PERFORMANCE EVALUATION OF
GIGABIT PASSIVE OPTICAL NETWORK (GPON)
ACCESS TECHNOLOGY

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A REPORT SUBMITTED TO
University Of Khartoum
In partial fulfilment for the requirements for the degree of
B.Sc. (HONS) Electrical and Electronics Engineering
(COMMUNICATION ENGINEERING)
Faculty of Engineering
Department of Electrical and Electronics Engineering
OCTOBER 2017
DECLARATION OF ORGINALITY

I declare this report entitled “Performance Evaluation of Gigabit Passive Optical Network (GPON) Access Technology” is my own work except as cited in references. The report has been not accepted for any degree and it is not being submitted currently in candidature for any degree or other reward.

Signature: ____________________
Name: _______________________
Date: ________________________
Dedication

I dedicate all of my work To Allah, Almighty GOD for his endless helping and guiding through my all life.

To my mother

The most ambitious, strongest and successful person I ever known, who taught me to trust in Allah and totally depend on myself.

To my father

For earning an honest living for us and for his patient supporting and encouraging.

To my sweetie sisters Awatif, Ruba and Reem

To my all friends

I give special thanks and love to ambitious and supporter pair and best friend too Abrar Amer.

Also dedicate this work to anyone who has supported, inspired me throughout the process.
Acknowledgment

I would like to thank my supervisor Dr. Mohammed Ali Abbas for his endless guiding and all informative knowledge in the field of communication systems throughout this work.

I would like to take this chance to thank Eng. Abdelfattah Al-Khalifa for his hardworking and endless helping.

And I am grateful to everyone provided me with any information and knowledge.
Abstract

Optical fiber plays an important role in the revolution of communication technologies as one of the most powerful access technologies. Passive Optical Network (PON) is a point to multi point (P2MP) network where an optical line terminal (OLT) at the service provider distributes services to many customers per shared fiber line.

Gigabit passive optical network (GPON) is one of Time Division Multiplexing (TDM) PON that consists of Optical Line Terminal (OLT) at the central office, Optical Distribution Unit (ODU) which is passive optical splitter for network connectivity and Optical Network Unit (ONU) that located at the user’s premises. This technology lowers network costs, energy consumption, and lower maintenance requirements. It also provides more bandwidth.

This project evaluated GPON bidirectional transmission performance of 32 users by taking different values of transmitted power, fiber cable length and operating wavelengths with multiple scenarios for both upstream and downstream directions. System analyzed depending on values of Bit Error Rate (BER), Q factor and eye diagram from simulation results when using OptiSystem-Optiwave version7.0 software.

Observed that power scenario’s affected most at both upstream and downstream results compared to distance’s and wavelength’s scenarios.

The project objectives have been successfully met. Some limitations have been discovered in the project and were exposed, and also future suggested work for the project is stated.
المستخلص

تلعب الالياف الضوئية دورا مهما في ثورة تقنية الاتصالات كواحدة من أقوى تقنيات إمكانيات الوصول. الشبكة البصرية الخاملة هي نقطة البداية للخدمات التي تشكل النقاط النهاية للخط البصري في مقدم خدمات أنظمة الاتصالات. الشبكة البصرية الخاملة بمعدلات الجيجابت واحدة من أنواع خلط تقسيم زمن الشبكة البصرية الخاملة، حيث أن نقطة النهاية للخط البصري موجودة في المقسم المركزي، نقطة التوزيع بالشبكة الضوئية وهي موزع بصري خامل لربط الشبكة. هذه التقنية تقلل تكلفة الشبكة واستهلاك الطاقة وتقلل متطلبات الصيانة. توفر أيضا سعات عالية.

هذا المشروع يقيم أداء الاتصالات الثنائية للشبكة البصرية الخاملة بمعدلات الجيجابت لعدد 32 مستخدم باخذ قيم مختلفة للقدرة المرسلة وأطوال مختلفة للكابل البصري. السلبيات الموجبة تمثل نقطة نهاية الخط البصري عند نقل البيانات من نقطة النهاية للشبكة البصرية. حلل النظام اعتمادا على قيم معدل الخطأ وعامل الجودة ومخطط العين من نتائج المحاكاة باستخدام برنامج النظام البصري.- الموجة البصرية النسخة ٧.

لوجد أن سيناريو القدرة هو الأكثر تأثيرا على قيم نتائج قدرة النهاية للخط البصري في الاتجاهين مقارنة بسيناريوهات المسافات والاطراف الموجية.

