Sudan University of Science and Technology

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Performance Evaluation of GPON Access Network Technologies

تقويم الأداء لتقنيات الوصول لشبكات جيجابت البصرية الخاملة

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of M.Sc. In Electronics Engineering (Computer and Networks Engineering)

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الاستـهلال

قال الله تعالى:

بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

﴿قَالَ رَبِّ اشْرَحْ لِي صَدْرِي (٢٥) وَيَسِّرْ لِي أَمْرِي (٢٦) وَاحْلُلْ عُقْدَةً مِنْ لِسَانِي (٢٧) يَفْقَهُوا قَوْلِي (٢٨)﴾

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Last but not least, gratitude shall be expressed to my beloved family; for their understanding & endless love, through the duration of my studies.

Abstract

Optical fiber plays an important role in the revolution of communication technologies as one of the most powerful access network technologies Passive Optical Network (PON) is a point to multi point (P2MP) network what consist of an Optical Line Terminal (OLT) located at the provider central office, Optical Distribution Network (ODN) and Optical Network Terminal (ONT) that located at the end-user's premises. Gigabit passive optical network (GPON) is one of Time Division Multiplexing (TDM) PON or (WDM) Wavelength Division Multiplexing. This technology lowers network costs, energy consumption, and lower maintenance requirements and it also provides more bandwidth.

The thesis considers a real case study for an existing network what suffering from a limitation in its bandwidth, fiber length and optical power, to overcome this, five simulation scenarios were done by Optisys-Optiwave v.7 and the parameters were gradually changed. The research tests a different values of bit rates, optical power and fiber length in the scenarios for both upstream and downstream directions It was observed at the changes of optical power values -3~10 dbm, bit rates start from 622/155 M ~10/10G and distance from 15 km ~40. The achieved results changed gradually from 37.1708 ~ 115.5180 for Quality factor(acceptable value is 6) that almost improved with 310 times, also the Bit Error Rate (its minimum acceptable value is$10^{-9)}$ changes from $1.31573x10^{-19}$ reached to $1.392\ x10^{-285}$ that is near to 1500%.That conclude the obtained results were exceeded the excellent values for both Q-Factor and Bit Error Rates.

المستخلص

تلعب الألياف الضوئية دورًا مهمًا في ثورة الاتصالات الرقمية كواحدة من أقوى تقنيات الوصول الشبكة البصرية الخامله، وهي شبكة من نقطة إلى نقطة متعددة تتكون من محطة خط الالياف البصري والذي يوجد عند المكتب المركزي لمزود الخدمة، وشبكة التوزيع البصري، بالإضافة الى وحدة الشبكة البصرية الموجودة في مباني المستخدم. تعد شبكة الالياف البصرية الخاملة واحدة من تقنيات استخدام تعدد الإرسال بتقسيم الوقت أو تعدد الإرسال بتقسيم الطول الموجي. تعمل هذه التقنية على تقليل تكاليف الشبكة واستهلاك الطاقة وذات متطلبات صيانة منخفضة، كما توفر المزيد من عرض النطاق الترددي.

يتناول البحث دراسة حالة حقيقية لشبكة موجودة تعاني من محدودية في عرض النطاق الترددي وطول الألياف والطاقة الضوئية ، للتغلب على ذلك ، تم إجراء خمسة سيناريوهات محاكاة بواسطة Optisys-Optiwave v.7 وتم تغيير القيم تدريجياً. يختبر البحث قيماً مختلفة لمعدلات البت والقوة الضوئية وطول الألياف في السيناريوهات المستخدمه في كلا الاتجاهين الارسال و الاستقبال ،و قد تلاحظ انه عند تغير قيم الطاقة الضوئية -3 ~ 10 ديسيبل ، و معدلات البت من 155/622 ميجا ~ 10 / 10قيقا والمسافة من 15 ~ 40 كلم. تبعاً لذلك تغيرت النتائج المحققة تدريجياً من 37.1708 إلى 115.5180 لعامل الجودة (القيمة القياسية 6) التي تحسنت تقريبًا حوالى 310 مرات ، كما تغير معدل الخطأ في السرعة (الحد الأدنى للقيمة المقبولة 10^{-9}) من $1.31573x10^{-19}$ الى $1.392\ x10^{-285}$ أي ما يقرب من 1500٪ ، وبذلك تم استنتاج أن النتائج التي تم الحصول عليها تخطت القيم الممتازة لكل من Q-Factor ومعدلات خطأ السرعة التي ذكرت سابقاً.

