بسم الله الرحمن الرحيم

كلية الدراسات العليا

Sudan University of Science and Technology

College of Graduate Studies

Performance Analysis of Passive Optical Network Using Wavelength Division Multiplexing

تحليل أداء الشبكة البصرية الخاملة بإستخدام تقسيم الطول الموجي متعدد الإرسال

Thesis submitted in partial Fulfillment to the Requirements for the award of the Degree of M.Sc. In Electronics Engineering (Communications)

Prepared by:

Nazik Abbas Sabah Mohamed Nour

Supervised by:

Dr. Mudathir Abdallah Osman Fagiri

2017

الآيـــة

بســـم الله الرحمن الرحيم

قال تعالى:

(ن وَالْقَلَمِ وَمَا يَسْطُرُونَ)

صدق الله العظيم

سورة القلم (الآية - 1)

Dedication

To my parents

Acknowledgement

Without the help and positive encouragement of many people, I am sure this thesis would not have come to light. I need to express great thanks to my helpful and cooperative supervisor, Dr. Mudathir Abdallah Osman Fagiri for accepting me as his student despite his huge workload, and for his extreme efforts that have been exerted.

Abstract

The demand was exceeded for speed to transmitting data, capacity and low cost that means there was a problem. The offers solution of limitation field in optical networks using Wavelength Division Multiplexing to increase the capacity and find the most cost-effective combination by designing four scenario unidirectional optical fiber(2,4, 6, and 8) users. In scenario four used Eridium Doped Fiber Amplifier to evaluate the system performance and study the effect of difference fiber length on the quality factor and bit error rate. The simulation was done in Optisystem 7.0 programs, when increasing the distance, the quality factor decreases and the bit error rate increases for a different scenarios, Eribum Dopted Fiber enhances the quality factor and minimized Bit Error Rate.

المستخلص

ونظراً لتجاوز الطلب لسرعة لنقل البيانات والقدرة وإنخفاض التكلفة وهذا يعني أن هناك مشكلة. وقد وفر هذا البحث حل مجال التقييد في الشبكات البصرية بإستعمال تعدد الإرسال بتقسيم الطول الموجي لزيادة القدرة والعثور على الجمع الأكثر فعالية من حيث التكلفة من خلال تصميم أربعة سيناريوهات بصرية أحادية الاتجاه (2 و 4 و 6 و 8) في سيناريو أربعة تستخدم مضخم الألياف الإريديوم وتقييم أداء النظام ودراسة تأثير الفرق طول الألياف على عامل الجودة ومعدل الخطأ في البت. تم إجراء المحاكاة في برامج أوبتسيستم 7.0، عند زيادة المسافة، ينخفض عامل الجودة ويزيد معدل خطأ البتات لسيناريوهات المختلفة، ومضخم الألياف الإريديوم يعزز عامل الجودة ويقليل معدل الخطأ في البتات.

Abbreviation

AWG	Arrayed Waveguide Grating
APD	A Photo Detector
BER	Bit Error Rate
CO	Central Office
CWDM	Coarse Wavelength Division Multiplexing
CW	Continuous Wave
D-MUX	De-Multiplexer (DMUX)
DWDM	Dense Wavelength Division Multiplexing
EDFA	Eridium Doped Fiber Amplifier
FTTH	Fiber To The Home
FDM	Frequency Division Multiplexing
ISI	Inter Symbol Interference
MUX	Multiplexer
MZM	Mach-Zehnder Modulator
RN	Remote Node
NRZ	Non Return To Zero
Q-Factor	Quality Factor
OLT	Optical Line Terminal
ONU	Optical Network Units
AON	Active Optical Network
PON	Passive Optical Network
PRBS	Pseudo Random Binary Sequence
TDM	Time Division Multiplexing
TDMA	Time Division Multiplexing
WDM	Wavelength Division Multiplexing

List of Figures

List of Tables

Table of Content

CHAPTER ONE
Introduction

CHAPTER TWO
Background and Literature Review

CHAPTER THREE
Methodology

CHPTER FOUR
Results and Discussion

CHAPTER FIVE
Conclusion and Recommendation

CHAPTER ONE

Introduction

CHAPTER ONE

Introduction

1.1 Introduction

Fiber optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber, the light forms an electromagnetic carrier wave that is modulated to carry information. There are two common systems available in fiber networks one of them is passive optical Network(PON) which 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. The bandwidth requirements of the telecommunication network users increased rapidly during the recent years, optical access network must provide the bandwidth demand for each user as well as support high data rate broadband multiple services and flexible and communication for various end users .Wavelength Division Multiplexing (WDM) techniques was employed in the PON for higher resources efficiency and capacity, which results in WDM-PON can solve the problems in Time Division Multiplexing-passive optical Network(TDM-PON) was provides much higher bandwidth for data application but it has a limited availability, by allocating specific wavelength to each subscriber[1].

Wavelength Division Multiplexing (WDM) is a method of transmitting data from different sources over the same fiber optic link at the same time where by each data channel is carried on its own unique wavelength. The result is a link with an aggregate bandwidth that increases with the number of wavelengths employed. In this way WDM technology can maximize the use of the fiber optic infrastructure that is available, what would normally require two or more fiber links instead requires only one. This technology is finding a tremendous attention as users are multiplying day by day to use data networks. The user usage requires huge bandwidth for various applications like data browsing over internet, video conferencing, voice over internet and several other java applications wavelength-division-multiplexing (WDM) has become a promising networking choice in optical communication. A high speed application has become very convenient and fast because of the use of optical networks. Besides optical interconnects, which play a vital role in networking channels are also an important factor which multiplies the speed and applications. BER is a parameter which affects the performance of the overall system, hence it should be minimized to a greater extent [2].

This search starts with an overview about PON and WDM technology followed by review of recent developments in this field. It is also presented that how utilization of this technology helps in incrementing the overall capacity of the communication network [1].

1.2 Problem statement

The development of communication led to increase the speed, capacity and low cost, some technique of communication used narrow band width and need Regenerators (repeaters) to transmitting data. To avoid this problems used passive optical network because its advantages of reduce the cost and power and WDM helps in expanding the capacity of a fiber optic network without requiring additional fiber by gives any user unique wavelength .

1.3 Objectives

In this search we offer a solution to the problem of the limited field in optical networks the use of WDM multiplies the effective bandwidth of a communications system and users may be multiplexed on the same fiber which reduces the cost dramatically.

- The performance parameter to evaluate the system is in term of Bit Error Rate (BER) and Q-Factor.
- Design four scenarios unidirectional (2, 4, 6, 8) users of WDM- PON.
- Study the effect of the Eridium Doped Fiber Amplifier (EDFA)in the fiber-optic link.
- The effect of different optical fiber length (L) in the quality factor and BER.

1.4 Methodology

The Optisystem7.0 software program is used to study the characteristics of the WDM Several measurements the results were obtained and discussed in curves plotted.

1.5 Thesis outlines

This thesis is divided to five chapters, in chapter two represent the background and literature reviews, in third chapter system model describes the methodology by showing Implementation and components of PON network, while chapter four include results and discussion and in chapter contain the conclusion and the recommendations and references.

CHAPTER TWO

Background and Literature Review

CHAPTER TWO

Background and Literature Review

2.1 Introduction

This chapter includes the introduction of PON, component of PON network, wavelength division multiplexed passive optical network (WDM-PON) and related work.

2.2 Passive Optical Network (PON)

The Passive Optical Network (PON) is a network, which carries data in the optical domain between the Optical Line Terminal (OLT) and the Optical Network Units (ONU), and the transport path of the optical signal is passive. This implies that the optical network devices(between the transmitter and receiver) are non-powered, i.e. no electrical devices are used. Powered equipment is required only at the source and receiving ends of the signal. A passive optical network shares fiber optic strands for portions of the network[3].

A PON is network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. While an Active Optical Network (AON) can cover a range to about 100 km (62 miles), a PON is typically limited to fiber cable runs of up to 20 km (12 miles).PONs also are called Fiber to the Home (FTTH) networks [4].

2.3 Passive Optical Network component

The (PON) can be presented through three sections, representing the OLT (Optical Line Terminal) transmitter ,splitter and ONT (Optical Network Unit) receiver show in fig(2.1):

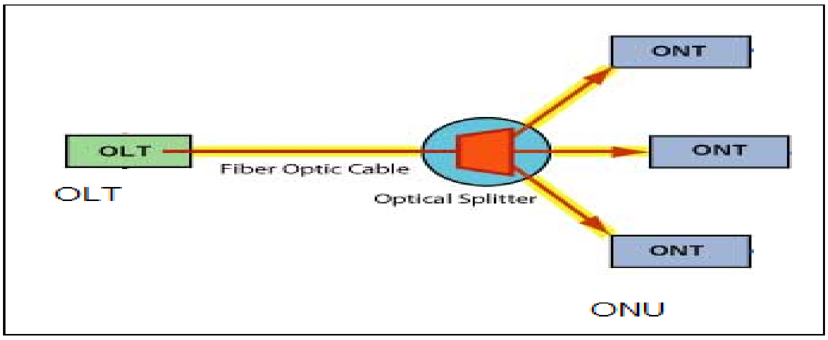

Figure 2.1: PON block diagram

2.3.1 Optical Line Terminal (OLT)

The OLT is located in a central office and controls the bidirectional flow of information across the Optical Distribution Network (ODN). An OLT must be able to support transmission distances across the ODN of up to 20 km. In the downstream direction the function of an OLT is to take in voice, data, and video traffic from a long-haul network and broadcast it to all the ONT modules on the ODN. In the reverse direction (upstream), OLT accepts and distributes all the traffic from the network users.

2.3.2 Optical Network Unit (ONU)

The ONU is installed within user's premises. It is also termed as Optical Network Terminal (ONT) because it is located in home/ building/ curb etc. This unit provides network access to the users. In other words, this provides an interface to the single or many users. Earlier, ONUs were designed for data reception only but now-a-days, these are capable of transmitting and receiving the data simultaneously.

2.3.3 Splitter and Combiners

These devices are used at the remote node or channel to distribute/ aggregate the signals to and from OLT to the number of ONUs. These devices are available in two types viz. active and passive. Active splitters and combiners which use external power for their operation are used inside the remote node in PON architectures. The passive splitters and combiners do not require external power and can be used in the channel or outside of the remote node. Most commonly used splitters are 1:4, 1:8, 1:16, 1:32 and 1:64 [5].

2.3.4 Arrayed Waveguide Grating (AWG)

AWGs uses different wavelength for upstream and downstream data transfer [6]. The limitation of AWGs is that the wavelength shifts about 0.01 nm per degree Celsius with variations in temperature which results due to change in the refractive index of silica waveguides. Mostly, AWGs are placed at outdoor 11 plants without electrical coolers in the passive remote node where temperature varies due to change in environmental changes. Therefore, it is essential to deploy temperature insensitive AWGs. Some efforts have been made to minimize the dependence of channel wavelength on temperature in AWGs [7].

2.3.5 Optical Amplifiers

Eridium Doped Fiber Amplifier(EDFA):

Eridium Doped Fiber Amplifiers an optical repeater device that is used to boost the intensity of optical signals which are carried through the optical fiber.

Communication technology has very vast growth for long distance transmission through optical fiber light signal gets attenuated and to recover from this type of attenuation we need an optical amplifier. There are number of optical amplifiers, EDFA is used mostly because of its high gain and low noise feature. Because the Doping material used for EDFA is erbium, so it is called as Erbium Doped Fiber Amplifiers. EDFAs are more reliable for long distance transmission using single or multi wavelength sources because of their wide bandwidth and optimum Bit Error Rate (BER).Wavelength Division Multiplexing (WDM) Networks is also used for multi-channel Amplification without crosstalk. The WDM networks employing EDFA which is used for cost effective solution for increased demand of network capacity. EDFA enhances the quality of the output signal. This is basically used to remove the problems like attenuation, distortion and Rayleigh [7].