الجودة تم تحقيق أهداف المشروع بنجاح. تم اكتشاف بعض المحدوديات والمشاكل في المشروع، كما تم اقتراح بعض العمل المستقبلي الذي يمكن اكماله في المشروع.
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<tbody>
<tr>
<td>ADSL</td>
<td>Asymmetric Digital Subscriber Line</td>
</tr>
<tr>
<td>AES</td>
<td>Advanced Encryption Standard</td>
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<td>Alloc-ID</td>
<td>Allocation Identification</td>
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<td>AON</td>
<td>Active Optical Network</td>
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<td>APD</td>
<td>Avalanche Photodiode</td>
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<td>APON</td>
<td>Asynchronous Transfer Mode Passive Optical Network</td>
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<td>BER</td>
<td>Bit Error Rate</td>
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<td>BDRu</td>
<td>Dynamic Bandwidth Report upstream</td>
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<td>BPON</td>
<td>Broadband PON</td>
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<tr>
<td>BW</td>
<td>Bandwidth</td>
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<td>CO</td>
<td>Central Office</td>
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<tr>
<td>CW</td>
<td>Continuous Wave</td>
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<tr>
<td>DBA</td>
<td>Dynamic Bandwidth Allocation</td>
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<td>DSL</td>
<td>Digital Subscriber Line</td>
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<td>EPON</td>
<td>Ethernet Passive Optical Network</td>
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<tr>
<td>FEC</td>
<td>Forward Error Correction</td>
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<td>FSAN</td>
<td>Full Service Access Network</td>
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<tr>
<td>FTTB</td>
<td>Fiber-to-the Businesses</td>
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<tr>
<td>FTTC</td>
<td>Fiber-to-the Curb</td>
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<tr>
<td>FTTH</td>
<td>Fiber-to-the Home</td>
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<td>FTTP</td>
<td>Fiber-to-the Premise</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>GPON</td>
<td>Gigabit Passive Optical Network</td>
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<td>GEM</td>
<td>GPON Encapsulating Method</td>
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<td>GTC</td>
<td>GPON Transmission Convergence</td>
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<td>HDSL</td>
<td>High bit rate Digital Subscriber Line</td>
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<td>IDSL</td>
<td>Integrated Services Digital Network Digital Subscriber Line</td>
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<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<td>ISI</td>
<td>Inter-Symbol Interference</td>
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<tr>
<td>ISP</td>
<td>Internet Service Provider</td>
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<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<td>LD</td>
<td>Laser Diode</td>
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<tr>
<td>MAC</td>
<td>Media Access Control</td>
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<td>MAN</td>
<td>Metropolitan Area Network</td>
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<tr>
<td>MPCP</td>
<td>Multipoint Control Protocol</td>
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<tr>
<td>MZM</td>
<td>Mack Zehnder Modulator</td>
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<tr>
<td>NGPON</td>
<td>Next-generation Passive Optical Network</td>
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<tr>
<td>NRZ</td>
<td>Non-Return to Zero</td>
</tr>
<tr>
<td>OAM&amp;P</td>
<td>Operation, Administration, Maintenance &amp; Provision</td>
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<tr>
<td>ODN</td>
<td>Optical Distribution Network</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
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<tr>
<td>OLT</td>
<td>Optical Line Terminal</td>
</tr>
<tr>
<td>ONT</td>
<td>Optical Network Termination</td>
</tr>
<tr>
<td>ONU</td>
<td>Optical Network Unit</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>PCBd</td>
<td>Physical Control Block Downstream</td>
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<td>PDU</td>
<td>Protocol Data Unit</td>
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<tr>
<td>PIN</td>
<td>Positive Intrinsic Negative</td>
</tr>
<tr>
<td>PLOAMu</td>
<td>Physical Layer Operations, Administration and Management upstream</td>
</tr>
<tr>
<td>PLOu</td>
<td>Physical Layer Overhead</td>
</tr>
<tr>
<td>PLSu</td>
<td>Power Leveling Sequence upstream</td>
</tr>
<tr>
<td>PRBS</td>
<td>Pseudo-Random Bit Sequence Generator</td>
</tr>
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<td>PON</td>
<td>Passive Optical Network</td>
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<tr>
<td>POTS</td>
<td>Plain Old Telephone Service</td>
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<td>P2MP</td>
<td>Point-to-Multipoint</td>
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<tr>
<td>P2P</td>
<td>Point-to-Point</td>
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<tr>
<td>Q Factor</td>
<td>Quality Factor</td>
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<tr>
<td>RADSL</td>
<td>Rate-Adaptive Digital Subscriber Line</td>
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<td>SDSL</td>
<td>Symmetric Digital Subscriber Line</td>
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<tr>
<td>SNR</td>
<td>Signal-to-Noise Ratios</td>
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<td>SMF</td>
<td>Single Mode Fiber</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
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<td>TDM PON</td>
<td>Time Division Multiplexing PON</td>
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<tr>
<td>WAN</td>
<td>Wide Area Network</td>
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<tr>
<td>WDM</td>
<td>Wavelength Division Multiplexing</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<tr>
<td>VDSL</td>
<td>Very high-bit-rate DSL</td>
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<tr>
<td>VoIP</td>
<td>Voice over Internet Protocol</td>
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</table>
10GEPON 10 Gigabit Ethernet PON
Chapter 1

Introduction

1.1 Overview
This chapter provides an overview of the project theory, problem definition, motivation for this work, suggested solutions, in addition to thesis layout.

1.2 Problem Statement

Optical fiber plays an important role in the revolution of communication world technologies as one of the most powerful access technology.

The passive optical network (PON) is a point to multi point (P2MP) network where an optical line terminal (OLT) at the service provider distributes services to as many as 16 to 128 customers per fiber line.

The aim of the project is to test the performance of Gigabit passive optical network (GPON) that uses optical wavelength division multiplexing (WDM) so a single fiber can be used for both downstream and upstream data.

1.3 Project Background and Motivation

This project aims to provide information about:
- GPON access technology
- Performance analysis of GPON

PON has different standards. One of them is GPON that provides higher resources usage with lower cost, lower maintenance requirements and more bandwidth delivered more efficiently.

The Performance of GPON access technology is specified by its Quality factor (Q factor), bit error rate (BER) and other parameters with eye diagrams representation.
Project motivation elements are as follows:

- Understanding fiber optics as fixed line communication networks and different parameters affect this type of communication.
- Having deep understanding of GPON technology.
- Knowledge in different communication engineering tracks.
- Applying theoretical knowledge and concepts of Broadband communication systems.
- Enhancing soft skills such as presentation skills
- Promoting teamwork morality.

1.4 Objectives

- Describe PON technology and identify its elements.
- Design and simulate a GPON standard.
- Evaluate Performance of GPON for multiple users.

1.5 Thesis Layout

This thesis is organized into five chapters as follows:
Chapter 1 (Introduction): This chapter introduces the whole project work and thesis.
Chapter 2 (Literature Review): This chapter provides description and explanation for various technologies and platforms used in the project.
Chapter 3 (Methodology): This chapter provides the communication concepts, practices and theories used to perform the project work. Also provides simulation setup for this project uses OptiSystem-Optiwave version7.0 software.
Chapter 4 (Results and Discussion): This chapter provides all results obtained, discussing and validating them.
Chapter 5 (Conclusion and future work): This chapter provides the completion status of the project, outcomes, and limitations as well as suggested future work.
Chapter 2

Literature Review

2.1 Introduction
This chapter provides a general description of broadband access technologies and deeply describes fiber optic transmission media. It describes theories and concepts of Gigabit Passive Optical Network (GPON) standard as a time division multiplexing passive optical network (TDM PON) technology. It also defines the performance parameters of digital communication system.

2.2 Broadband Access Technologies

2.2.1 Digital Subscriber Line (DSL)
Digital subscriber line (also known as digital subscriber loop) is a family of access technologies that transmit digital data over telephone lines (copper pair) to provide broadband access services. While the band of the voice signal carried by telephony is from 300 to 3400 Hz, the copper pair connecting the users to the central office (CO) is capable of carrying frequencies well beyond 3.4 kHz which is the upper limit of the telephony system. However, the upper limit can extend to tens of megahertz depending on the length and the quality of the copper pair. Some types of DSL allow simultaneous use of the telephone and broadband access on the same copper pair. [1] DSL internet speed is affected by the distance from Internet Service provider (ISP) as the longer distance the slower the speed is.

There are different types of DSL:

- Asymmetric DSL (ADSL).
- Symmetric DSL (SDSL).
- ISDN DSL (IDSL).
- High-bit-rate DSL (HDSL).
- Very high-bit-rate DSL (VDSL).
- Rate-Adaptive DSL (RADSL).
Each one presents different downstream and upstream data rates.

Asymmetric DSL offers higher downlink speeds than upload speeds, while symmetric DSL offers equal download speeds and upload speeds.

### 2.2.2 Wireless Broadband Access

Wireless broadband access networks provide high speed access wireless connection by using radio link.

Wireless Local Area Networks (WLANs) provide wireless broadband access over short distances and are often used to extend the reach of a last-mile wire line or fixed wireless broadband connection within a home or a building. [2]

### 2.2.3 Optical Fiber

Optical fiber is widely used as a transmission channel for optical communication systems and supports high-bit-rate over long distance because data is transmitted through glass wires as light waves.

Optical communication light wave is usually described in one of three ways:

Firstly, the classical physics (ray theory) that the propagation of a ray of light in optical fiber follows Snell Law.

Secondly, think of light as an electromagnetic wave (electromagnetic theory).