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LIST OF ABBRIVIATION

10GEPON	10 Gigabit Ethernet Passive Optical Network
ADSL	Asymmetric Digital Subscriber Line
AES	Advanced Encryption Standard
Alloc-ID	Allocation Identification
AON	Active Optical Network
APD	Avalanche Photodiode
APON	Asynchronous Transfer Mode Passive Optical Network
BER	Bit Error Rate
BPON	Broadband Passive Optical Network
BW	Bandwidth
CO	Central Office
CW	Continuous Wave
DBA	Dynamic Bandwidth Allocation
DBRu	Dynamic Bandwidth Report upstream
DSL	Digital Subscriber Line
EPON	Ethernet Passive Optical Network
FAT	Fiber Access Terminal
FDT	Fiber Distribution Terminal
FEC	Forward Error Correction
FSAN	Full Service Access Network
FTTB	Fiber-to-the Businesses
FTTC	Fiber-to-the Curb
FTTH	Fiber-to-the Home
FTTP	Fiber-to-the Premise

GEM	GPON Encapsulating Method
GPON	Gigabit Passive Optical Network
GTC	GPON Transmission Convergence
HDSL	High bit rate Digital Subscriber Line
HSP	Higher Speed PON
IDSL	Integrated Services Digital Network Digital Subscriber Line
IEEE	Institute of Electrical and Electronics Engineers
ISI	Inter-Symbol Interference
ISP	Internet Service Provider
ITU	International Telecommunication Union
LED	Light Emitting Diode
LD	Laser Diode
MAC	Media Access Control
MAN	Metropolitan Area Network
MPCP	Multipoint Control Protocol
MZM	Mack Zehnder Modulator
NGPON	Next-generation Passive Optical Network
NRZ	Non-Return to Zero
OAM&P	Operation, Administration, Maintenance &Provision
ODN	Optical Distribution Network
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical Line Terminal
ONT	Optical Network Termination
ONU	Optical Network Unit
OTDR	Optical Time Domain Reflectometry
P2P	Point-to-Point
P2MP	Point-to-Multipoint

PCBd	Physical Control Block Downstream
PDU	Protocol Data Unit
PIN	Positive Intrinsic Negative
PLOAMu	Physical Layer Operations, Administration and Management upstream
PLOu	Physical Layer Overhead
PLSu	Power Leveling Sequence upstream
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PRBS	Pseudo-Random Bit Sequence Generator
Q Factor	Quality Factor
RADSL	Rate-Adaptive Digital Subscriber Line
SDSL	Symmetric Digital Subscriber Line
SNR	Signal-to-Noise Ratios
SMF	Single Mode Fiber
TDMA	Time Division Multiple Access
TDM PON	Time Division Multiplexing PON
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network
VDSL	Very high-bit-rate DSL
VoIP	Voice over Internet Protocol

CHAPTER ONE

INTRODUCTION

Chapter One

Introduction

1.1 Preface

A Gigabit Passive Optical Network (GPON) is a fiber-optic telecommunication technology that uses for delivering fixed broadband network access to the end-users, It usually implements a point-to-multipoint (P2MP) topology, in which a single optical fiber connects and serves multiple end-users by using a passive fiber optic splitters to divide the fiber bandwidth between multiple access points. Gigabit Passive Optical Networks can be described as the "last mile" between an Internet Service Providers (ISPs) and their multiple homes or small businesses users capacity is usually measured by Gb/s[1], It has a downstream capacity, and upstream signals are combined using a multiple access protocol, mostly Time Division Multiple Access TDMA. GPON network consists of an active components : Optical Line Terminal (OLT) at the ISP central office and a number of Optical Network Units (ONTs) “IEEE” or optical network terminals (ONTs) “ITU-T”, near end users. A GPON reduces the amount of fiber and central office equipment required compared with point-to-point architectures, what uses an optical splitters as a passive components. In today’s rapidly changing telecoms marketplace, fixed line service providers face many challenges as they compete for greater market share and look to provide next generation services.

