transmissions. The block diagram for bidirectional BPON with 2 users is shown in the Fig. 3 with the OLT having the downstream transmitter block with a User Defined Bit Sequence Generator, NRZ Pulse Generator, a Continuous Wave Laser and Mach-Zehnder Modulator and the upstream receiver block consists of APD photodetector, low pass Bessel filter, 3R regenerator and BER analyzer and the ONU with corresponding downstream receiver and upstream transmitter sections.

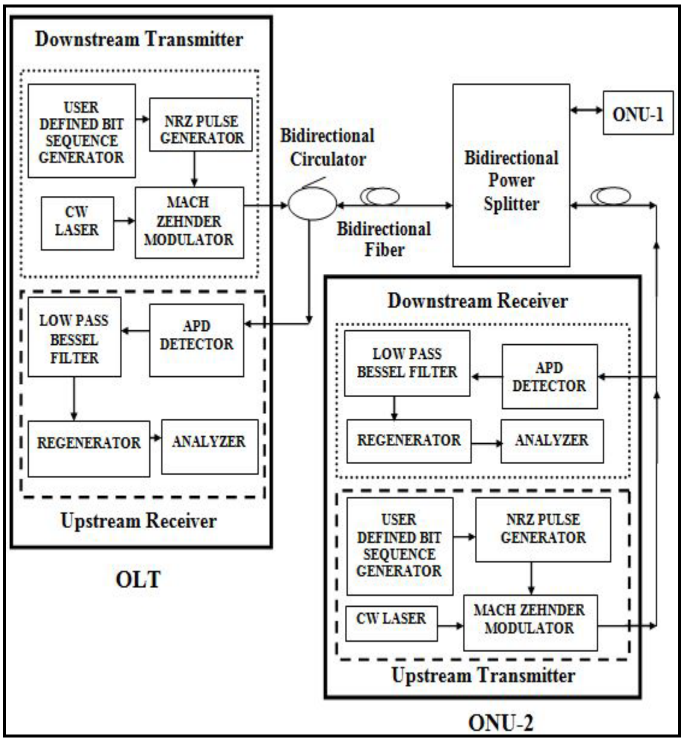


Fig. 3: Block Diagram of Bidirectional BPON with 2 Users

The simulation setup for analyzing downstream traffic and upstream traffic in the bidirectional BPON is indicated in the Fig. 4 with the wavelength 1490 nm and power 0.2dBm.

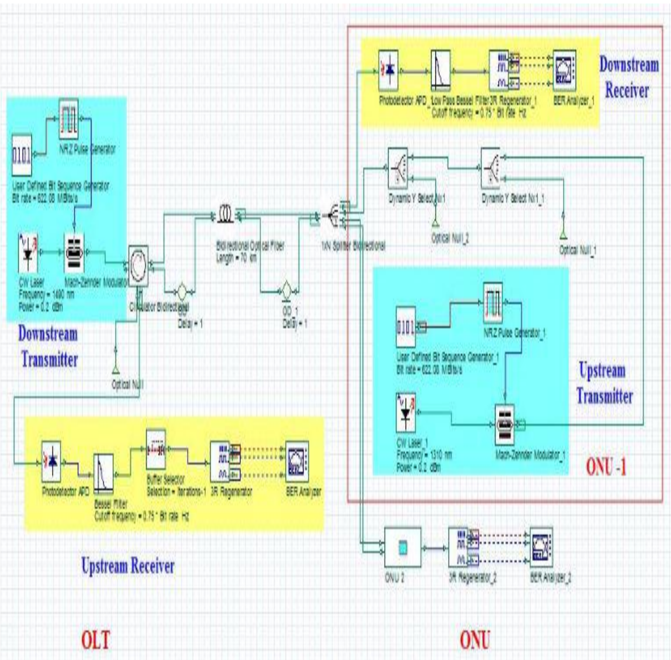


Fig. 4: Simulation Layout of Bidirectional BPON with 2 Users

The transmitter, single mode fiber, an optical splitter, the Optical Network Units (ONUs) and BER analyzer have been connected systematically. All the ONUs contain a separate transmitter to modulate user data onto laser beam and send to the optical splitter, which acts as signal combiner in the upstream case. The combined signal is then travelled on the optical fiber and at the OLT side a receiver detects the optical signal and produces a BER value corresponding to the signal quality received.

The transmitter section for both the downstream and upstream directions consist of a User Defined Bit Sequence generator with the help of which the transmitted signal is generated at a data rate of 622.08 Mbps corresponding to BPON. A CW laser source with downstream wavelength as 1490 nm and the upstream wavelength as 1310 nm with power 0.2 dBm is used for varying the intensity of the transmitted data from the NRZ pulse generator with the help of the Mach-Zehnder Modulator. The modulated signal is then passed through a bidirectional circulator along a bidirectional fiber.