Thirdly, the light consists of tiny particles- photons-(quantum theory).

Fiber optics communication systems consist of three elements as shown in figure (2.1)

![Figure (2.1) Optical Communication System](image-url)
2.2.3.1 Optical Transmitters

Optical transmitter converts the information carrying electrical signals to optical signals and launches the optical signals into an optical fiber. The most common light sources are Light Emitting Diodes (LEDs) and Laser Diodes (LDs).

LEDs emit light through spontaneous emission and are used extensively in fiber optic communication systems due to their small size, long lifetime and low cost. They are used in short distance and low bandwidth networks.

LDs emit light through amplification of radiation by simulated emission. Laser has a higher output power than LED and so they are capable of transmitting information over longer distances and provide high bandwidth communication. [3]

2.2.3.2 Fiber Link

Optical fiber is a dielectric waveguide that operates at optical frequencies and transmits information in the light form. It provides a data connection between the transmitter and receiver. As shown in figure (2.2) optical fiber has a central core in which the light is guided, embedded in an outer cladding of slightly lower refractive index. Core and cladding are protected by buffer and outer jacket. [3]

Figure (2.2) Optical Fiber Core with Surrounding Cladding and Protective Jacket
Optical fiber is classified into two categories based on number of modes (single mode, multimode) or on the refractive index (step, graded).

A mode in an optical fiber corresponds to one of the possible multiple ways in which a wave may propagates through the fiber. More formally, a mode corresponds to a solution of the wave equation that is derived from Maxwell's equations and subject to boundary conditions imposed by the optical fiber waveguide. [3]

Single mode fiber (SMF) with a relatively narrow diameter, through which only one mode will propagate typically 1310 or 1550nm, carries higher bandwidth than multimode fiber. However, it requires a light source with a narrow spectral width. Also SMF has a narrow core (eight microns) and the index of refraction between the core and the cladding changes less than it does for multimode fibers.

A fiber is called multimode if more than one mode propagates through it. In general, a larger core diameter or high operating frequency allows a greater number of modes to propagate. [3]

Attenuation is the loss of optical power of a signal as it travels down a fiber. Attenuation depends on the wavelength of the light propagating within it and is measured in decibels per length (dB/m, dB/km). Attenuation characteristics can be classified into intrinsic and extrinsic. Intrinsic attenuation occurs due to substances inherently present in the fiber, whereas extrinsic attenuation occurs due to external influences such as bending or connection loss. [3]

### 2.2.3.3 Optical Receivers

An optical detector which converts the optical signals back to electrical signals so that the information is recovered and delivered to the destination found here. An ideal optical receiver will have high sensitivity, large bandwidth and low temperature sensitivity, low power consumption and polarization independence.

The most common optical receivers found in fiber optic communication systems are positive intrinsic-negative (PIN) photodiodes and avalanche photodiode (APD) receivers. Both are highly sensitive semiconductor devices that convert light pulses into electrical signals. [3]

PIN photodiode consists of a thick intrinsic depletion region sandwiched between positive and negative doped regions. PINs are the most commonly employed receivers in fiber optic communication systems due to their ease in fabrication, high reliability, low noise, low voltage and relatively high bandwidth.
APD is a photodiode that internally amplifies the photocurrent by an avalanche process. It has a greater sensitivity by internally amplifying the photocurrent without introducing the noise associated with external electronic circuitry. It has higher gain and bandwidth than PIN but it requires a much greater voltage to be applied across the active region. This requirement for higher power reduces the capability of miniaturization of a receiver unit and limits the possibilities of integration in communication systems. [3]

2.3 Optical Access Network

Because of ultrahigh bandwidth and low attenuation, optical fibers have been widely deployed for Wide Area Networks (WAN) and Metropolitan Area Networks (MAN).

Low-cost photonic components and PON architecture have made fiber very attractive.

In the past few years, various PON architecture and technologies have been studied by the telecom industry and a few PON standards have been approved by International Telecommunication Union–Telecommunication (ITU-T) and Institute of Electrical and Electronics Engineers (IEEE). [1]

2.3.1 Point-to-Point Fiber

A point-to-point (P2P) is an Active Optical Network (AON) and referred to the network when a direct fiber connection exists between the CO and the Optical Network Termination (ONT) located at the subscriber’s home as shown in figure (2.3).

Fiber is dedicated to each user, so optical power experiences small loss, and the power budget allows the distance between the CO and user’s home to be as long as ten km. [4] There is no need for network addressing in P2P network, because every user is connected by a dedicated fiber to the CO.

![Figure (2.3) Point-to-Point Fiber](image-url)
2.3.2 Passive Optical Network (PON)

PON is a point to multipoint network (P2MP) as shown in figure (2.4).

PON uses a passive optical splitter where there is no need for power at all.
In the downstream direction, the splitter divides the light sending from the CO and then broadcasts it to all Optical Network Units (ONUs).
In the upstream direction, the splitter combines the light coming from ONU, and transmits it over the fiber connected to the OLT.
Since there are no optical repeaters or other active devices in the network, the network is referred to as passive optical network. [4]

2.4 PON Architecture

PON was created by the Full Service Access Network (FSAN) working group which is an affiliation of network operators and telecom vendors.
PON convert and encapsulate multiple services such as Plain Old Telephone Service (POTS), Voice over Internet Protocol (VoIP), data and video in a single packet type for transmission over the PON fiber.
From figure (2.5) PON consists of three main parts [5]:
• Optical Line Terminal (OLT):
OLT is located at the service provider’s CO. It provides the interface between PON and the backbone network and it is responsible for the enforcement of any media access control (MAC) protocol for upstream bandwidth arbitration. [4]
• Optical Network Unit (ONU):

Figure (2.4) Point to Multipoint Network
The ONU is located near end users. It provides the service interface to end users. It also cooperates with the OLT in order to control and monitor all PON transmission and to enforce the MAC protocol for upstream bandwidth arbitration. [4]

- **Optical Distribution Network (ODN):**

  The ODN in PON connects the OLT at the CO and ONUs near user. It consists of the distribution fibers and all the passive optical distribution elements, mainly optical splitters and/or wavelength division multiplexing selective elements (WDM filters), that are located in sockets or cabinets. [4]

  The splitting ratio in most cases is between 1:8 and 1:128 and can be performed in lumped or cascaded elements.

![Figure (2.5) PON Architecture](image)

PON doesn’t require electrical power in the outside plant to power the distribution elements, thereby lowering operational costs and complexity. Moreover, PON highly reduces the number of required optical ports in the CO compared to P2P solutions. [5]

There are three main types of PONs depending on the data multiplexing scheme [4]:

- **Time Division Multiplexing (TDM) PON,** where traffic from/to multiple ONUs are TDM multiplexed onto the upstream/downstream wavelength.