The excessive demand for a higher bandwidth broadband, ‘quad-play’ services which including high-speed data, voice, video-on-demand and IPTV have focused service providers on the need to invest in Cutting-edge solutions, that comes with the needs to improve the bandwidth and QoS accordingly, this led to the next generation of GPON what known as XG-PON (2010) and XGS-PON (2013) ITU-T G.987 .To remain competitive, this has been based upon the deployment of Fiber-To The (home/premises/building/cabinet/curb/ node) service what works in GPON platform. The situation necessitates that critical strategic, network planning, build and operations support.

Decisions are taken to ensure that an adequate return-on-investment (ROI) is achieved through determining the best, and most cost effective, path for network deployment. To implement this, service providers need to define a comprehensive framework that can effectively manage the complex interactions in the deployment process, supported by strategic investment in the systems, tools and skilled resources, required to effectively deliver a high-quality service of FTTx and overcome the challenges [2].

For digitalization and modernization purpose, the network must be introduced in a fully Digital Transmission components, that to improve and extend services to the end-users, improve transmission quality as well as to improve Administration Operation & Maintenance (AO&M) facilities.

1.2 Problem Statement

In this research, the crucial question, is the end-users’ requirements can be met with the current design of FTTx/GPON? and gratify their needs in term of quality of service, bandwidth demand and service stability, the research will study and evaluate the performance from different points of view e.g., distance, optical power and broadband capacity. The research study the simulation scenarios what include a real case study for an existing network, and it will evaluate the results focusing on how to overcome the limitation for the all above factors, the research will show the limitation and weak points of PON, putting in consideration how the changes in these factors will contribute in this overcome, also it will lead to satisfy the future demand of end-users.

1.3 Proposed Solution

To overcome the limitation and answer the research question regard the bandwidth, distance, optical power and QoS, the research will try to improve the network by doing the following:

- Upgrade the bandwidth gradually starting from 622M/155M till reach to till 10/10 Gb/s
- Change the system design in components, parameters, fiber distance optical power and wavelength as PON standards.
- Make performance evaluation and analysis for each design scenarios.

1.4 Aim & Objectives

The main aim of this work is to evaluate the performance of GPON access network at the end-user site in terms of bit rate, distance, optical power and QoS, that with different parameters and values to improve the final throughput.

The research will try to achieve the aim, , by designing the block diagrams for upstream and downstream transmission and do its simulations scenarios accordingly. To evaluate the performance of the system, the optical power, bit rates and the fiber length will be changed gradually by increasing its values to check the effects of their changes in BER (Bit Error Rate) and Q-Factor (Quality factor), that to enhance the throughputs starting from 155/622 M up to the quality of the bit rate 10/10 G.

1.5 Methodology

The research methodology implements the standards of the PON systems, firstly it shows the concepts of GPON technologies and the functions of network elements what are, Optical line terminal OLT(Transmitter), ODN: Optical Distribution Network and ONTs (Receiver).

Then the network design is done for both upstream/downstream by schematic diagrams describing the fiber links between each component. Optisys/Optiwave software is used to simulate the design of the systems, it simulates five scenarios, one of them (GPON 1.25/2.55G) is a real network design what is currently deployed by one of the fixed telecom operators, and the analysis performed is testing GPON network. The simulation evaluates the performance of the network in bandwidths per second for 622M/155M, 1G/1G, 2.5G/1.25G, 10G/2.5G and finally 10G/10G as the main factor in the research beside the modifications and analysis of the other values (optical power, distance and wavelength) was done in each stage. The optical power meters are used to check and adjust the optical power at each stage of the design, while the BER analyzer is connected to the end-user ONTs to measure the BER, Q-factor, eye diagram for each value.

1.6 Thesis Outlines

This thesis is organized into five chapters their outlines are:

Chapter One is an Introduction that consists of preface, problems statement, proposed solution, and methodology. Chapter Two is the Literature review what present the background of GPON networks and provides description and explanation for various technologies and platforms also it includes the related works. Chapter Three represents the Simulation & Analysis, it provides the communication concepts, practices and theories used to perform the thesis work, also it provides simulation setup uses Optisystem-Optiwave version7.0 software consists of GPON network design and its implementation and fundamentals. Chapter Four is the Results and Discussion, this chapter provides all results obtained, discussing and validating them. Finally, in Chapter Five describe the outlines of the main conclusion and the recommendations for future work.