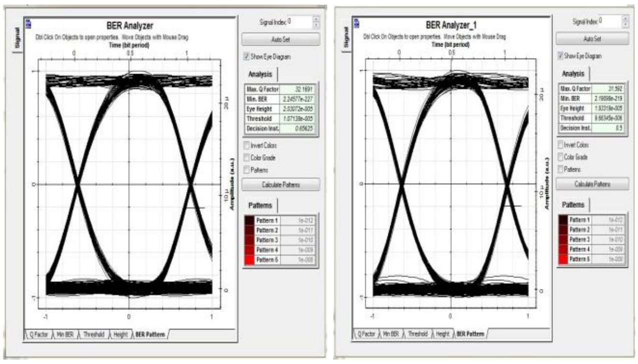
The transmission channel is the bidirectional optical fiber channel with attenuation of 0.2 dB/km and dispersion of 16.75ps/nm/km. A bidirectional circulator with wavelength dependent isolation, insertion and return losses is used to isolate optical signals of uplink and downlink. At the receiver end a 1 x N bidirectional power splitter is used for the bidirectional transmission of signals and later each of the signals is detected by the photo detector. Delay element which is used in transmission is used to generate optical signal delay. The delay is added by sending null signal to the output port. The dynamic Y select is used to transmit the upstream signals within the same optical fiber through which downstream signals are transmitted.

The photodetector, APD is used to convert optical signals into electrical signals, which pass through low-pass Bessel filters and 3R regenerators. By using 3R generator, it is possible to recover the original bit sequence and electrical signal. These three signals can be directly connected to BER analyzer, avoiding additional connections between the transmitter and receiver stage. The BER analyzer can be used to generate the eye diagram, which can be used for the performance analysis of the system. The eye diagram indicates the value of maximum Q factor, minimum BER, eye height and threshold of the received signal at the ONUs.

III. RESULTS AND DISCUSSIONS

A. Performance Analysis of Unidirectional BPON

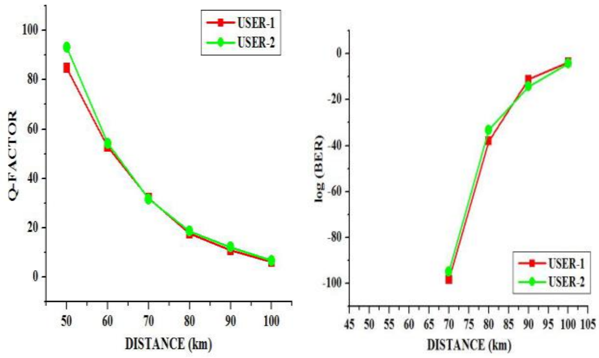
The performance of a BPON system with 2 users is analyzed using the parameters such as Q-factor and Bit Error Rate (BER). Fig. 5 shows the eye diagrams of the users in the unidirectional BPON system for a distance of 70 km.



(a) (b)

Fig. 5: Eye Diagrams for the (a) First User (b) Second User of the Bidirectional BPON at 70km in the Downstream Direction

It can be seen that the eye opening is better indicating that the received signal is less distorted. As the fiber length increases, the eye opening is becoming less and the output signal is highly distorted.



(a) (b)

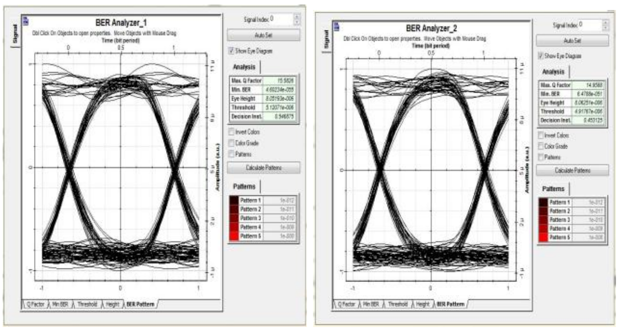
Fig. 6: Relationship of (a) Q-factor and (b) log (BER) with Distance for Unidirectional BPON with 2 users

The quality and the bit error rate of the output signal that is received by the users is varying with the distance. Fig. 6 (a) and (b) indicates the relationship between Quality factor (Q-factor) and log (BER) with distance for unidirectional BPON with 2 users. The Q-factor and BER value is taken for a distance of 50 to 100 km at an input power of 0.2 dBm. The graphs show that as the distance increases, the Q-factor decreases and log (BER) increases.