- **Wavelength Division Multiplexing (WDM) PON.**

- **Orthogonal Frequency Division Multiplexing (OFDM) PON.**
2.4.1 TDM PON

Time division multiplexing passive optical network system include ATM (Asynchronous Transfer Mode) PON (APON), Broadband PON (BPON), Ethernet PON (EPON), Gigabit PON (GPON), 10 Gigabit Ethernet PON (10G EPON) and Next-generation PON (NG-PON) for provision different data rates. [4]

APON/BPON, GPON, and NG-PON architectures were standardized by the FSAN. These PON architectures are optimized for TDM traffic and rely on framing structures with a very strict timing and synchronization requirements.

EPON and 10G-EPON are standardized by the IEEE 802 study group. They focus on preserving the architectural model of Ethernet. No explicit framing structure exists in EPON and Ethernet frames are transmitted in bursts with a standard inter-frame spacing. [4]

In TDM PON each subscriber is allocated a time slot to transmit data towards the OLT.

Each standard has different data rates speed for upstream and downstream communication.

Table (2.1) Data Rates of Several PON Standards

<table>
<thead>
<tr>
<th>PON Type</th>
<th>Standard</th>
<th>Downstream Speeds</th>
<th>Upstream Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>APON/BPON</td>
<td>ITU-T G.983</td>
<td>622Mbps</td>
<td>155Mbps</td>
</tr>
<tr>
<td>GPON</td>
<td>ITU-T G.984</td>
<td>2.488 Gbps</td>
<td>1.244 Gbps</td>
</tr>
<tr>
<td>EPON</td>
<td>IEEE 802.3ah</td>
<td>1.25 Gbps</td>
<td>1.25 Gbps</td>
</tr>
<tr>
<td>10G-EPON</td>
<td>IEEE 802.3av</td>
<td>10.3125 Gbps</td>
<td>1.25 Gbps</td>
</tr>
</tbody>
</table>

2.5 Concept of FTTx

Fiber-to-the-x includes fiber-to-the-home (FTTH), fiber-to-the-curb or cabinet (FTTC), fiber-to-the-building or businesses (FTTB) and fiber-to-the-premise (FTTP).
Figure (2.6) Different Types of FTTx

- **FTTH**
  FTTH Network connects large number of end users to a central point using optical fiber. It is the most expensive one because there is just a single fiber to every home and from every CO as shown in figure (2.7).

![Figure (2.7) FTTH Architecture](image)

- **FTTC**
  In FTTC fiber is between the CO and local switch near the curb. Then there is a copper cable already connected to the home to carry DSL. FTTC bandwidth depends on DSL performance
where the bandwidth declines over long lengths from the node to the home. The cost of FTTC is lower than that for FTTH for first installation but it will not provide the high bandwidth of fiber because of the copper cable.

Figure (2.8) shows the architecture of FTTC

![Figure (2.8) FTTC Architecture](image)

- **FTTB**
  Fiber to the building or businesses (FTTB) connects the central point to the optical termination box that is often located in basement of the building by a dedicated fiber. Then the connections between subscribers and the building switch are by Digital Subscriber Line Access Multiplexer (DSLAM) that is installed in the building.

- **FTTP**
  Fiber to the premises is where the fiber network includes both homes and small businesses. It refers to both FTTH and FTTB.

### 2.6 GPON

GPON has enhanced capability comparing with APON and BPON. It is defined by ITU-T recommendation series G.984.1 through G.984.4 which define general characteristics. [6]

GPON can transport not only Ethernet, but ATM and TDM traffic by using GPON encapsulating method (GEM).

The main characteristics of the GPON standard are [7]:

- Physical reach of at least 20 km, with support for logical reach up to 60 km.
- GPON supports triple play service and several data rate options using the same protocol.
- Management of end-to-end services with good capabilities of OAM&P (Operation, Administration, Maintenance and Provision).
• Security of downstream traffic at protocol level, due to the multicast nature of the PON.

The operating wavelength range in GPON is 1480-1500 nm for the downstream direction and 1260-1360 nm for upstream direction.

GPON standard defines a lot of different line transmission rates for downstream and upstream directions as shown in Table (2.2). [6]

Table (2.2) Different Transmission Rates in GPON

<table>
<thead>
<tr>
<th>Transmission direction</th>
<th>Bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream</td>
<td>1.244 Gbps</td>
</tr>
<tr>
<td></td>
<td>2.488 Gbps</td>
</tr>
<tr>
<td>Upstream</td>
<td>155.52 Mbps</td>
</tr>
<tr>
<td></td>
<td>622.08 Mbps</td>
</tr>
<tr>
<td></td>
<td>1.244 Gbps</td>
</tr>
<tr>
<td></td>
<td>2.488 Gbps</td>
</tr>
</tbody>
</table>

The most often vendors offer only 1.2 Gbps in upstream and 2.4 Gbps in downstream direction. Figure (2.9) illustrates GPON Architecture.

Figure (2.9) GPON Architecture
To separate upstream / downstream signals of multiple users over a single fiber, GPON adopts two multiplexing mechanism:

- Downstream traffic is broadcasted by the OLT to all ONUs. Each of these processes the traffic which is assigned to it through an address contained in the header of the Protocol Data Unit (PDU).

- Upstream traffic uses Time Division Multiple Access (TDMA) mechanism under control of the OLT located at the CO which assigns time slots to each ONU for synchronized transmission of its data bursts.

The bandwidth assigned to each user may be static or dynamically variable, for support of voice, data and video applications.

Figure (2.10) and figure (2.11) illustrate broadcast and TDMA modes. [8]

Figure (2.10) Broadcast Mode

Figure (2.11) TDMA Mode
2.7 GPON Transmission

Media access control (MAC) layer control protocol is needed to coordinate the traffic transmission such as the collision between traffic from different ONUs can be avoided. [4]

GEM is a method which encapsulates data over GPON. It provides connection-oriented communication which is based on slightly modified version of the ITU-T Recommendation G.7041 Generic framing procedure. [6]

2.7.1 Downstream Transmission

In the downstream, the OLT multiplexes GEM frames onto the transmission medium by using the GEM Port ID as a key to identify the GEM frames that belong to different downstream logical connections.

Each ONU filters the downstream GEM frames based on their GEM Port IDs and processes only the GEM frames that belong to that ONU. [4]

2.7.1.1 Downstream GPON Frame Format

Downstream frames are layering maps data using GPON transmission convergence (GTC). Figure (2.12) shows the downstream GTC frame format.

GPON frames have different amount of bytes with different transmission rates; the higher the rate, the bigger the frame.

![Downstream GTC Frame Format](image)

Figure (2.12) Downstream GTC Frame Format
Downstream traffic is broadcasted from the OLT to all ONUs in TDM manner. Every ONU must take into account only frames intended for what is assured by encryption.

The downstream frame consists of a header section called the physical control block downstream (PCBd) the length range of which is the same for both speeds and depends on the number of allocation structures per frame and payload section which contains the actual data which has to be transferred. Payload section has the ATM partition and a GEM partition.

The downstream frame provides the common time reference for the PON and provides the common control signaling for the upstream.

If there is no data for sending, downstream frame will still be transmitted and used for time synchronization. [6]

GPON downstream frame structure is shown in figure (2.13), the frame is 125 micro second and 38880 bytes long.