2.4 Wavelength Division Multiplexed Passive Optical Network (WDM-PON)

The architecture of WDM-PON employs a separate wavelength channel from the OLT to each ONU, for each of the upstream and downstream directions. This approach creates a point to-point link between the central offices(CO) and each ONU, In the WDM-PON; each ONU can operate at a rate up to the full bit rate of a wavelength channel. Moreover, different wavelengths may be operated at different bit rates, if necessary; hence, different varieties of services may be supported over the same network. In other words, different sets of wavelengths may be used to support different independent PON sub networks, all operating over the same fiber infrastructure. The wavelength channels are routed from the OLT to the ONUs by a passive arrayed waveguide grating (AWG) router[10].This is deployed at a remote node (RN), by which multiple spectral orders are routed to the same output port from an input port. This allows for spatial reuse of the wavelength channels. A multi wavelength source at the OLT is used for transmitting multiple wavelengths to the various ONU. For the upstream direction; the OLT employs a WDM de-multiplexer along with a receiver array for receiving the upstream signals. Each ONU is equipped with a transmitter and receiver for receiving and transmitting on its respective wavelengths shown in fig(2.2),Since ONU deals with different wavelength it required multi wave length sources it make ONU costlier. To avoid this wavelength reuse scheme is used[11].

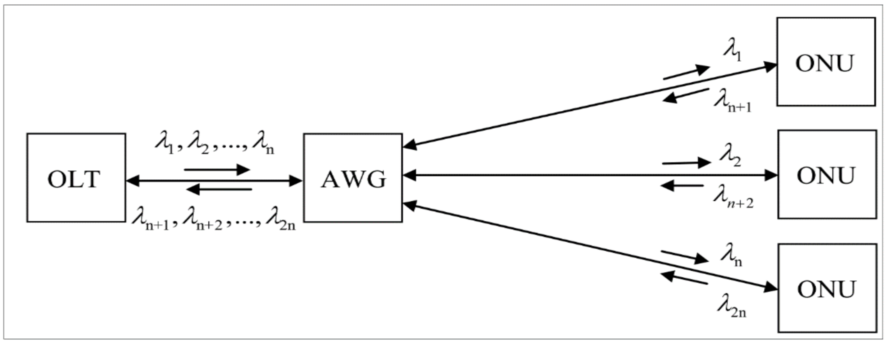

Figure 2.2: WDM-PON architecture.

2.4.1 WDM Access Passive Optical Networks

The next generation is WDM-PON in development of access networks. They can present the largest bandwidth at the lowest cost. The planning of WDM PON is similar to the planning of the PON. The major difference is that ONUs work on different wavelengths and thus higher transmission rates can be achieved [10].The explicatory example of this architecture as shown in fig (2.3)

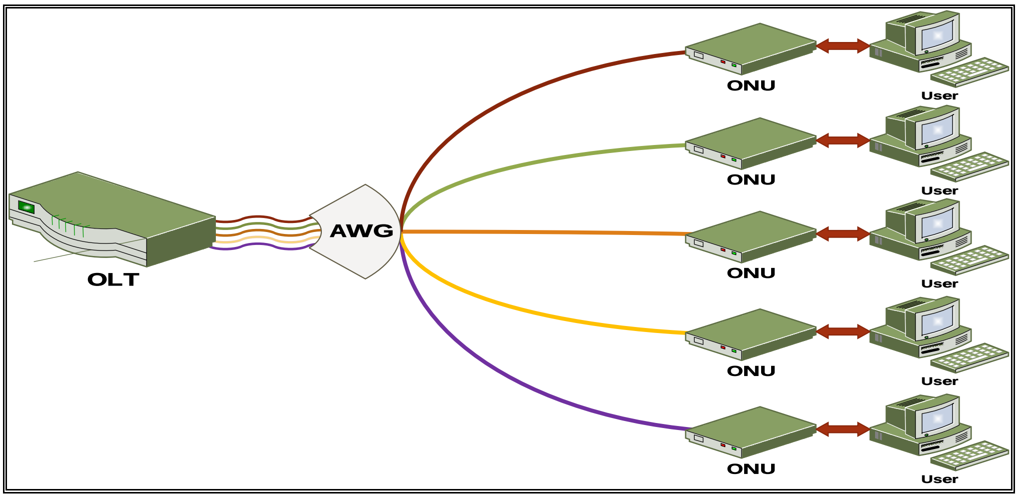

Figure 2.3: Configuration of WDM-PON in FTTH Network

But the major problem with WDM PONs is that usually the assigned wavelength to an ONU is fixed so it makes upgrades in this network topology difficult. It is need manual reconfiguration of the equipment in the customers' side, which largely increases the cost of maintenance. The solution to this is the using of "colorless" ONUs that allow ONU to detect what wavelength is used in the downstream direction and sends its data on this wavelength in the upstream direction. A system can contain 128 different wavelengths were and is used to carry the signal to the users' side. In the upstream direction, an ONU modulates the carrier wavelength provided by the OLT with its data. The advantage is that ONUs do not have to be equipped with expensive light sources. This not only lowers the overall cost of the equipment but also makes ONUs transparent to the signal and different wavelengths can be used at any time but the disadvantage of WDM-PONs is the high cost of tools. A lot research was focused on enhancing WDM-PONs ability to serve larger numbers of users in attempt to increase earning from invested resources and its cost efficiency [11].

2.4.2 WDM Technology

In fiber-optic communications, the wavelength-division multiplexing (WDM) is a technique which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths. This technique enables well as multiplication of capacity a WDM system uses a multiplexer at the transmitter to join the signals together, and de-multiplexers at the receiver to split them apart. With the right type of fiber WDM systems become popular in most communication systems since they expand the capacity of the network simply by upgrading the multiplexers and de-multiplexers at each end and without laying more fiber the optical WDM networking technology as suitable method for wide area network (WAN) environments due to its ability to meet the rising demands of high bandwidth [9].

Wavelength division multiplexing (WDM) is an optical multiplexing technology for exploiting the huge bandwidth capacity inherent in optical fibers. Conceptually, it is similar to frequency division multiplexing (FDM) that has already been used in radio communication systems for over a century. The basic principle is to divide the huge bandwidth of an optical fiber into a number of no overlapping sub bands or optical channels and transmit multiple optical signals simultaneously and independently in different optical channels over a single fiber, each signal being carried by a Single wavelength. In wavelength division multiplexing, we transmit the signals of different wavelengths through a multiplexer and the channel used is an optical fiber so that the bandwidth and transmission efficiency increases [9].

Shows a block diagram of a basic WDM transmission system the network medium can be a simple fiber link, a passive star coupler, or any type of optical network. The transmitter consists of a laser and a modulator. The laser is the light source, which generates an optical carrier signal at either a fixed wavelength or a tunable wavelength. In the modulator, the carrier signal is modulated by an electronic signal and is then sent to the multiplexer (MUX). The multiplexer combines multiple optical signals on different wavelengths at its input ports into a single optical signal, which is transmitted to a common output port or optical fiber. The de-multiplexer (DMUX) uses optical filters to separate the optical signal received on the input port into multiple optical signals on different wavelengths, which are then sent into the receivers. The receiver consists of a detector (e.g., photodiode) that can convert an optical signal to an electronic signal. The optical amplifiers are used to maintain the power strength of an optical signal at appropriate locations in the transmission system [8].

A large number of optical carrier signals is combined based on a laser that is designed to emit single color of light. Each signal that needs to transmit is attached to the laser that will emit a colored light beam and the color will be different for different signal. These light beams are then sent simultaneously. At the receiving end, the combined colors then splits back into the original individual colors again [11].

2.4.3 Types of wavelength division multiplexing

There are two types of wavelength division multiplexing.

1. DWDM (Dense wavelength division multiplexing)
2. CWDM (Coarse wavelength division multiplexing)

There are two types of WDM implementations: Dense Wave Division Multiplexing (DWDM) and Coarse Wave Division Multiplexing (CWDM). DWDM systems utilize temperature-stabilized lasers and narrow band filters to achieve narrow channel spacing of 0.8 nm or less, enabling the transmission of 16 or more wavelengths/data channels within a given color spectrum. CWDM systems in comparison use non-stabilized lasers along with broadband filters for wider channel spacing of 20 nm, allowing for up to 16 transmitted wavelengths. In general, DWDM is the best choice for applications where channel density/bandwidth is of high priority. At the same time, CWDM remains an excellent option for applications where deployment costs are to be considered [9].

2.4.4 High-Capacity Point-to-Point Links for WDM PON

For long-haul fiber links forming the backbone or the core of a telecommunication network, the role of WDM is simply to increase the total bit rate, fig (2.4)shown schematically point-to-point, high-capacity and WDM link. The output of several transmitters, each operating at its own carrier frequency (or wavelength), is multiplexed together. The multiplexed signal is launched into the optical fiber for transmission to the other end, where a de multiplexer sends each channel to its own receiver. Where N is numbers of chanel.

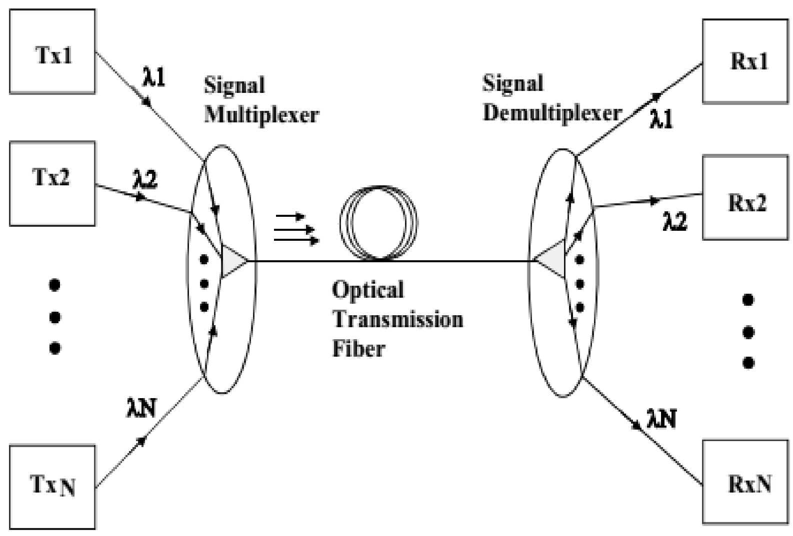

Figure 2.4: Multichannel point-to-point fiber link. Separate transmitter-receiver

2.4.5 Advantages of WDM

- It provides the greater transmission capacity in the system.
- It has a capability of bidirectional and Duplex data transmission.
- Easily can handle simultaneous transmission of various signals.
- Easy system expansion due to this we can use multiple channels at a same time.
- Faster access the new channels and require minimum time to transmit information from source to destination.

2.4.6 Disadvantages of WDM

- Lack of flexibility
- Lack of capacity.
- Requirement of costly infrastructure.

2.5 Previous Studies OR Related work

The authors in [12] successfully demonstrated that wavelength division multiplexing passive optical network (WDM-PON) system can be successfully implemented for 65Km. It delivers downstream 20-Gbps data and upstream 10-Gbps data on a single wavelength.

In [13] the authors investigated two possible cases of combining WDM with TDM/TDMA based on 40 Gb/s and 20 Gb/s optical transceivers. The second system architecture is slightly more complex compared to the first one .But in term of cost of the devices, an ONT in the first case might be more expensive. And they found that both systems need particular attention during the task of design and precisely in the selection of the wavelength to allocate to subscribers in a given area.

In [13] passive optical networks were analyzed and the performance of circuit elements used in some topologies designed with OptiSystem 12.0 simulation program were reviewed. The effects of the type, length and dispersion values of the optical fiber used in the network and the additional loss, return loss and the noise dynamic parameters of splitter, which is one of the main components of passive optical networks, on the system were analyzed. Then by adding an optical modulator, optical amplifier, optical filter and an optical coupler to the passive optical network, the factors which can affect the efficiency of the passive network topology positively or negatively were reviewed through BER diagrams, time domain and spectrum outputs. As their result of the measurements carried out, increase inefficiency on the second window in 1300-1350 nm and on the third window in 1500-1550 nm in passive optical networks was observed.

Lei Shi et al. [15] proposed long reach PON architecture using AWG and EDFA. They have analyzed ring and tree architectures of PON system for wavelength allocation scheme. A mathematical model for BER was analyzed for calculating the consequence of AWG and EDFA on the overall system performance. Various performance parameters like channel numbers, wavelength assignment schemes, wavelength numbers with respect to BER have been discussed in detail.

Ben yang Chen et al. [16] proposed ring topology based WDM PON using dynamic wavelength assignment technique. A feeder fiber was used to provide the protection to the ring architecture. The performance of various components like AWG, coupler, splitter, fiber and optical switch was investigated in terms of insertion loss.