CHAPTER TWO

LITRITURE REVIEW

Chapter Two

Background and Literature Review

2.1 Background

This chapter provides a general description of broadband access networks 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.

2.1.1 Broadband Access Technologies

The broadband is a term commonly referring to high-speed Internet access, that is always on and faster than the traditional dial-up access. Broadband includes several high-speed transmission technologies such as:

2.1.1.1 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 end-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 MHz 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 [3]. DSL internet speed is affected by the distance from

Internet Service provider (ISP) office as the longer distance the slower the speed is, also it is susceptible to electrical noise 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).

2.1.1.2 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. The main issues regard the wireless broadband is that the neighbors can easily use the internet without any kind of permission, also the signal strength weakens if the users are very far away from the wireless router. The signal strength also tends to weaken if it needs to pass through brick walls resulting in slow internet browsing speed [3].

2.1.1.3 Broadband over Power line (BPL)

BPL is the delivery of broadband over the existing low- and medium-voltage electric power distribution network. BPL speeds are comparable to DSL and cable modem speeds. BPL can be provided to homes using existing electrical connections and outlets. BPL is an emerging technology that is available in very limited areas. It has significant potential because power lines are installed virtually everywhere, alleviating the need to build new broadband facilities for every end-user. BPL has a serious bandwidth and radio interference issues[4] .

2.1.1.4 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) and thirdly, the light consists of tiny particles- photons - (quantum theory). Fiber optics communication systems consist of three elements as shown in Figure 2-1

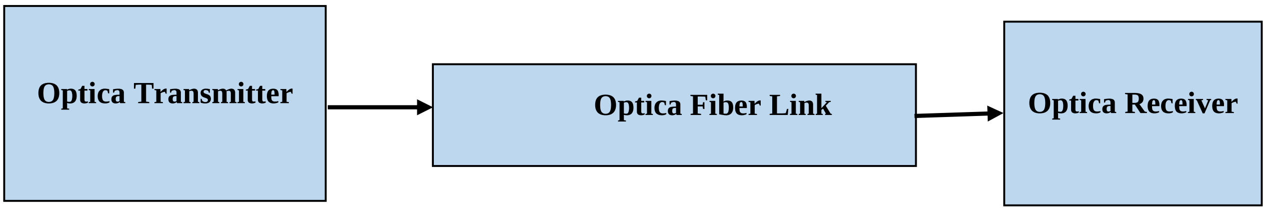


Figure 2-1 Optical Communication System

Optical Transmitter

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 [5].

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. [5]

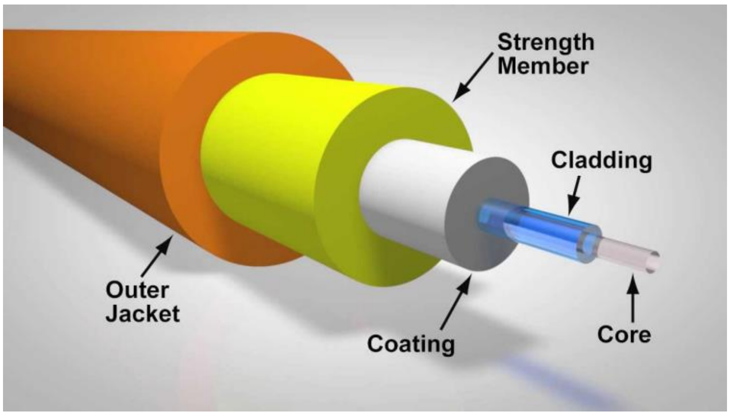


Figure 2-2 Optical Fiber Core with Surrounding Cladding and Protective Jacket [6]

Optical fiber is classified into two categories based on number of modes (single mode, multi-mode) 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 [5].
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. [5].
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 [5].

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 [5]. 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 [5].

2.1.2 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) [3] .

2.1.2.1 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.

Figure 2-3 Point-to-Point Fiber

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. [3] There is no need for network addressing in P2P network, because every user is connected by a dedicated fiber to the CO.