![Downstream GPON Frame](image)

**Figure (2.13) Downstream GPON Frame**

### 2.7.2 Upstream Transmission

In the upstream direction, the traffic multiplexing functionality is distributed. The OLT grants upstream bandwidth allocations to the traffic-bearing entities within the subtending ONUs. The traffic-bearing entities of ONU are identified by their allocation IDs (Alloc-ID). The bandwidth allocations to different Alloc-ID are multiplexed in time as specified by the OLT in the bandwidth maps (BW Maps) transmitted downstream. Within each bandwidth allocation, the ONU uses the GEM Port-ID as a multiplexing key to identify GEM frames that belong to different upstream logical connections. [4]
2.7.2.1 Upstream GPON Frame Format

Media access control and resource allocation for upstream traffic are implemented in the GTC layer as specified in ITU-TG.984.3. Basically, downstream frames indicate permitted locations for upstream traffic in upstream GTC frames.

The media access control concept in the GTC system is illustrated in figure (2.14). [4]

Upstream GTC frame duration is also 125 micro second and 19440 Bytes long.

Figure (2.14) GTC Media Access Control

Upstream traffic uses TDMA under control of the OLT located at the CO which assigns variable time slots to each ONU for transmission of its data bursts.

The OLT sends pointers in the upstream BW Map field of the PCBd. These pointers indicate the time at which each ONU may begin and end its upstream transmission so only one ONU can access the medium at specified time. There is no contention in normal operation. The pointers are given in units of bytes allowing the OLT to control the medium at an effective static bandwidth granularity of 64 kbps. However, some implementations of the OLT may choose to set the values of the pointers at a larger granularity and to achieve fine bandwidth control via dynamic scheduling. [4]

The upstream frame consists of multiple transmission bursts. Each upstream burst contains at a minimum the Physical Layer Overhead (PLOu). Besides the payload, it may also contain the Physical Layer Operations, Administration and Management upstream (PLOAMu), Power
Leveling Sequence upstream (PLSu) and Dynamic Bandwidth Report upstream (DBRu) sections. [6]

A diagram of the upstream frame structure is shown in Figure (2.15). The frame length is the same as in the downstream for all rates. Each frame contains a number of transmissions from one or more ONU's. The BW Map dictates the arrangement of these transmissions. During each allocation period according to the OLT control, the ONU can send from one to four types of PON overheads and user data. [6]

![Upstream GPON Frame](image)

**Figure (2.15) Upstream GPON Frame**

### 2.8 Forward Error Correction

Forward Error Correction (FEC) is a mathematical signal-processing technique that encodes data so that errors can be detected and corrected.

With FEC, redundant information is transmitted along with the original information. The amount of redundant information is small so FEC doesn’t introduce a lot of overhead. FEC results in an increased link budget by approximately 3-4dB. Therefore, higher bit rate and longer distance from the OLT to the ONU can be supported, as well as higher number of splits per a single PON tree [5].
2.9 Multipoint Control Protocol (MPCP)

Multipoint Control Protocol (MPCP) has been developed by the IEEE 802.3ah task force which supports OLT for the time slot allocation. It provides timing reference to synchronize ONUs and allows the negotiation of access to the medium through the exchange of control messages. The MPCP specifies mechanism between an OLT and ONUs connected to a P2MP PON segment to allow efficient transmission of data in the upstream direction [9].

2.10 Security in GPON

Downstream data are broadcasted to all ONUs and every ONU has allocated time when data belongs to it. Because of that, some malicious user can reprogram its own ONU and capture all downstream data belonging to all ONUs connected to that OLT. In upstream direction GPON uses point-to-point connection so that all traffic is secured from eavesdropping. Therefore, each of confidential upstream information (such as security key) can be sent in clear text.

The GPON recommendation G.984.3 describes the use of information security mechanism to ensure that users are allowed to access only the data intended for them. The encryption algorithm to be used is the Advanced Encryption Standard (AES). It accepts 128, 192, and 256 byte keys which makes encryption extremely difficult to compromise. A key can be changed periodically without disturbing the information flow to enhance security. [6]

2.11 Protection in GPON

The protection architecture of GPON is considered to enhance the reliability of the access networks. However, protection is considered as an optional mechanism because its implementation depends on the realization of economical systems. There are two types of protection switching one of them is automatic switching which is triggered by fault detection such as loss of signal, loss of frame, signal degrade and so on. The other one is forced switching which is activated by administrative events such as fiber rerouting and fiber replacement. [6]


2.12 Performance Parameters in GPON Network

2.12.1 Error Rates

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 example, a BER of $10^{-6}$, meaning that, one bit was in error out of 1,000,000 bits transmitted. Too high BER may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data so the BER indicates how often data has to be retransmitted because of an error. [10]

BER can be applied to characterize the performance of communication system, for optical communication systems typically ranges from $10^{-9}$ to $10^{-12}$ depending on the service types. [11]

2.12.2 Eye Diagram

The Eye diagram shows the superposition of all mutually overlapping bits in the signal. The Eye opening indicates the differentiability of the logic one from the logic zero. The more the Eye is widely open, the greater the differentiability is, because of this it is better signal to noise ratio. There are other readable parameters from this diagram like jitter which is the delay in sending packet data that varies over time. It can also be said that it is a variation in delays. Also inter-symbol interference (ISI) can be read.

Figure (2.16) illustrates interpretation of the eye diagram. [12]
2.12.3 Q Factor

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. There are only two possible signal levels in binary digital communication systems and each of these signal levels may have a different average noise associated with it. This means that there are essentially two discrete signal-to-noise ratios one is electrical SNR and the other is optical SNR, which is associated with the two possible signal levels. In order to calculate the overall probability of bit error, we must account for both of the signal-to-noise ratios. [13]

Figure (2.17) illustrates relationship between Q factor and bit error rate. [11]
Figure (2.17) BER versus the Q Parameter
Chapter 3

Methodology

3.1 Introduction

This chapter gives a deep sight and describes the details of implementation of bidirectional transmission of GPON and demonstrate the steps used to simulate the work in order to show the behavior and performance of the network when the signal goes through all elements.

3.2 OptiSystem Software

Optical communication systems are increasing in complexity on an almost daily basis. Computer simulations have become a useful part of mathematical modeling of many natural systems; they play a role in the process of engineering new technology to gain insight into the operation of those systems.

OptiSystem is an innovative optical communication systems simulation package that designs, tests and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks.

OptiSystem is a stand-alone product that does not rely on other simulation frameworks. It is a physical layer simulator based on the realistic modeling of fiber-optic communication systems also possesses a powerful new simulation environment and a hierarchical definition of components and systems.

The extensive library of active and passive components includes realistic, wavelength-dependent parameters. Parameter sweeps allow investigating the effect of particular device specifications on system performance. [14]

To carry out project simulations, OptiSystem-Optiwave version7.0 used.
3.3 Network Setup and Design
This section briefly describes the simulation setup in OptiSystem where all necessary parameters based on the GPON standardized properties.