R. S. Kaler et al. [17] Reported the impact of EDFA power on optical systems. The performance of optical communication systems with subsequent increase in different types of fibers used in optical systems was also examined. The need of accurate toning among the EDFA power and fiber link for best result was highlighted.

M. A. Elmagzoub et al. [18] Proposed two architectures of hybrid and stacked PON. 4 channels at 40 Gbps data rate with 1490 nm and 1330 nm center wavelengths and 100 19 GHz channel spacing for downlink and uplink have been transmitted and received at 50 Km distance with 32, 64 and 128 number of ONUs respectively.

Abdel Hakeim M. Husein et al. [19] proposed WDM PON using AWG de-multiplexer with spectrum slicing technique for 32 number of ONUs. The system was investigated for 3 Gbps data rate over a distance of 40 Km with 50 GHz channel spacing. Various results for BER with respect to received output power and eye diagrams have been shown.

Komal Preet Kaur et al. [20] Investigated WDM PON for different types of filters such as Integrator, Gaussian, Bessel, Inverse Rectangular filters with four WDM channels at 10 Gbps data rate for 100 GHz channel spacing. The results were shown that a good BER and Q factor were achieved by Bessel filter than other filters.

In this study it’s considered to design and implement an expanded WDM-PON network to provide higher data rate by EDFA, the network model designed using OptiSystem 7.0 software, further performance analysis procedures are done by calculating BER and Q factor.

CHAPTER THREE

Methodology

CHAPTER THREE

Methodology

3.1 Introduction

Opti-System7.0 is an innovative optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks They were monitoring output signals after each component. It is essential to study and measure the performance of a whole system having several components. A whole system starts, for example, with an optical transmitter such as a laser, optical fiber, and ends with an optical receiver. For that reason, the ultimate measurement of the performance for optical communication system in bit error rate (BER) and Q factor with distance. In this chapter design four scenarios unidirectional of WDM-PON.

1. Transmitter for PON Using WDM

Consists of pseudo-random bit sequence generator, NRZ Generator, Match zehnder, CW laser, pseudo random bit sequence generator and multiplexing fig (3.1) shown the transmitter

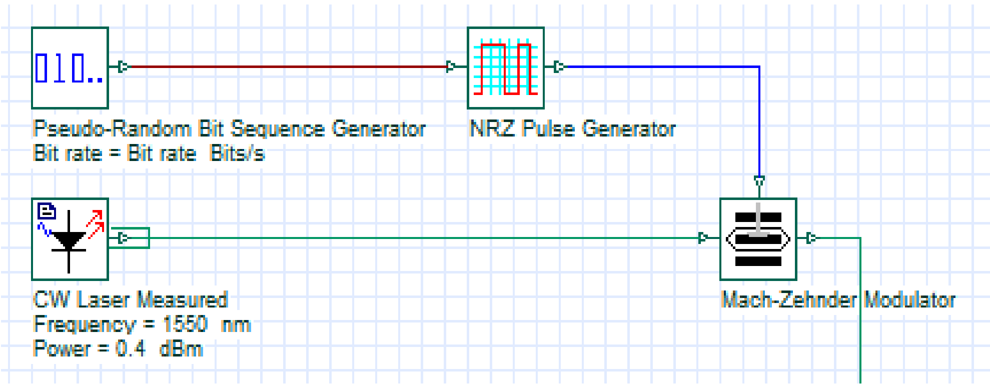

Fig 3.1: Transmitter

2. Receiver

The receiver in fig (3.2) consists of Photo detector PIN, 3R regenerator, Bessel filter and BER analyze

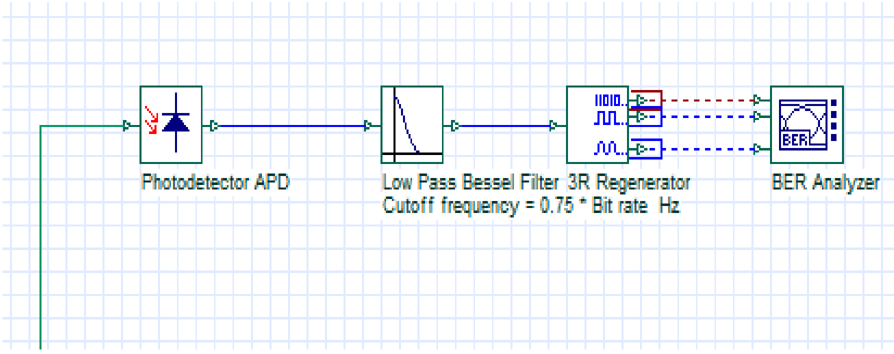

Fig 3.2:Receiver

3.2 Model components

1. Pseudo-Random Bit Sequence Generator

Generates a Pseudo Random Binary Sequence (PRBS) according to different operation modes. The bit sequence is designed to approximate the characteristics of random data (0, 1)

2. NRZ Pulse Generator

Generates a Non Return to Zero (NRZ) coded signal a number of different NRZ codes are widely used, and their bandwidths serve as references for all other code groups. For a serial data stream an on-off (or Unipolar) signal represents a 1 by a pulse of current or light filling an entire bit period, whereas for a 0 no pulse is transmitted. These codes are simple to generate and decode. The minimum bandwidth is needed with NRZ coding, but the average power input to the receiver is dependent on the data pattern.

3. Continues Wave (CW) laser

Generates a continuous wave (CW) optical signal and also work in these frequencies (Hz, THz, nm) and generate power (W, mW, dBm).

4. Mach -Zehnder Modulator

Simulates a Mach- Zehnder modulator using an analytical mode the different paths can lead to constructive and destructive interference at the output, depending on the applied voltage. Then the output intensity can be modulated according to the voltage.

5. Fiber optic

The optical fiber component simulates the propagation of an optical field in a single mode fiber with the dispersive and nonlinear effects the optical sampled signals reside in a single frequency band.

6. WDM MUX & De-MUX

Multiplexes &de-multiplex defined number of input/out put WDM signal channels.

7. Photo detector APD

Filter with a square cosine roll off frequency transfer function.

8. Low Pass Bessel filter

Filter with a Bessel frequency transfer function. Cutoff frequency is .75*bit rate hz.

9. 3R Regenerator

This component regenerates an electrical signal.

10.BER Analyzer

This visualizer allows the user to calculate and display the bit error rate (BER) of an electrical signal automatically. It can derive different metrics from the eye diagram, such as Q factor, eye opening, eye closure eye height, etc.it can also plot BER patterns.

3.3 Experimental setup

- PRBS generator (Pseudo-Random Bit Sequence Generator) Bit Rate 2.5, 4.5 Gbits/s.
- CW laser (Continuous wave laser source) frequencies and powers depend on selected scenarios.
- Optical fiber (single mode) select from 20km -160km.
- WDM Mux2x1.4x1,6x1 and 8x1, De-MUX1x2,1x4,1x6 and 1x8.

3.4 Scenario1

Use two channels with different wavelength 193.1Thz, 193.2Thz,and changed fiber lengths from 20km to 160km. Here the OLT, with data rate 2.5Gbps. The generated signal is encoded by using NRZ pulse generator. The wavelengths are set power as 0.2 dBm in the Continuous Wave (CW) laser sources. 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 output of the Mach-Zehnder modulator will be transmitted to the ONUs through the optical fiber channel. A WDM multiplexer present at the OLT is used for combining these signals and transmitting as a single signal through the optical fiber. The WDM de-multiplexer forms the Remote Node (RN), which splits the signals corresponding to each of the earlier wavelengths and the ONUs with the corresponding wavelengths, receive the signals by APD Photo detector, low pass Bessel filter, 3R regenerator and BER analyzer show the output for each user in fig (3.3) bellow:

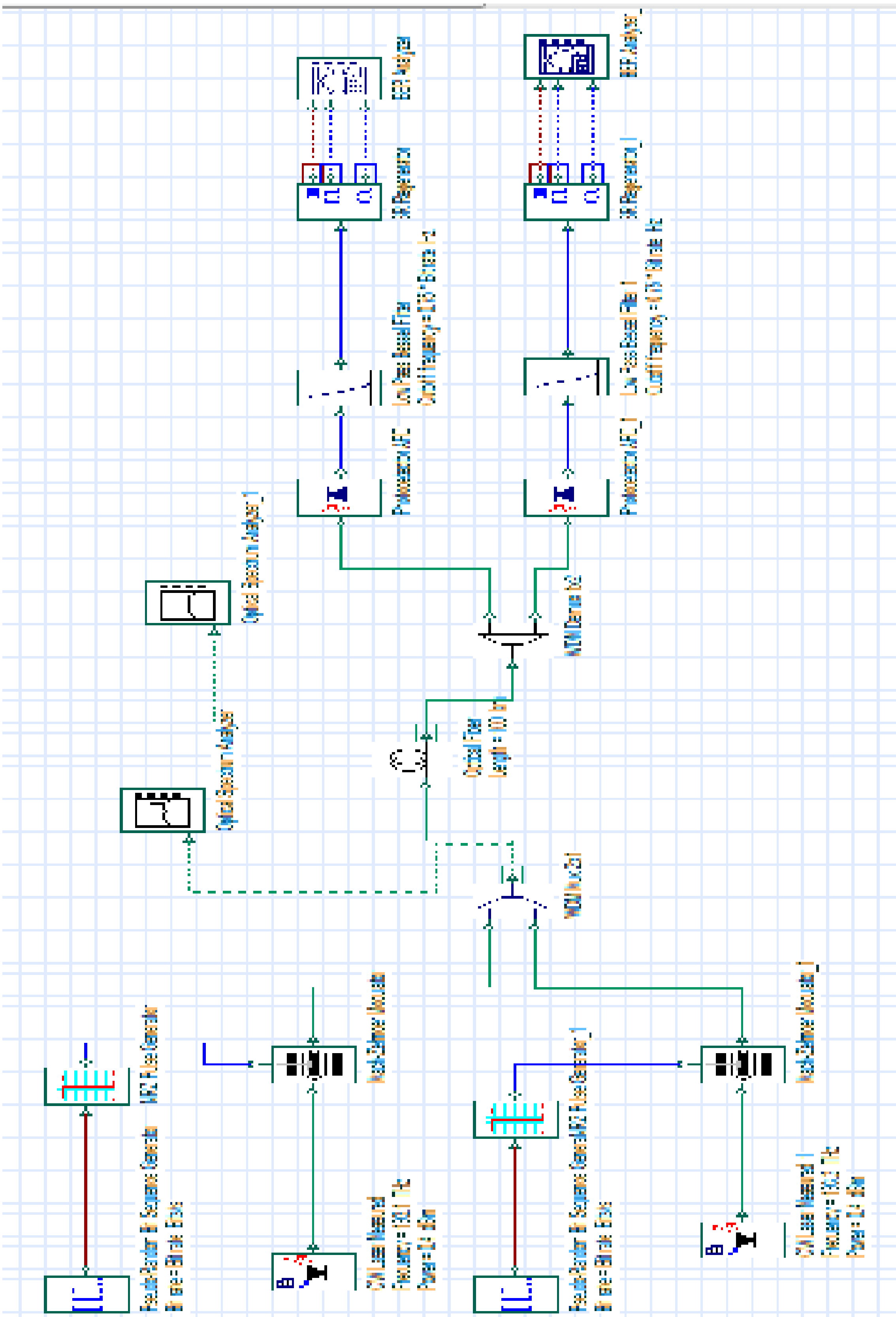

Figure 3.3: Simulated diagram of WDM PON of 2 users

3.5 Scenario2

Use four channel with different wavelength 1490 nm, 1491 nm, 1492 nm and 1493 nm and changed fiber lengths from 20km to 160km, with data rate 2.5Gbps and power 0.2 dBm ,fig(3.4) show the scenario .