2.1.2.2 Passive Optical Network (PON)

PON uses a passive optical splitter where 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 (ONTs).In the upstream direction, the splitter combines the light coming from ONTs, 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, [3] PON is a point to multipoint network (P2MP) as shown in Figure 2-4.

Figure 2-4 Point to Multipoint Network

2.1.3 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 :

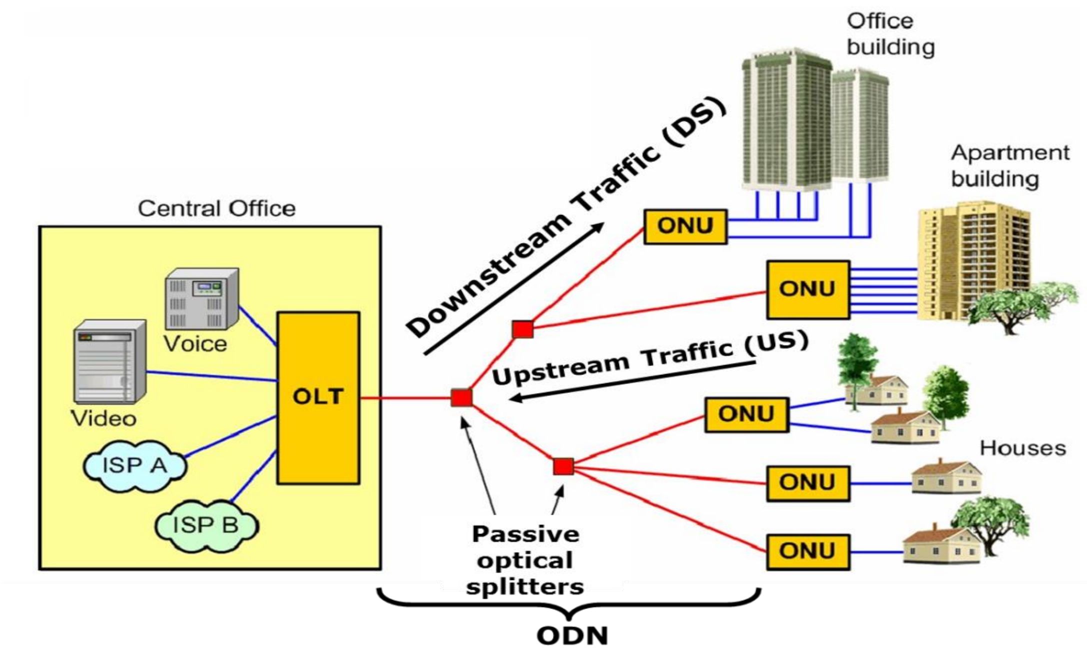


Figure 2-5 PON Architecture [2]

- **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.
- **ONTs**: are located at the end-users' premises. 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.

- **ODN:** it connects the OLT at the CO and ONTs 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.

  The splitting ratio in most cases is between 1:8 and 1:128 depends on technology used, and can be performed in lumped or cascaded elements. 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. There are three main types of PONs depending on the data multiplexing scheme:

  - Time Division Multiplexing (TDM) PON, where traffic from/to multiple ONTs are TDM multiplexed onto the upstream/downstream wavelength.
  - Wavelength Division Multiplexing (WDM) PON.
  - Orthogonal Frequency Division Multiplexing (OFDM) PON.

2.1.3.1 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. [3]

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. [3]. In TDM PON each user is allocated a time slot to transmit data towards the OLT. Each standard has different data rates speed for upstream and downstream communication.

2.1.3.2 T-WDM PON

Time Wavelength Division Multiplexing PON (TWDM-PON) provides four or more wavelengths per fiber, each of which is capable of delivering symmetrical or asymmetrical bit rates of 2.5 Gbps or 10 Gbps, FSAN named TWDM-PON technology as its solution of choice for implementing the Next Generation of NG-PON2 architecture [6]. As shown in Figure 2-6, light from four OLTs , each of a different wavelength, are combined into a single fiber using a wavelength mux. Each ONU is dynamically assigned to just one OLT and communicates with tunable lasers (upstream) and active filters (downstream).