Figure (3.1) shows the schematic bidirectional transmission of GPON system.

One transmitter and one receiver used at the OLT then distributed to 32 ONUs via 1x32 bidirectional passive optical splitter. Optical circulator used to separate downstream and upstream signals and optical delay used to ensure the correct timing of circulation. Figure (3.2) and Figure (3.3) illustrate block diagrams of the transmitter and the receiver respectively.

To analyze the performance of the signal in both downstream and upstream directions the network constructed illustrated in figure (3.4)
Figure (3.2) Transmitter of Bidirectional GPON

Figure (3.3) Receiver of Bidirectional GPON

Figure (3.4) Simulation of GPON
At the transmitter, Pseudo Random Bit Sequence (PRBS) Generator generates sequence of numbers constructs the data signal then Non Return to Zero (NRZ) pulse generator creates a sequence of non-return to zero pulses coded by an input digital signal. Continuous wave (CW) laser generates a continuous wave optical signal; the laser is continuously pump and continuously emits light.

The output of NRZ pulse generator and CW laser goes to Mach-Zehnder Modulator (MZM) to convert the electrical signal to an optical signal.

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) analyzer used for data analysis.

The description of the components used illustrated in table (3.1)

Table (3.1) Component used in Simulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRBS Generator</td>
<td><img src="image1.png" alt="PRBS Generator" /></td>
<td>Generates PRBS according to different mode operation</td>
</tr>
<tr>
<td>NRZ Pulse Generator</td>
<td><img src="image2.png" alt="NRZ Pulse Generator" /></td>
<td>Generates NRZ coded signal</td>
</tr>
<tr>
<td>CW Laser</td>
<td><img src="image3.png" alt="CW Laser" /></td>
<td>Generates a continuous wave optical signal</td>
</tr>
<tr>
<td>M Z M</td>
<td><img src="image4.png" alt="MZM" /></td>
<td>Converts electrical signal to an optical signal</td>
</tr>
<tr>
<td>Component</td>
<td>Function</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Circulator Bidirectional</td>
<td>Separates upstream and downstream signals</td>
<td></td>
</tr>
<tr>
<td>Optical Null</td>
<td>Creates a zero optical signal</td>
<td></td>
</tr>
<tr>
<td>Optical Delay</td>
<td>Adds delay to make the bidirectional signals pass at the same time</td>
<td></td>
</tr>
<tr>
<td>Bidirectional Optical Fiber</td>
<td>Allows optical signals to travel in both directions at the same time</td>
<td></td>
</tr>
<tr>
<td>1xN Splitter Bidirectional</td>
<td>Splits the signal into required number of signal streams (N=32) to transmit it to ONUs</td>
<td></td>
</tr>
<tr>
<td>APD Photodetector</td>
<td>Convert an optical signal to an electrical signal</td>
<td></td>
</tr>
<tr>
<td>Low pass Bessel Filter</td>
<td>Filters the signal with a Bessel frequency transfer function</td>
<td></td>
</tr>
<tr>
<td>Dynamic Y-Select</td>
<td>Used in upstream due to TDMA mechanism</td>
<td></td>
</tr>
<tr>
<td>Buffer Selector</td>
<td>Selects the signal data associated with a specified iteration in a series of iterations</td>
<td></td>
</tr>
</tbody>
</table>
3R Regenerator
Regenerates the optical signal

BER Analyzer
Measures the performance of the system based on the signal before and after the propagation

Optical Power Meter
Measures the optical power in different ports

3.4 Downstream Link
In the downstream direction, the signal travelled from OLT transmitter and passed through bidirectional SMF then split via 1x32-bidirectional splitter and received to 32 ONUs receivers.

3.4.1 Transmitter Stage
As shown in Figure (3.2), the transmitter consists of PRBS that was set to 2.5Gbps, which is the downstream data rate of GPON then the data coded via NRZ.

The optical modulation consists of LD and MZM, works at operating wavelength of GPON to prepare the electrical signal for transporting through the bidirectional fiber. LD power was set to different values in 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.

MZM has three ports, the first port for electrical modulation type, the second is the CW laser input and the third one represents the output of the optical signal.

Extinction ratio of the MZM was set to 30 dB, which characterizes the ratio of two optical power level created by the optical source.

\[
\text{Extinction-Ratio}(ER) = \frac{P_0}{P_1}
\]  

(3.1)
Where $P_0$ is the optical power level generated when LD is on and $P_1$ is the optical power level generated when LD is off. [11]

### 3.4.2 Bidirectional Channel Stage

Bidirectional channel consists of circulator to separate downstream from upstream traffics and an optical delay with one unit to ensure correct timing of circulation.

Insertion losses of optical circulator characterize the loss of signal power resulting from the insertion of the optical fiber was set to zero dB.

\[
\text{Insertion Losses (IL)} = 10 \log \left( \frac{P_t}{P_r} \right) \text{ dB} \tag{3.2}
\]

Where $P_t$ is the transmitted power to the load before insertion and $P_r$ is the power received by the load after insertion.

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

\[
\text{Return Losses (RL)} = 10 \log \left( \frac{P_i}{P_r} \right) \text{ dB} \tag{3.3}
\]

Where $P_i$ is the incident power and $P_r$ is the reflected power.

The power measured after the circulator did not change.

The fiber cable has a reference wavelength of 1490 nm, dispersion value and dispersion slope value were set to 16.75 ps nm$^{-1}$km$^{-1}$ and 0.075 ps nm$^{-2}$ km$^{-1}$ respectively, which are the standard values. Attenuation loss set to 0.2 dB/km.

For example when optical fiber length is 10km and LD power is zero dBm, the output power measured by using the optical power meter after MZM is ($P = -3.218$dBm), the loss in power is due to the modulation.

After the bidirectional fiber the loss in power is (0.2 dB/km $\times$ 10 km = 2dB) and the power measured by the optical meter is (-3.218-2 = -5.218 dBm).
The power before splitter is \((-5.218 \text{ dBm} = 300.720 \times 10^{-6} \text{ W})\) and after splitter by calculations it becomes \((300.720 \times 10^{-6} / 32 = 9.3975 \times 10^{-6} = -20.269 \text{ dBm})\) which is the same value as measured by the optical power meter.

The signal goes through 1x32-bidirectional splitter with zero dB value for insertion losses and 65 dB for return losses.

### 3.4.3 Receiver Stage

As shown in figure (3.3), the receiver consists of an APD with responsivity set to 10 A/W. Responsivity \((R_d)\) measures the electrical output per optical input and can be expressed in terms of a fundamental quantity called the quantum efficiency \((n)\). [11]

\[
R_d = \frac{nq}{hv}
\]  \hspace{1cm} (3.4)

Dark current was set to 10 nA which is the leakage of current that flows when a bias voltage is applied.

The signal filtered by low pass Bessel filter that have a cutoff frequency of \(0.75 \times \text{bitrate}\) and there is a loss in power due to filtering.

3R regenerator connected after receiving and filtering the signal.