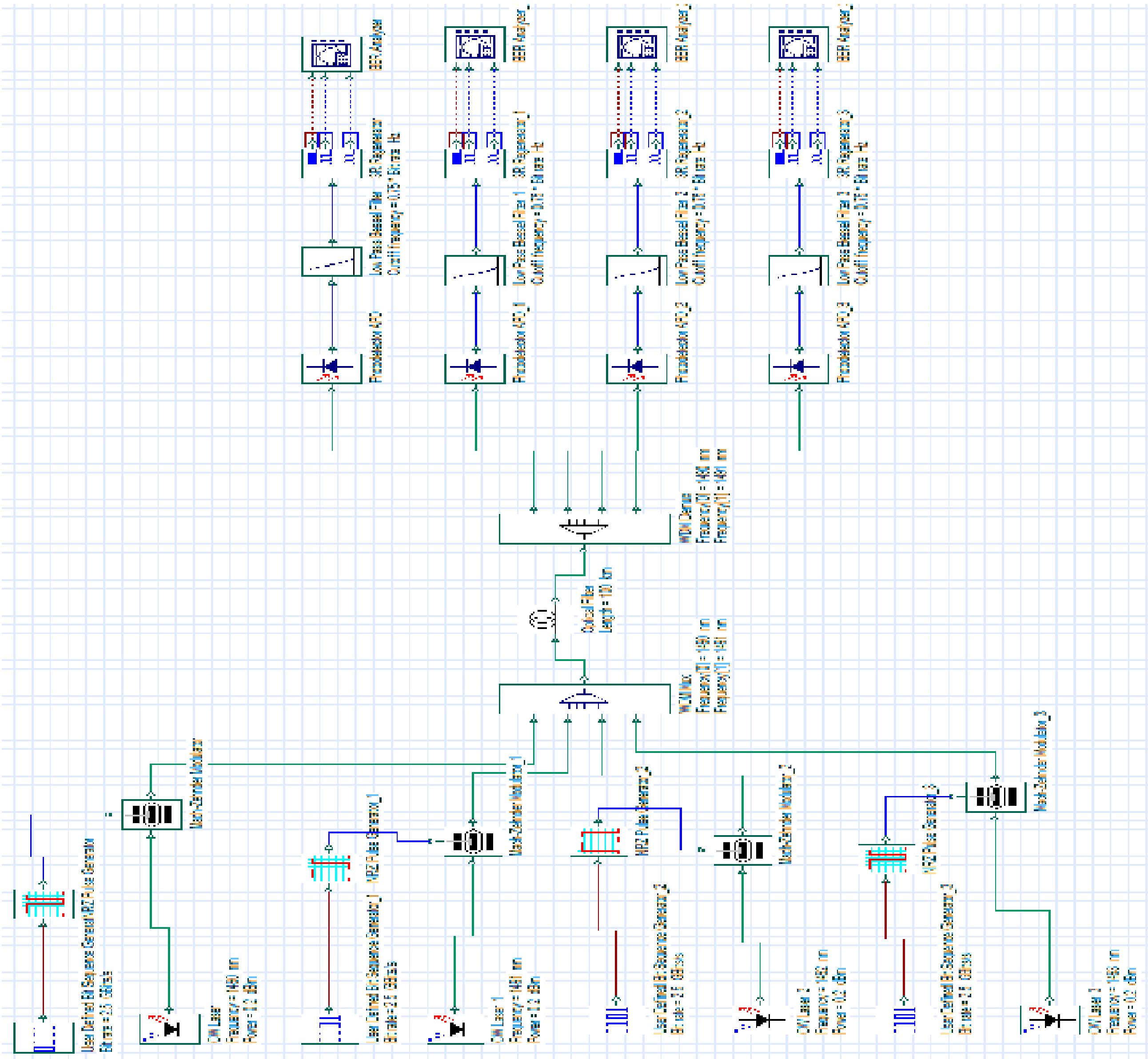

Figure 3.4: Simulated diagram of WDM PON of 4 users

3.6 Scenario 3

Fig (3.5)use six users with different wavelength 193.1THz, 193.2THz, 193.3THz, 193.4THz, 193.5 THz and 193.6 THz and changed fiber lengths from 20km to 160km, with data rate 2.5Gbps,and power 0.2 dBm.

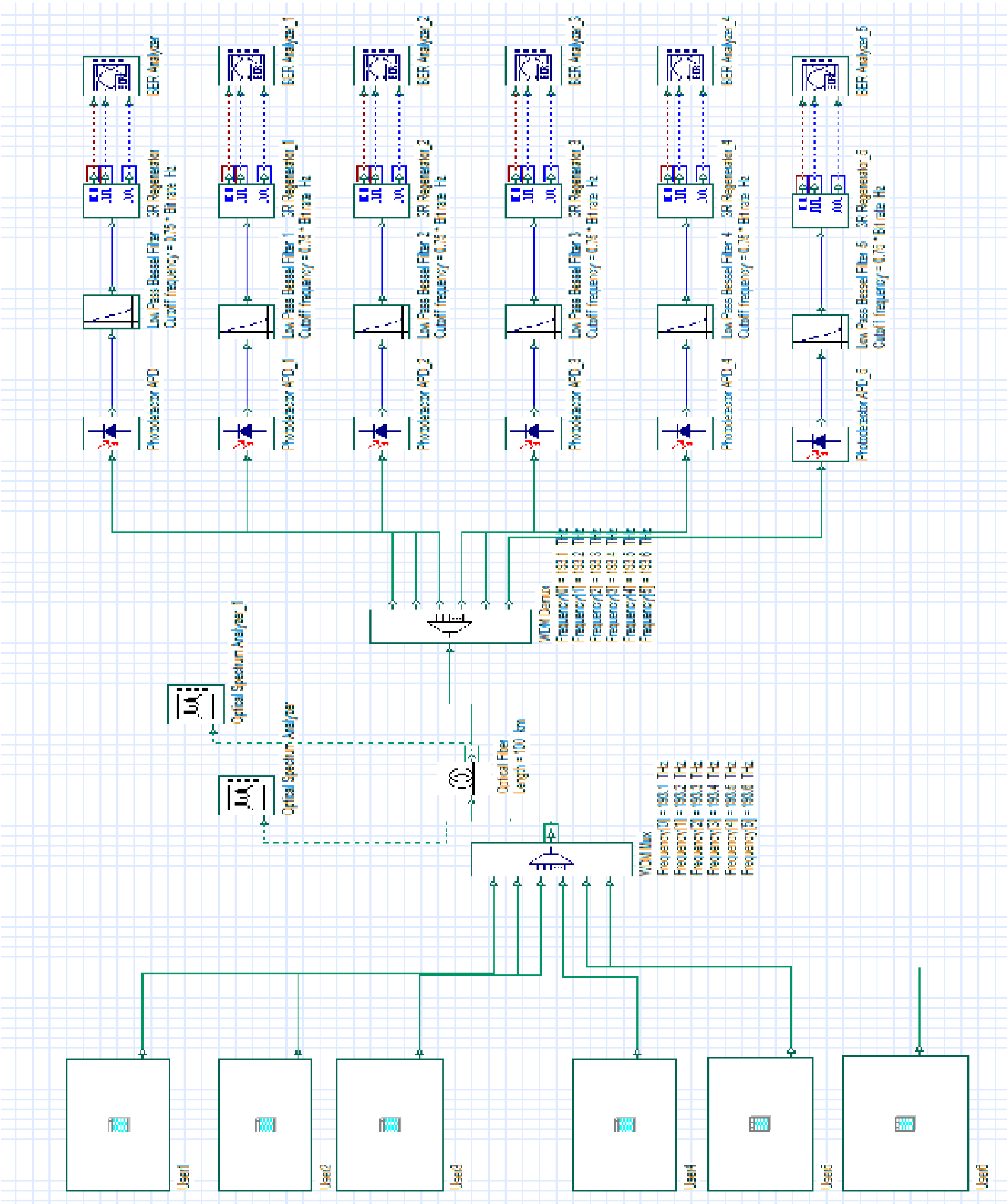

Figure 3.5: Simulated diagram of WDM PON of 6-users

3.7 Scenario 4

Use eight channel with different wavelength 1552.4 nm, 1551.6 nm, 1550.8 nm,1550 nm, 1549.2 nm, 1548.4 nm, 1547.6 nm and 1546.8 nm and changed fiber lengths from 20km to 160km, with data rate 4.5Gbps,and power as 0.4 dBm, study the effect of EDFA in system.

The two simulated configurations are as follows:

1. WDM System without using EDFA.
2. WDM System using EDFA.

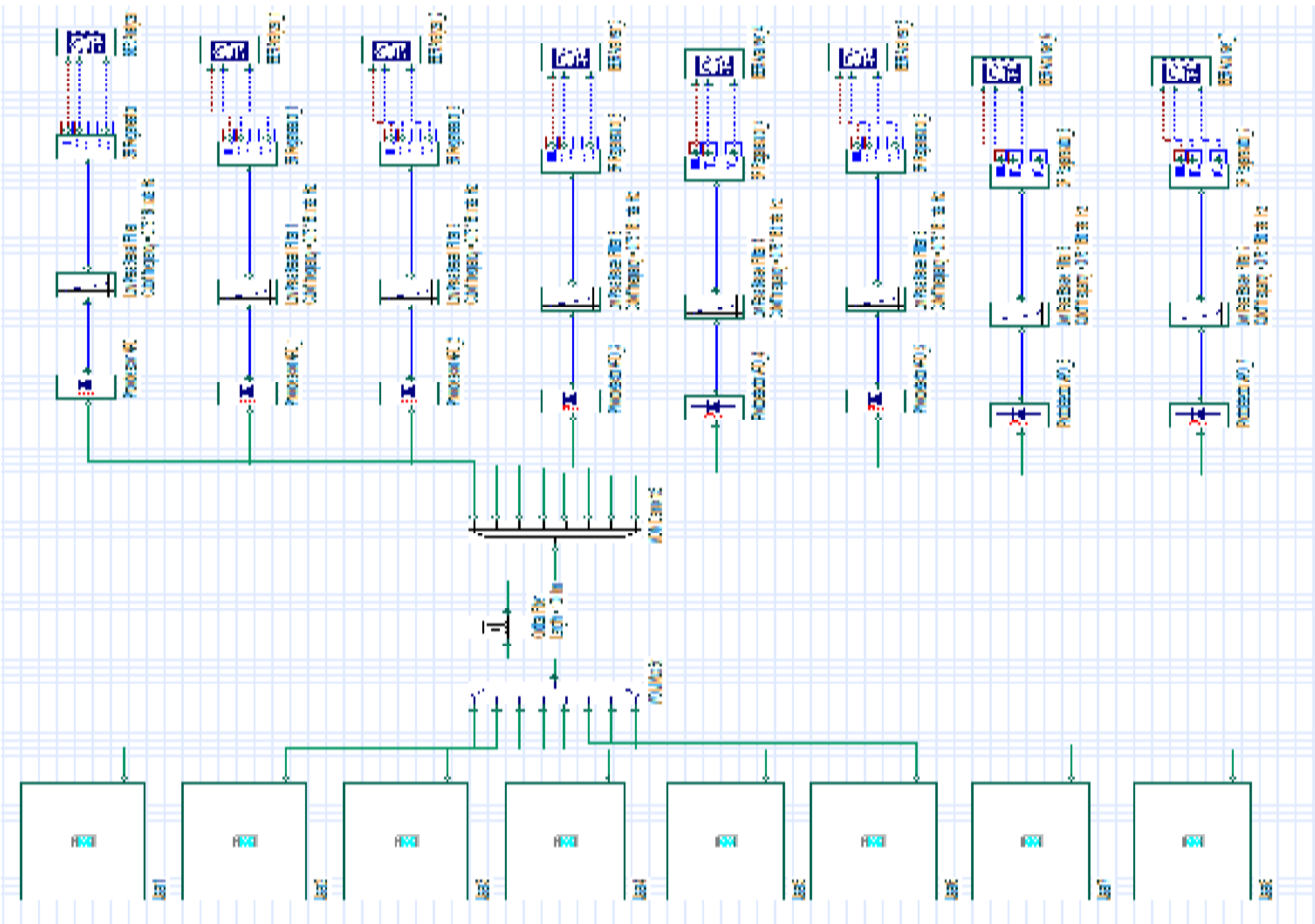

Figure 3.6: Simulated model WDM for 8 users without EDFA

2-WDM-PON System using EDFA

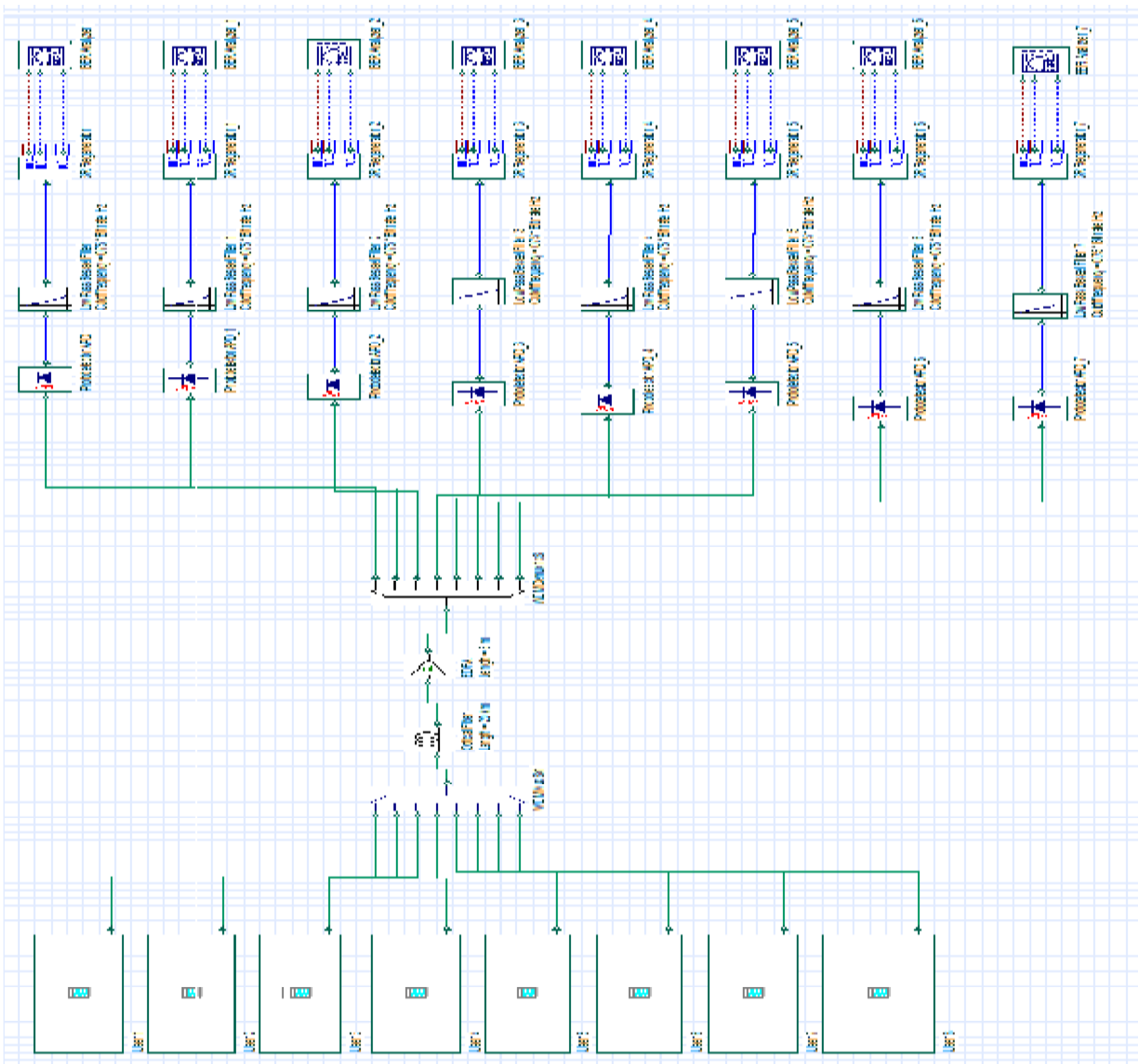

Figure 3.7: Simulated model WDM for 8 users with EDFA

CHPTER FOUR

Results and Discussion

CHPTER FOUR

Results and Discussion

4.1 Introduction

The following chapter represents the results and discussion of the simulated work. a simulation was made using optisystem and some parameters which are bit error rate, Q-factor and number of users.

4.1.1 Quality Factor

Q factor or quality factor give us the quality of signal with respect to distance of signal of signal from the noise .It covers all the noises ,dispersions and nonlinearities, which deteriorate the signal quality and thereby increase the bit error rate .It follows that the higher Q factor ,the higher signal quality.

4.1.2 Bit Error Rate

Bit error rate is one of the main indicators of quality of optical connection. It is under the influence of the same parameters as the Q factor. Bit error rate gives us the ratio between the numbers of mistakenly received bits and the total number of received bits.

The result of all scenarios shown in tables and carves bellow:

4.2 The Result of Quality Factor in Scenario one

Table (4.1) Result of WDM for scenario 1 relation between Q factor and Distance

Distance/km	Q factor for user1	Q factor for user2
20	49.9618	48.7787
40	49.9618	48.7787
60	49.9618	48.7787
80	29.9837	27.2453
100	15.3926	17.219
120	7.36655	7.58644
140	3.00641	3.45502
160	0	0

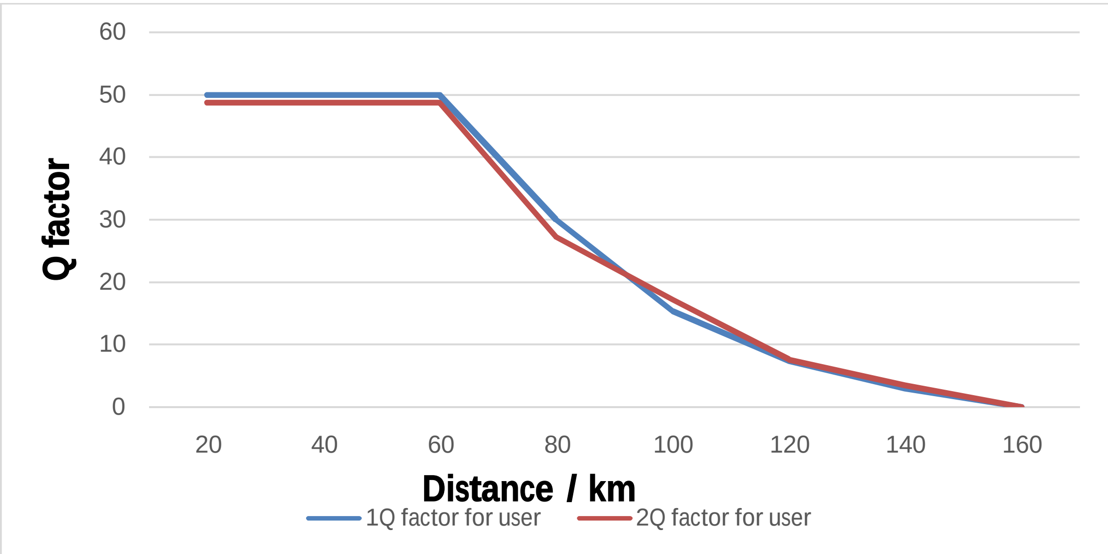

Figure 4.1: Relation between Q factor and Distance for 2 users

The value of Q factor is [49.9618]at distances (20-40-60 /km) and after that it decreased to zero at distance (160/km) because signal loss by dispersion and attenuation.

4.3 The Result to Bit Error Rate in Scenario one

Table (4.2) Result of WDM for 2 channel relation between BER and Distance

Distance/km	BER user1	BER user2
20	0	0
40	0	0
60	0	0
80	7.43343e-198	8.52239e-164
100	8.98357e-054	9.16307e-067
120	8.66078e-014	1.62888e-014
140	0.00131705	0.000275114
160	1	1

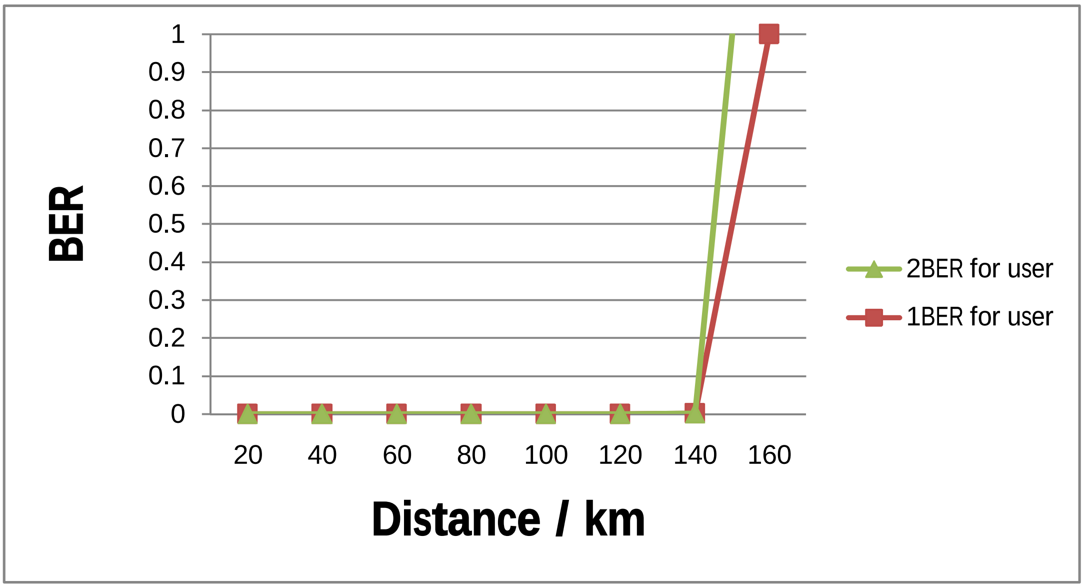

Figure 4.2: Relation between BER and Distance for 2 users

BER=7.04343e^{-198} for user 1, 8.52239e^{-164} for user2 in 80 km. then BER increase up to one in 160km.

4.4The Result of Quality Factor in Scenario Two

Table (4.3) Result of WDM for 4 channel relation between Q factor and Distance

Distance/km	Q for user1	Q for user2	Q for user3	Q for user4
20	176.714	166.423	163.743	179.268
40	139.652	138.27	138.299	133.183
60	86.4017	92.0031	95.7301	100.219
80	47.7038	54.9903	52.4058	53.27
100	22.6806	22.4704	25.716	25.8817
120	10.6835	9.74284	10.7941	11.1275
140	4.44822	4.13751	4.4013	4.35468
160	0	0	0	0

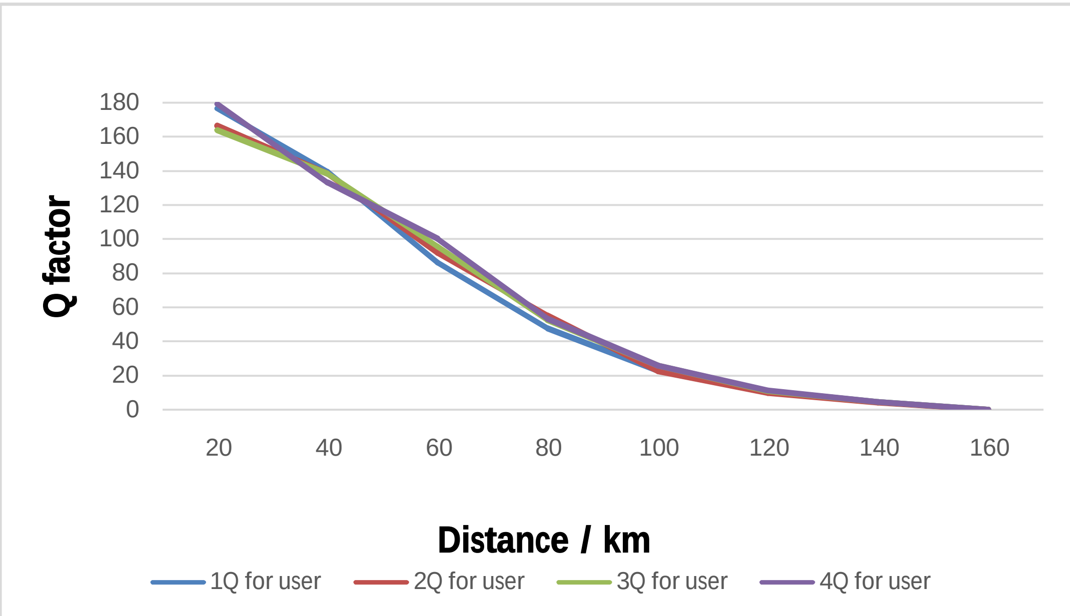

Figure 4.3: Relation between Q factor and Distance for 4 users

Q factor at distance 20km equal (176.714, 166.423, 163.743, 179.268)

The value of Q factor increased when number of channels was increased and decreased to zero in distance 160 km for all users.