B. *Performance Analysis of Bidirectional BPON*

i. *Downstream Direction*

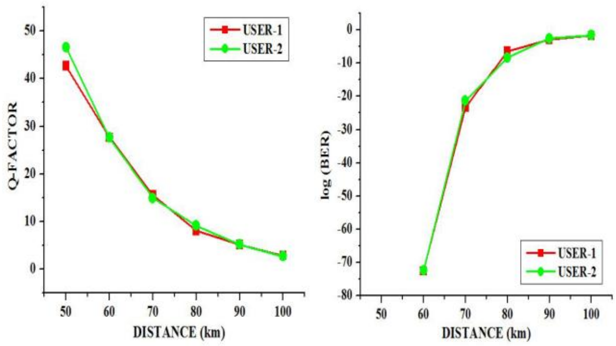
The performance of the bidirectional BPON systems with 2 users is analyzed using the parameters such as Q-factor and Bit Error Rate (BER). Fig. 7 shows the eye diagrams of the two users in the bidirectional BPON systems at a distance of 70 km in the downstream direction.



(a) (b)

Fig. 7: Eye Diagrams for the (a) First User (b) Second User of the Bidirectional BPON at 70km in the Downstream Direction

It can be seen that for BPON with 2 users, the eye opening is better indicating that the received signal is less distorted. Also, as the fiber length increases, the eye closure will be higher.



(a) (b)

Fig. 8: Relationship of (a) Q-factor and (b) log (BER) with Distance for Bidirectional BPON with 2 users in the Downstream Direction

The quality and the bit error rate of the output signal that is received by the users is varying with the distance. Fig. 8 (a) and (b) indicates the relationship between Q-factor and log (BER) with distance for bidirectional BPON with 2 users in the downstream direction. The Q-factor and BER value is taken for a distance of 50 to 100 km at an input power of 0.2 dBm. The graphs show that as the distance increases, the Q-factor decreases and log (BER) increases.

ii. *Upstream Direction*

The performance of the bidirectional BPON system for the upstream direction is analyzed using the parameters such as Q-factor and Bit Error Rate (BER). Fig. 9 shows the eye diagrams of the two users in the bidirectional BPON systems at a distance of 70 km in the upstream direction.

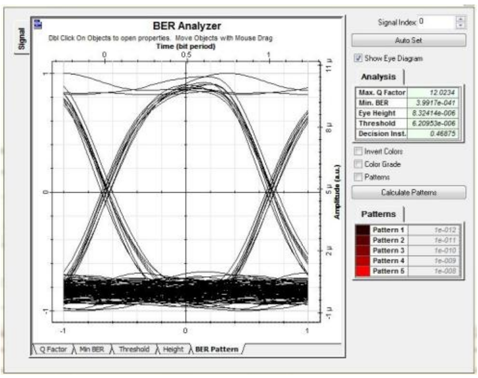
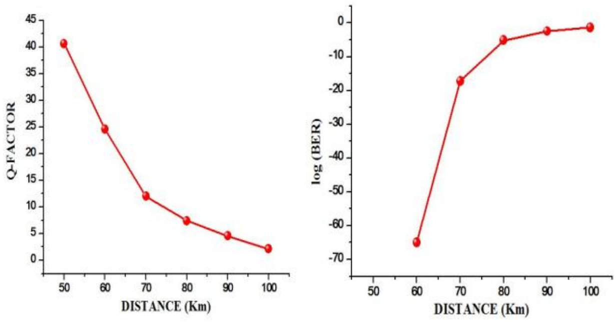


Fig. 9: Eye Diagram for OLT of the Bidirectional BPON at 70km in the Upstream Direction

It can be seen that the eye opening is better indicating that the upstream received signal is less distorted. Also, as the fiber length increases, the eye closure will be higher.



(a) (b)

Fig. 10: Relationship of (a) Q-factor and (b) log (BER) with Distance for Bidirectional BPON in the Upstream Direction

Fig. 10 (a) and (b) indicates the relationship between Q-factor and log (BER) with distance for bidirectional BPON in the upstream direction. The Q-factor and BER value is taken for a distance of 50 to 100 km at an input power of 0.2 dBm. The graphs show that as the distance increases, the Q-factor decreases and log (BER) increases.

IV. CONCLUSION

Passive Optical Networks (PON) plays an important role in the development of the Fiber to the Home (FTTH) networks. The PON is considered as one of the most successful access architecture that can provide high capacity and long reach. From the analysis, the performance of the unidirectional BPON 2 user system is better with high Q-factor and low BER compared to that of bidirectional BPON system. BPON is having lower bit rates, so the occurrence of error is lower and the received signal is having high Q-factor. It is found that as the length of the fiber increases, the Q-factor decreases and the BER increases.

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