3R regenerator has three output ports, the first output port is the bit sequence, the second one is a reference signal and the last one is the output signal. These three signals connected directly to the BER Analyzer to analyze the performance.

### 3.5 Downstream Transmission Scenarios

#### 3.5.1 Variable Power with Fixed Wavelength and Fiber Length

First scenario tested the performance by taking different values of LD power of OLT from 0.5 to 2.5 dBm with 100 km length and 1490 nm wavelength in order to show how the performance of the system affected by increasing power.
3.5.2 Variable Fiber Length with Fixed Power and wavelength

In this scenario, LD power of OLT was set to zero dBm with random values of fiber length from 10 to 100km to show at which length the system has a good performance.

3.5.3 Variable Wavelength with Fixed power and Fiber Length

This scenario took into account different values of the operating wavelength used for downstream direction (1470-1530) nm at fixed power of CW laser of OLT (zero dBm) and 100 km of the fiber length for all wavelengths to test the performance.

3.6 Upstream Link

In upstream direction, the optical signal directed from 32 ONUs to OLT. The signal travelled from the transmitter at the ONU to the receiver in the OLT and passed through 1x32-bidirectional splitter that combined signals then passed through bidirectional fiber to receive by OLT receiver.

3.6.1 Transmitter Stage

As shown in figure (3.2), transmitter consists of PRBS that was set to 1.25Gbps, which is the upstream data rate then data coded via NRZ pulse generator.

The optical modulation consists of LD and MZM, works at range of GPON upstream operating wavelength to prepare the electrical signal to transport through the bidirectional fiber.

LD power in OLT was set to different values and the value of CW laser in ONUs is set to zero. Excitation ratio of the MZM is set to 30 dB.

In the case of upstream, it has more than one transmitter operating in harmony take into account the TDMA. Therefore, it will use two-cascaded Dynamic Select Y that they will allow to pass the signal only at a determined time instant and the rest will be zero. For each one of Dynamic Y select, the time interval or switching time defined to have the following values. For first Dynamic Y select:

\[
\text{Switching Time} = \text{TimeSlot} \times (1/\text{Bit rate}) \times \text{Sequence length} / 32
\]

For second Dynamic Y select:
Switching Time = TimeSlot × (1/Bit rate) × (Sequence length / 32) + Time window / 32 \ (3.6)

The number 32 refer to 32 ONU’s.

In the beginning, the parameter TimeSlot for every ONU has been defined and assigns value of zero to the first ONU, 1 for the second ONU and so on until assign 31 for ONU number 32.

The signals transmitted by the various ONU’s do not overlap in time. The idea explained on ONU1 and ONU32 by applying the following parameters in equations (3.5) and (3.6). Time window = 51.2ns, Global Bit rate = 2.5 Gbps and Sequence length=128 Bits.

Firstly, for ONU1, TimeSlot = zero, Switching time for first Dynamic Y select = zero ns and switching time for second Dynamic Y select = 1.6 ns. First Dynamic Y select will pass the input signal to the output from 0 ns to the end of time window, while second Dynamic Y select will allow passing the signal from switching time of first Dynamic Y select to the switching time of second Dynamic Y select. This means that the signal will pass to the output from zero ns to 1.6 ns and the rest will be zero.

Lastly, for ONU32, TimeSlot =31, Switching time for first Dynamic Y select = 49.6 ns and switching time for second Dynamic Y select = 51.2 ns. First Dynamic Y select will pass the input signal to the output from 49.6 ns to the end of time window, while second Dynamic Y select will allow passing the signal from switching time of first Dynamic Y select to the switching time of second Dynamic Y select. This means the signal will pass to the output from 49.6 ns to 51.2 ns and the rest will be zero. This proves that the signals transmitted by the various ONU’s don’t overlap in time.

3.6.2 Bidirectional Channel Stage

After the two Dynamic Y selects, signals combined by 1x32-bidirectional splitter with zero dB insertion losses value and 65 dB for return losses, then passed through bidirectional channel that consists of optical fiber, circulator and an optical delay.
3.6.3 Receiver Stage
Upstream receiver consists of an APD with responsivity of 10 A/W and dark current was set to 10 nA, the signal was filtered by low pass Bessel filter with cutoff frequency of 0.75×bitrate. After that, signal passed through buffer that is used for selection of the iteration. 3R regenerator used and connected directly to the BER Analyzer to analyze the performance.

3.7 Upstream Direction Scenarios

3.7.1 Variable Power with Fixed Wavelength and Fiber Length
This scenario designed to test the performance by taking different high values LD power of OLT (0 to 30) dBm and 1310nm at 100 km.

3.7.2 Variable Fiber Length with Fixed Power and Wavelength
In this scenario, LD powers in OLT was set to 15 dBm and of ONUs were set to zero dBm with wavelength of 1310 nm and different lengths of the fiber.

3.7.3 Variable Wavelength with Fixed Power and Fiber Length
This scenario took into account three different values of the wavelength from the operating range used for the upstream direction (1260, 1310 and 1360) nm at 100 km of the fiber to test the effect of variable wavelength in performance.

3.8 Performance Evaluation Parameters

3.8.1 BER

\[ BER = \frac{E}{N} \]  \hspace{1cm} (3.7)

Where E is the Errors and N is the Total Number of Bits transmitted.

BER also defined in terms of probability of error (POE) as:

\[ BER = \frac{1}{2} (1-\text{erf}) \sqrt{Eb/N0} \]  \hspace{1cm} (3.8)
Where erf is the error function, Eb is the energy in one bit and N0 is the noise power spectral density (noise power in a 1 Hz bandwidth). [15]

### 3.8.2 Q Factor

Q factor defined according to the following formula [11]:

$$Q = \frac{(I_1 - I_0)}{(\alpha_1 + \alpha_0)}$$  \hspace{1cm} (3.9)

Where $I_1$ is a logic level “1“, $I_0$ is a logic level “0“, $\alpha_1$ is a standard deviation of a logic level “1”, $\alpha_0$ is a standard deviation of a logic level “0”.
Chapter 4

Results and Discussion

4.1 Introduction
This chapter shows the implementation details for the simulation and obtains results.

Also discusses results and some problems or concepts had met during the implementation of the system.

4.2 Downstream Link Results

4.2.1 Variable Power with Fixed Wavelength and Fiber Length

Table (4.1) Results of Min BER and Max Q Factor at 1490 nm, 100 km for Varied Power Values

<table>
<thead>
<tr>
<th>Power</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$4.84464 \times 10^{-15}$</td>
<td>7.74314</td>
</tr>
<tr>
<td>0.5</td>
<td>$3.70731 \times 10^{-18}$</td>
<td>8.60816</td>
</tr>
<tr>
<td>1</td>
<td>$6.39055 \times 10^{-22}$</td>
<td>9.55135</td>
</tr>
<tr>
<td>1.5</td>
<td>$1.94371 \times 10^{-26}$</td>
<td>10.575</td>
</tr>
<tr>
<td>2</td>
<td>$6.13717 \times 10^{-32}$</td>
<td>11.7027</td>
</tr>
<tr>
<td>2.5</td>
<td>$7.4889 \times 10^{-39}$</td>
<td>12.984</td>
</tr>
</tbody>
</table>
Chapter 4

Results and Discussion

Figure (4.1) Max Q Factor at 0.5 dBm, 100 km and 1490 nm

Figure (4.2) Min BER at 0.5 dBm, 100 km and 1490 nm
This scenario illustrates power relationship with BER and Q factor. When power increased both of BER and Q factor had better values; less BER and more Q factor due to high SNR. Figures
represent system performance by eye diagrams. When BER values are increased there is less distortion, less ISI, higher SNR, better synchronization and better eye height.