4.5 The Result of Bit Error Rate in Scenario Two

Table (4.4) Result of WDM for 4 channel relation between BER and Distance

Distance/km	BER for user 1	BER for user 2	BER for user 3	BER for user 4
20	0	0	0	0
40	0	0	0	0
60	0	0	0	0
80	0	0	0	0
100	3.46407e-114	4.04495e-112	3.86317e-146	5.3482e-148
120	6.02792e-027	9.89259e-023	1.83529e-027	4.59912e-029
140	4.23648e-006	1.70151e-005	5.28232e-006	6.52588e-006
160	1	1	1	1

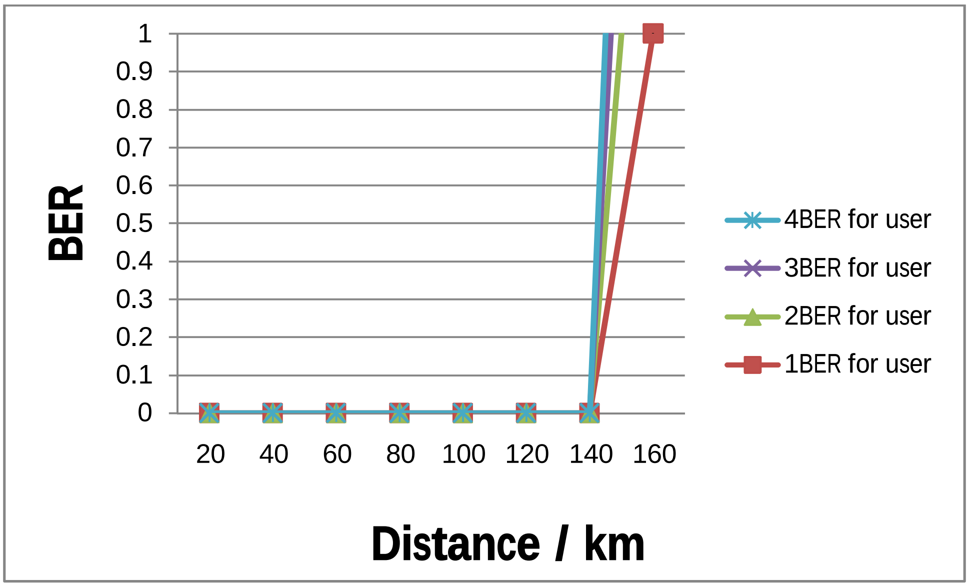

Figure 4.4: Relation between BER and Distance for 4 users

There is no BER up to 80 km, from 100 – 160 km increase to reach 1.

4.6 The Result of Quality Factor in Scenario Three

Table (4.5) Result of WDM for 6 channel relation between Q factor and Distance

Distance /km	Q factor for user1	Q factor for user2	Q factor for user3	Q factor for user4	Q factor for user5	Q factor for user6
20	165.166	175.54	164.058	156.076	181.781	152.94
40	110.717	130.58	142.49	114.585	119.85	127.993
60	83.4209	91.7	97.1957	77.6146	88.4007	86.5472
80	42.7548	49.2098	53.234	47.5587	42.8463	48.3612
100	21.2331	22.1932	24.8616	23.0838	24.4855	22.0181
120	9.72709	9.8156	10.58	10.0199	9.83103	9.47037
140	4.01456	4.03492	4.37121	4.60415	3.86225	4.05742
160	0	0	0	0	0	0

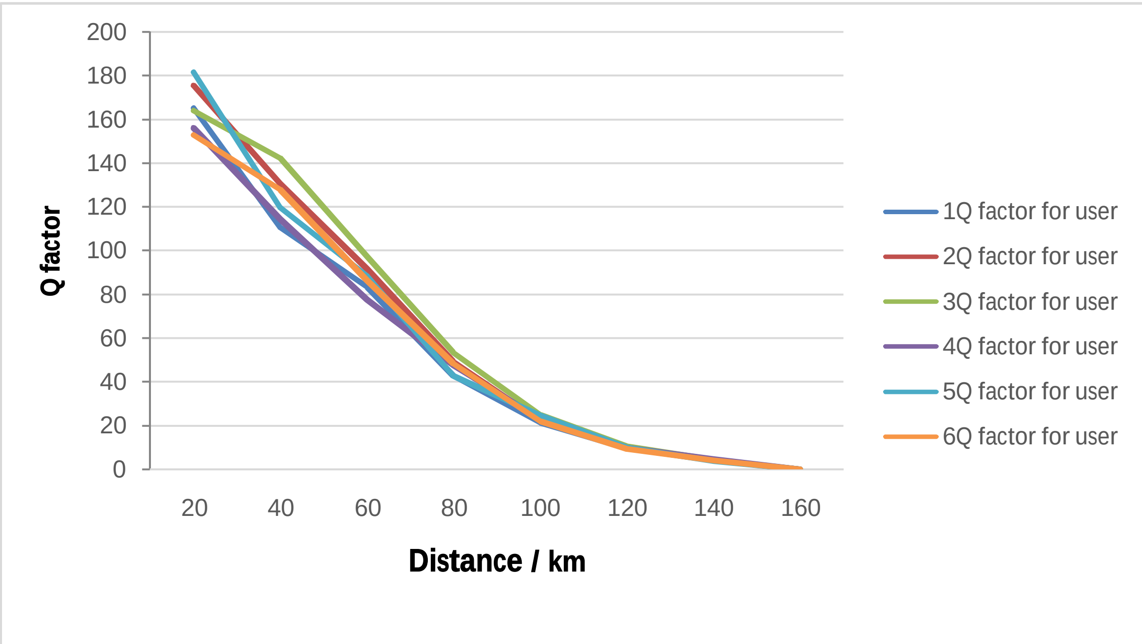

Figure 4.5: Relation between Q factor and Distance for 6 users

4.7 The Result of Bit Error Rate in Scenario Three

Table (4.6) Result of WDM for 6 channel relation between BER and Distance

Distance/km	BER user1	BER user2	BER user3	BER user4	BER user5	BER user6
20	0	0	0	0	0	0
40	0	0	0	0	0	0
60	0	0	0	0	0	0
80	0	0	0	0	0	0
100	2.35034e -100	1.99273e -109	9.69249e -137	3.36142e -118	1.05333e -132	9.63449e -108
120	1.15198e -022	4.78116e -023	1.84321e -026	5.97977e -024	4.12433e -023	1.37962e -021
140	2.97106e -005	2.72172e -005	6.1584e-006	2.02905e -006	5.53959e -005	2.48066e -005
160	1	1	1	1	1	1

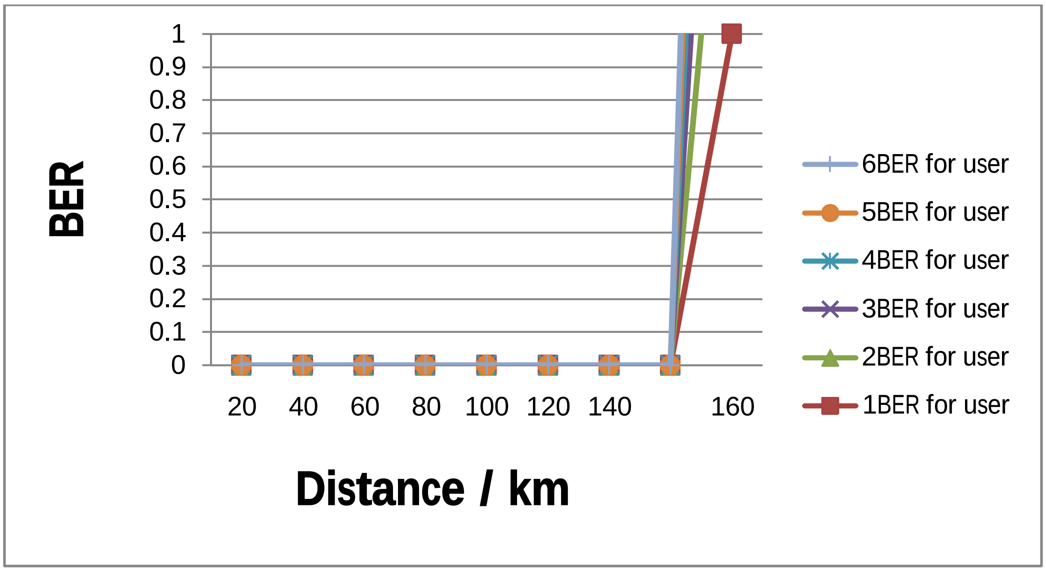

Figure 4.6: Relation between BER and Distance for 6 users

BER = 0 from (20-80 km), at 100 km BER = 2.35034e-100 for user 1, and increase gradually to 1 at 160 km.

4.8 The Result of Quality Factor in Scenario Four without EDFA

Table (4.7) Result of WDM for 8 channels without EDFA relation between Q factor and Distance

Distance/ km	Q factor for 1	Q factor for 2	Q factor for 3	Q factor for 4	Q factor for 5	Q factor for6	Q factor for 7	Q factor for 8
20	50.892	51.2857	53.0783	50.7631	52.0353	54.7696	51.3699	52.1486
40	48.4836	45.4471	52.0211	50.2849	48.6388	48.5394	45.4491	49.6229
60	42.4355	39.9672	40.1393	40.2293	44.1013	44.0155	41.8955	42.7895
80	29.6312	28.5932	29.7023	31.4791	29.1911	31.6018	30.2421	33.2996
100	15.5099	15.3349	14.6139	18.8901	17.3146	19.1081	14.5438	15.453
120	6.92719	7.10592	7.55075	8.158	7.89217	8.03396	6.8708	7.56332
140	2.70628	3.07895	2.96742	3.05627	3.36314	3.1891	3.36219	3.32702
160	0	0	0	0	0	0	0	0

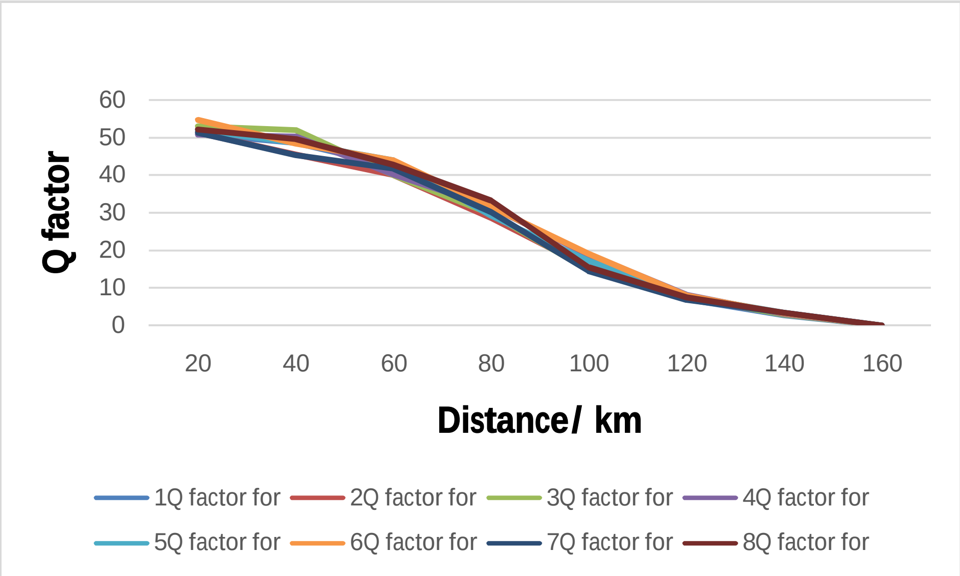

Figure 4.7: Relation between Q factor and Distance for 8 users without EDFA

4.9 The Result of Bit Error Rate in Scenario Four without EDFA

Table (4.8) Result of WDM for 8 channels without EDFA relation between BER and Distance

Distance/ km	BER user1	BER user2	BER user3	BER user4	BER user5	BER user6	BER user7	BER user8
20	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
80	2.7324 9e-193	3.7005 7e-180	3.2442 9e-194	7.8812 9e-218	1.1606 3e-187	1.6078 5e-219	2.99425 e-201	1.81493 e-243
100	1.4295 1e-054	2.1295e -053	1.1378e -048	6.7556 5e-080	1.7881 4e-067	1.0645 6e-081	3.06439 e-048	3.51668 e-054
120	2.1413 7e-012	5.8845 9e-013	2.1393 9e-014	1.6980 5e-016	1.4654 8e-015	4.6807 4e-016	3.18796 e-012	1.9486e- 014
140	0.0034 0132	0.0010 3625	0.0015 0141	0.0011 1961	0.0003 85209	0.0007 1313	0.00038 5565	0.00043 2409
160	1	1	1	1	1	1	1	1

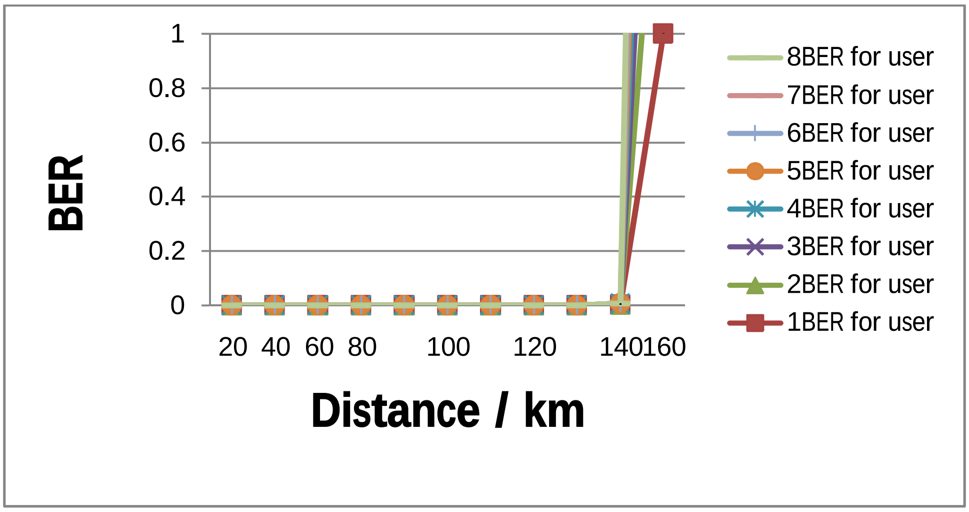

Figure 4.8: Relation between BER and Distance for 8users without EDFA

BER=0 (20, 40, 60 km) increase up to 1

4.10 The Result of Quality Factor in Scenarios Four with EDFA

Table (4.9) Result of WDM for 8 channels with EDFA relation between Q factor and distance

Distance/km	Q factor user1	Q factor user2	Q factor user3	Q factor user4	Q factor user5	Q factor user6	Q factor user7	Q factor user8
20	51.1696	51.0027	52.8069	52.8069	51.8127	53.8773	51.2113	54.0691
40	50.8953	47.689	53.3178	51.6494	49.959	52.6879	49.4859	53.7021
60	49.3831	49.0939	51.1464	50.4134	46.8296	52.733	48.1876	50.005
80	46.0623	42.5568	48.475	51.6752	47.3293	47.1892	43.6947	46.2701
100	41.1443	36.7028	41.7519	37.1256	40.1255	40.1514	36.9645	40.7375
120	34.3921	28.4793	36.3796	32.3094	32.7953	34.3932	31.8955	30.5221
140	25.4766	26.9666	24.8443	19.6483	24.965	25.5221	25.409	22.2105
160	16.4483	13.5654	13.8341	16.0145	16.9323	19.4598	15.3039	14.4805
180	11.5394	12.376	10.5239	9.77372	10.1318	11.723	10.2985	11.2417
200	7.22011	6.76816	6.15765	6.15763	5.79414	6.48023	6.40232	5.65139
220	4.66245	4.60902	4.23406	3.57432	4.08826	4.76385	3.59566	4.15892
240	2.75384	0	2.17609	2.32724	2.16022	2.29701	2.31218	2.11996
260	0	0	0	0	0	0	0	0

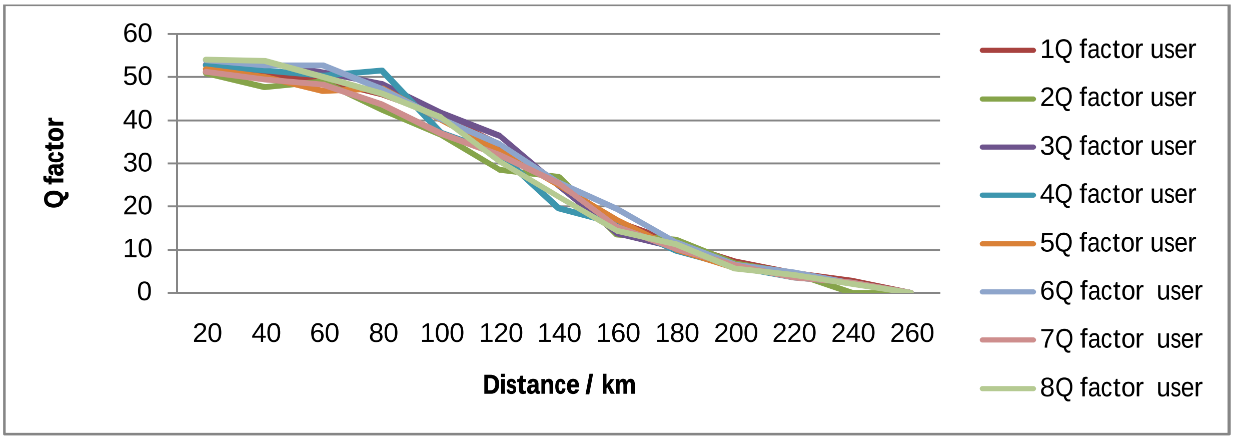

Figure 4.9: Relation between Q factor and Distance for 8 users with EDFA

The Erbium doped fiber amplifier (EDFA) enhanced the quality factor and increased the distance for transmitting data.

4.11 The Result of Bit Error Rate inScenario fourusing EDFA

Table (4.10) Result of WDM for 8 channels with EDFA relation between BER and Distance

Distance /km	BER user1	BER user2	BER user3	BER user4	BER user 5	BER user 6	BER user7	BER user8
20	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
100	0	2.49555 e-295	0	4.26141 e-302	0	0	1.65786 e-299	0
120	1.3018 6e-259	8.0243e-179	3.70342 e-290	2.09989 e-229	2.67961 e-236	1.24231 e-259	1.25876 e-223	4.97716 e-205
140	1.3803 4e-143	1.47902 e-160	1.13756 e-136	2.26e-086	5.88078 e-138	4.3597e-144	8.09668 e-143	1.0363e -109
160	3.2723 5e-061	2.22169 e-042	5.65597 e-044	3.85233 e-058	9.71938 e-065	9.30268 e-085	2.86686 e-053	5.7611e -048
180	3.0800 3e-031	1.33862 e-035	2.42791 e-026	5.32997 e-023	1.36692 e-024	3.55455 e-032	2.57016 e-025	8.92687 e-030
200	1.8448 1e-013	4.91548 e-012	2.61592 e-010	2.79403 e-010	2.38262 e-009	3.19299 e-011	6.00555 e-011	5.44903 e-009
220	1.1993 2e-006	1.5519e-006	9.31893 e-006	0.00013 68	1.78679 e-005	6.92138 e-007	0.00013 5451	1.19564 e-005
240	0.0024 6504	1	0.01195 62	0.00773 848	0.01146 96	0.00900 068	0.00830 277	0.01306 35
260	1	1	1	1	1	1	1	1

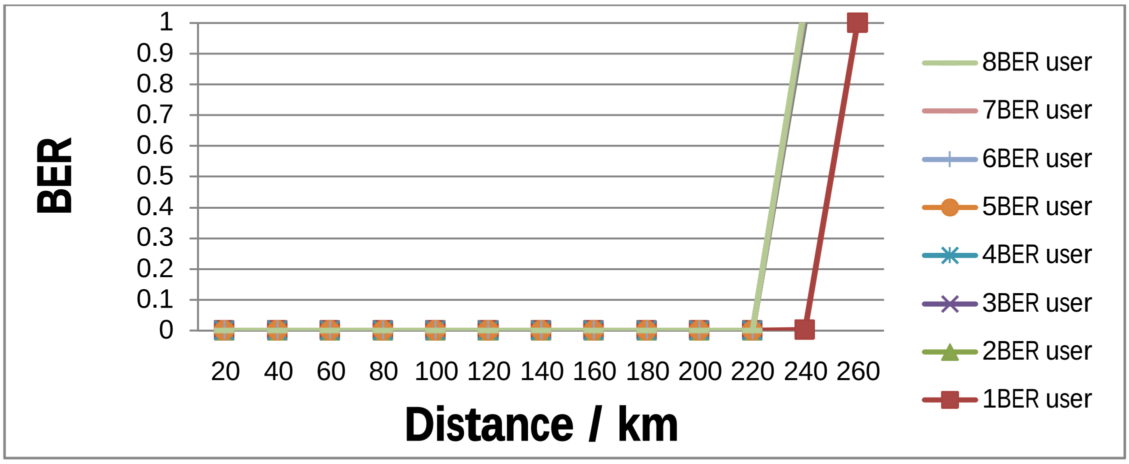

Figure 4.10: Relation between BER and Distance for 8users with EDFA

4.12 Comparisons between First users in all Scenarios for Q Factor

Table (4.11) Comparison between 2, 4, 6 and 8 channels of WDM

Distance	2-channel 2.5 GBit/s	4-channel 2.5 GBit/s	6-channel 2.5 GBit/s	8-channel 4.5 GBit/s
	Q factor User1	Q factor User1	Q factor User1	Q factor User1
20	49.9618	176.714	165.166	50.892
40	49.9618	139.652	110.717	48.4836
60	49.9618	86.4017	83.4209	42.4355
80	29.9837	47.7038	42.7548	29.6312
100	15.3926	22.6806	21.2331	15.5099
120	7.36655	10.6835	9.72709	6.92719
140	3.00641	4.44822	4.01456	2.70628
160	0	0	0	0

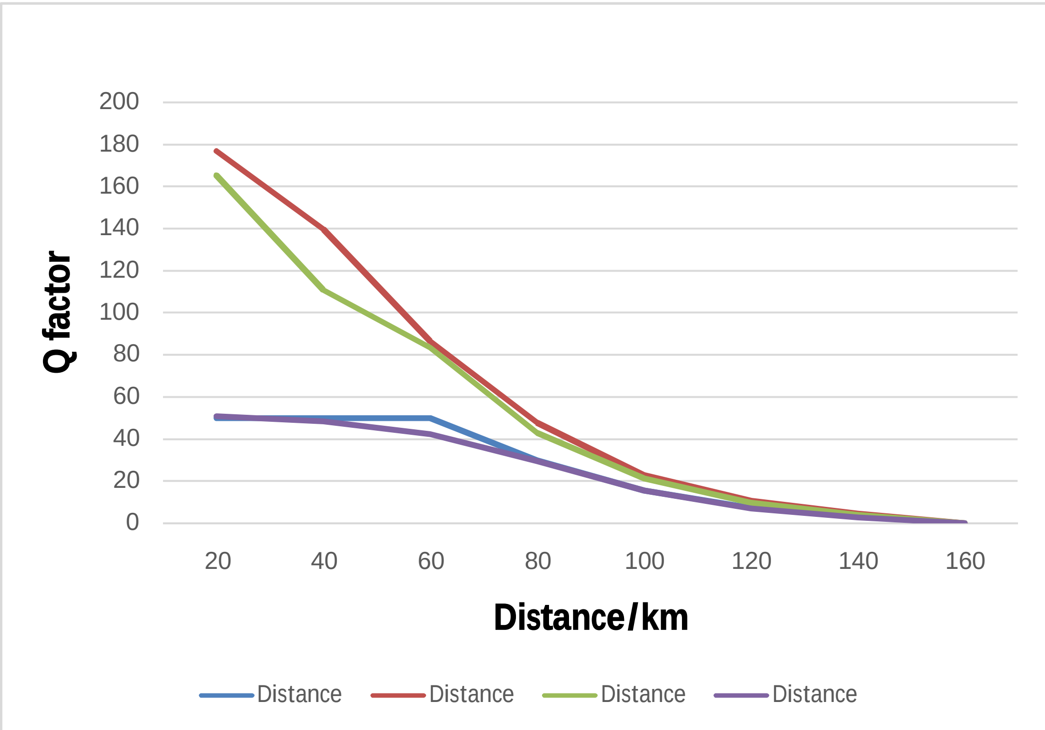

Figure 4.11: Comparison between 2, 4, 6 and 8 channels for user 1

From graphs and table observed the high value for quality factor in scenario4 and decreasing with the increase in fiber length.