### 4.2.2 Variable Fiber Length with Fixed Power and wavelength

Table (4.2) Results of Min BER and Max Q Factor at 0 dBm, 1490 nm for Varied Length Values

<table>
<thead>
<tr>
<th>Length</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>247.994</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>173.654</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>121.042</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>83.9781</td>
</tr>
<tr>
<td>61</td>
<td>1.99405 $\times 10^{-320}$</td>
<td>38.2505</td>
</tr>
<tr>
<td>80</td>
<td>7.90159 $\times 10^{-15}$</td>
<td>18.0111</td>
</tr>
<tr>
<td>100</td>
<td>4.84464 $\times 10^{-15}$</td>
<td>7.74314</td>
</tr>
</tbody>
</table>

Figure (4.5) Max Q factor at 0 dBm, 61 km and 1490 nm
Figure (4.6) Min BER at 0 dBm, 61 km and 1490 nm

Figure (4.7) Max Q Factor at 0 dBm, 100 km and 1490 nm
The table illustrates BER and Q factor by taking random distance values. At the beginning BER values are found not to be affected by distance, then they started to increase when the distance is increased. On the other hand Q factor values are found to be affected by power values, they are decreased when the distance is increased due to losses. Figures represent system performance by eye diagrams, It is found to be better at 61 km than at 100 km.
4.2.3 Variable Wavelength with Fixed Power and Fiber Length

Table (4.3) Results of Min BER and Max Q Factor at 0 dBm, 100 km for Varied Wavelength Values

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1470</td>
<td>1.29511×10^{-15}</td>
<td>7.90909</td>
</tr>
<tr>
<td>1480</td>
<td>3.25133×10^{-15}</td>
<td>7.79333</td>
</tr>
<tr>
<td>1490</td>
<td>4.84464×10^{-15}</td>
<td>7.74314</td>
</tr>
<tr>
<td>1500</td>
<td>2.26262×10^{-16}</td>
<td>8.12337</td>
</tr>
<tr>
<td>1510</td>
<td>4.1583×10^{-15}</td>
<td>7.7634</td>
</tr>
<tr>
<td>1520</td>
<td>2.61278×10^{-16}</td>
<td>8.10521</td>
</tr>
<tr>
<td>1530</td>
<td>1.613429×10^{-17}</td>
<td>8.43755</td>
</tr>
</tbody>
</table>

It has been observed that BER and Q factor variations are not linear according to wavelength (frequency) variation.

4.3 Upstream Link Results

4.3.1 Variable Power with Fixed wavelength and Fiber Length

Table (4.4) Results of Min BER and Max Q Factor at 1310 nm, 100 km for Varied Power Values

<table>
<thead>
<tr>
<th>Power</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0.00428369</td>
<td>2.62522</td>
</tr>
<tr>
<td>20</td>
<td>5.8669×10^{-16}</td>
<td>8.0055</td>
</tr>
<tr>
<td>25</td>
<td>2.03588×10^{-121}</td>
<td>23.4007</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>63.0859</td>
</tr>
</tbody>
</table>
Figure (4.9) Max Q factor at 15 dBm

Figure (4.10) Min BER at 15 dBm
It has been found that upstream requires high power to operate. It has been noticed that at high power, BER values start to decrease and Q factor values start to increase. It has also noticed that upstream is controlled by CW laser of the OLT.

Figure (4.11) Max Q factor at 30 dBm

Figure (4.12) Min BER at 30 dBm
Figures represent system performance by eye diagrams. It is found that when power is increased BER values are decreased. There is less distortion, less ISI, higher SNR, better synchronization and better eye height at 30 dBm than at 15 dBm.

### 4.3.2 Variable Fiber Length with Fixed Power and Wavelength

Table (4. 5) Results of Min BER and Max Q factor at 15 dBm, 1310 nm for Varied Length Values

<table>
<thead>
<tr>
<th>Length</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
<tr>
<td>50</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
<tr>
<td>100</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
</tbody>
</table>

As expected in this scenario, with increasing distance, BER would increase and Q factor would decrease. However, from the table it is observed that BER has high value and Q factor has low value and both of them remain constant for the whole distance range.

### 4.3.3 Variable Wavelength with Fixed Power and Fiber Length

Table (4.6) Results of Min BER and Q factor at 15 dBm, 100 km for Varied Wavelength Values

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Min BER</th>
<th>Max Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1260</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
<tr>
<td>1310</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
<tr>
<td>1360</td>
<td>0.00626561</td>
<td>2.49303</td>
</tr>
</tbody>
</table>

This table illustrates that BER has high value and Q factor has low value. Both of them remain constant for the whole wavelength range unlike the expectations that BER and Q factor values would change according to wavelength variation.
Chapter 5

Conclusion and Future Work

5.1 Conclusion

Gigabit Passive Optical Network (GPON) technology lowers network costs, energy consumption, and lower maintenance requirements. It also provides more bandwidth.

The aim of the project is to test the performance of GPON uses shared fiber for both downstream and upstream data for 32 users and one OLT.

This project simulated using Optisystem-Optiwave version7.0 software by taking different values of transmitted power, fiber cable length and operating wavelengths with multiple scenarios. Then results evaluated based on BER, Q factor and eye pattern obtained.

Observed that power scenario’s affected most at both upstream and downstream results comparing to distance’s and wavelength’s scenarios.

5.1.1 Completion status

- GPON architecture was successfully implemented
- GPON theoretical knowledge was understood
- Downstream transmission performance evaluation for power, fiber length and wavelength scenarios were successfully clarified
- Upstream transmission performance evaluation for power scenario was successfully clarified
- The basic needed knowledge and methods to generate communication problems solutions in Optisystem-Optiwave version7.0 were learned
5.1.2 Limitations

However, the simulation still suffers some limitations such as:

- In the upstream direction, BER and Q factor values seem not to be represented correct behavior in different fiber distances.
- In the upstream direction, BER and Q factor values seem not to be represented correct behavior in different fiber wavelengths.
- Limited number of available books and references about GPON.

5.2 Future Work

- Upstream problem should be resolved
- This Project performance can be study from different prospective like system dispersion, scattering and types of modulation in order to give better performance of the GPON.
- The system efficiency can be developed by increasing the data rate. Also the number of optical network units can be increased from 32 users to 64 users or more.
- Today the version scale of OptiSystem-Optiwave reach version 14 which can be more flexible and have a more techniques for simulation.
References