4.13 Comparisons between WDM with EDFA and without EDFA in Scenario four For Q Factor and Bit Error Rate

Table (4.12) Comparison between WDM with EDFA and without EDFA

Distance	WDM Configuration without using EDFA		WDM Configuration using EDFA		Difference Between using EDFAand without using EDFA
	Q Factor for user1	BER for user1	Q Factor for user1	BER for user1	
20	50.892	0	51.1696	0	0.2776
40	48.4836	0	50.8953	0	2.4117
60	42.4355	0	49.3831	0	6.9476
80	29.6312	2.73249e-193	46.0623	0	16.4311
100	15.5099	1.42951e-054	41.1443	0	25.6344
120	6.92719	2.14137e-012	34.3921	1.30186e-259	27.46491
140	2.70628	0.00340132	25.4766	1.38034e-143	22.77032
160	0	1	16.4483	3.27235e-061	16.4483

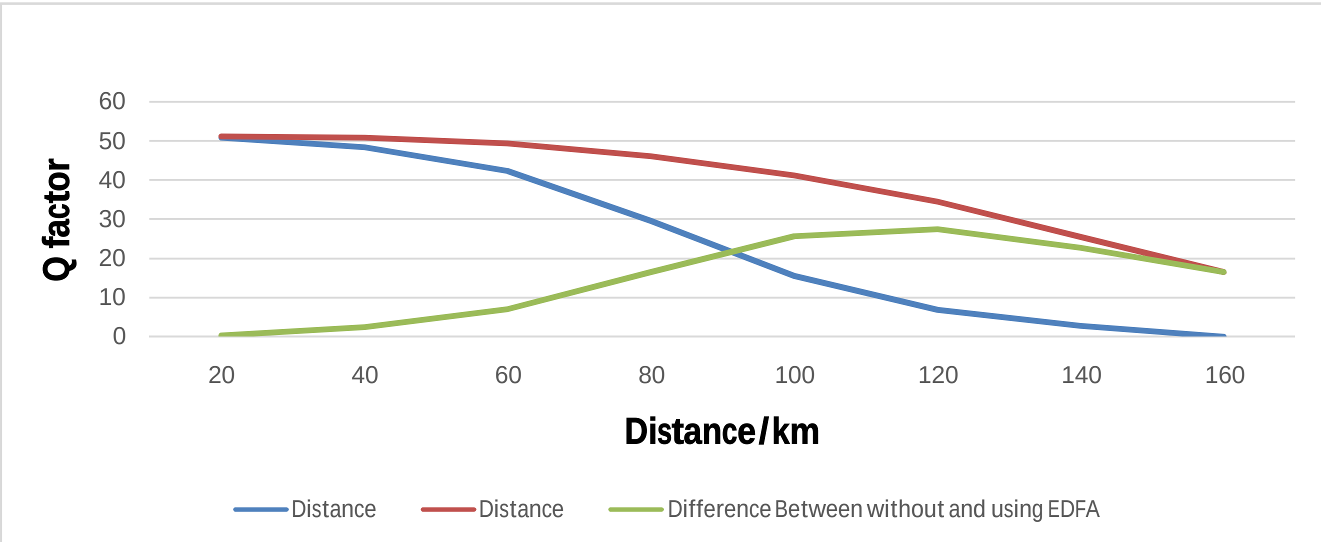

Figure 4.12: Comparison Q factor between WDM with EDFA and without EDFA for user 1

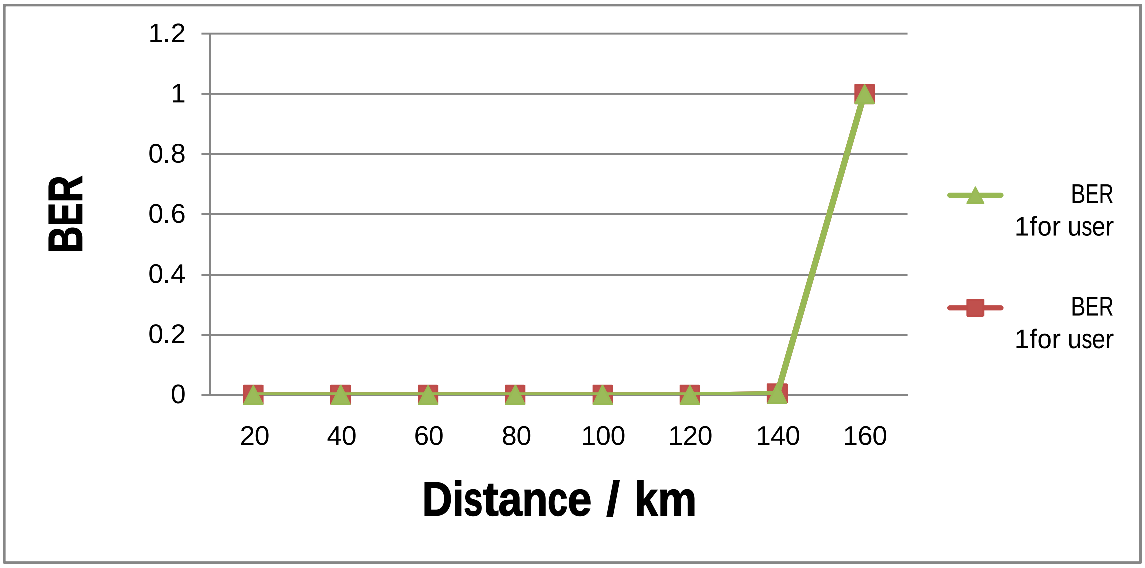

Figure 4.13: Comparison BER between WDM with EDFA and without EDFA for user 1

The simulation and analysis result using the Optisystem 7.0,and observed the quality factor increased extrusive with increased number of user and decrease with distanceby attenuation, BER increased extrusive with increased distance because the signal was loss by dispersion (inter symbol interference), Quality factor is better when used Eridium Doped Fiber Amplifierand data transmitted to long distance, BER increase as Q-Factor decrease.

CHAPTER FIVE

Conclusion and Recommendation

CHAPTER FIVE

Conclusion and Recommendation

5.1 Conclusion

This study design four scenario of Wavelength Division Multiplexing WDM-PON used unidirectional to send data from OLT to ONU, The study compared the performance of four scenario and analysis the performance depends on the values of bit error rate (BER) and quality factor (Q-factor) of the network. Using different numbers of users, different lengths of fiber and used Erbium doped fiber amplifier (EDFA) to enhance the quality factor and minimized BER, a comparative studied using Opti-System 7.0 program. The conclusion of this studied the quality factor decreased when the distance increased and BER increased when the distance increased

5.2 Recommendation

- It’s very necessary to increase the number of channel inside the optical fiber.
- Increase the amount the data rate which we need to transmit it.
- Add other parameters such as SNR, through put and cross talk.
- Study the next generation of PON.

References

[1] Anita, S., Anu, S. and Parveen, K, "Simulative Analysis of Bidirectional WDM/TDM-PON Using NRZ and RZ Downstream Signals and Narrowband AWG".High Performance Architecture and Grid Computing, pp.588-59,2011 .

[2] Kaur, A., Singh, M.L. and Sheetal, A, "Performance Analysis of 10G/2. 5G Asymmetric XGPON Transmission using RZ and NRZ Data Formats".International Journal of Computer Applications,2013.

[3] Sharma, N. and Gupta, A., "Investigation of bidirectional ftth passive optical network for large number of users at 10 Gbps"In Next Generation Computing Technologies(NGCT), 2015 1st International Conference onIEEE7, pp. 356-360,September2015.

[4] Xu, Z., Wen, Y.J., Zhong, W.D., Attygalle, M., Cheng, X., Wang, Y., Cheng, T.H. and Lu, C., "WDM-PON architectures with a single shared interferometric filter for carrier-reuse upstream transmission". Journal of lightwave technology, 25 (12), pp.3669-3677, 2007.

[5]Winzer, P.J., "Optical Networking Beyond WDM," IEEE Photonics Journal, Vol. 4, No. 2, pp. 647-651, April 2012.

[6] Han, K.H., Son, E.S., Choi, H.Y., Lim, K.W. and Chung, Y.C., "Bidirectional WDM PON using light-emitting diodes spectrum-sliced with cyclic arrayed-waveguide grating". IEEE Photonics Technology Letters, 16(10), pp.2380-2382, 2004.

[7] Hasegawa, J. and Nara, K., "Ultra low loss a thermal AWG module with a large number of channels". Furukawa Rev,26, pp.1-5 ,2004.

[8] Sifta, R., Munster, P., Krajsa, O. and Filka, M., "Simulation of bidirectional traffic in WDM-PON networks".Przeglad Elektrotechniczny, 90(1), pp.95-100, 2014.

[9] Khan, A.M., Jie, Z., Khan, Y., Idrees, M., Zhao, Y., Niazi, S., Husein, A., Munir, A., Ahmed, I. and Liu, J., "A Simple and Cost-effective Design for Simultaneous Transmission of Point-to-point and Broadcast Services in WDM-PON".International Journal of Future Generation Communication and Networking, 6(3), pp.41-56 ,2013.

[10] Munoz, P., Pator, D. and Capmany, J. "Modeling and design of arrayed waveguide gratings". Journal of Light wave Technology, 20: 66 , 2002.

[11] Elndash, A., Mohammed, N.A., Rashed, A.N.Z., Elndash, A. and Saad, F.A., "Estimated optimization parameters of arrayed waveguide grating (AWG) for C-band applications".International Journal of Physical Sciences, 4(4), pp.149-155, 2009.

[12] Surya, M. and Gokul, P.G.," ANALYSIS OF BIDIRECTIONAL LONG REACH WDM PON", 2011.

[13] Diouf, M.D., Kora, A.D., Ringar, O. and Aupetit-Berthelemot, C., "Evolution to 200G passive optical network". ArXiv *preprint* arXiv: 1304.0722,2013.

[14] Özge, G.Ü.R.E. and ÜNVERDİ, N.Ö., "Performance Analysis and Applications of Passive Optical Networks". IU-Journal of Electrical & Electronics Engineering, 14(2), pp.1843-1848 ,2014.

[15] Shi, L., Nag, A., Datta, D. and Mukherjee, B., "New concept in long-reach PON planning: BER-aware wavelength allocation. Optical Switching and Networking", 10(4), pp.475-480 ,2013.

[16] Chen, B. and Gan, C. "Novel architecture of WDM-PON based on single-fiber ring topology featuring protection and dynamic wavelength assignment". Optik - International Journal for Light and Electron Optics, vol. 124, no. 3, pp. 234– 237 ,(2013).

[17] Kaler, R.S., Sharma, A.K. and Kamal, T.S., "Comparison of pre-, post-and symmetrical-dispersion compensation schemes for 10 Gb/s NRZ links using standard and dispersion compensated fibers". *Optics Communications*, *209*(1), pp.107-123 ,2002.

[18] Elmagzoub, M.A., Mohammad, A.B., Shaddad, R.Q. and Al-Gailani, S.A., "Physical layer performance analysis of hybrid and stacked TDM–WDM 40G-PON for next generation PON". Optik-International Journal for Light and Electron Optics, 125(20), pp.6194-6197 ,2014.

[19] Husein, A.H.M. and El Nahal, F.I., "Optimal design of 32 channels spectrum slicing WDM for optical fiber access network system". Optik-International Journal for Light and Electron Optics, 125(18), pp.5141-5143 ,2014.

[20] Kaur, K.P., Randhawa, R. and Kaler, R.S., "Performance analysis of WDM-PON architecture using different receiver filters". Optik-International Journal for Light and Electron Optics, 125(17), pp.4742-4744 ,2014.