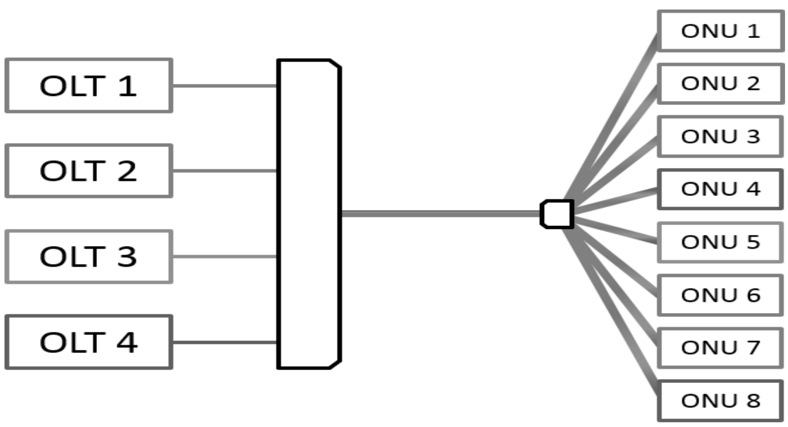


Figure 2-6 TWDM PON

2.1.3.3 T-CONT

T-CONT (Transmission /Traffic Container) is a service carrier in the upstream direction in the GPON systems, and it is the basic control unit of the upstream service stream, it carries traffic flows / connections and are used for the management of upstream bandwidth allocation in the PON section of the transmission convergence layer.[7] T-CONTs are primarily used to improve the bandwidth utilization in PON section and GEM frames to be transmitted upstream are encapsulated into the corresponding T-CONT, T-CONT has five types what can be classified the bandwidth to fixed bandwidth what mainly uses for TDM, assured bandwidth, assured and maximum uses for VoIP, maximum bandwidth uses for IPTV and type five what is combination of all four types. Figures 2-7 shows T- CONT work diagram

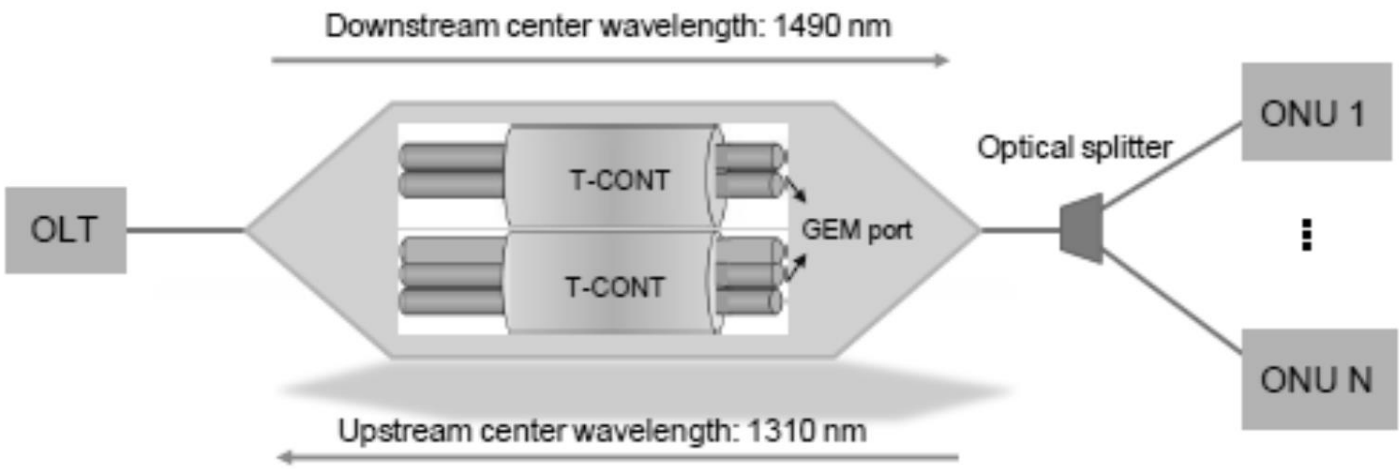


Figure 2-7 T-CONT work diagram [8]

2.1.4PON Standards

The Figure 2.8 shows the evolution and standards of PON starting from BPON till the future standard G.hsp.x

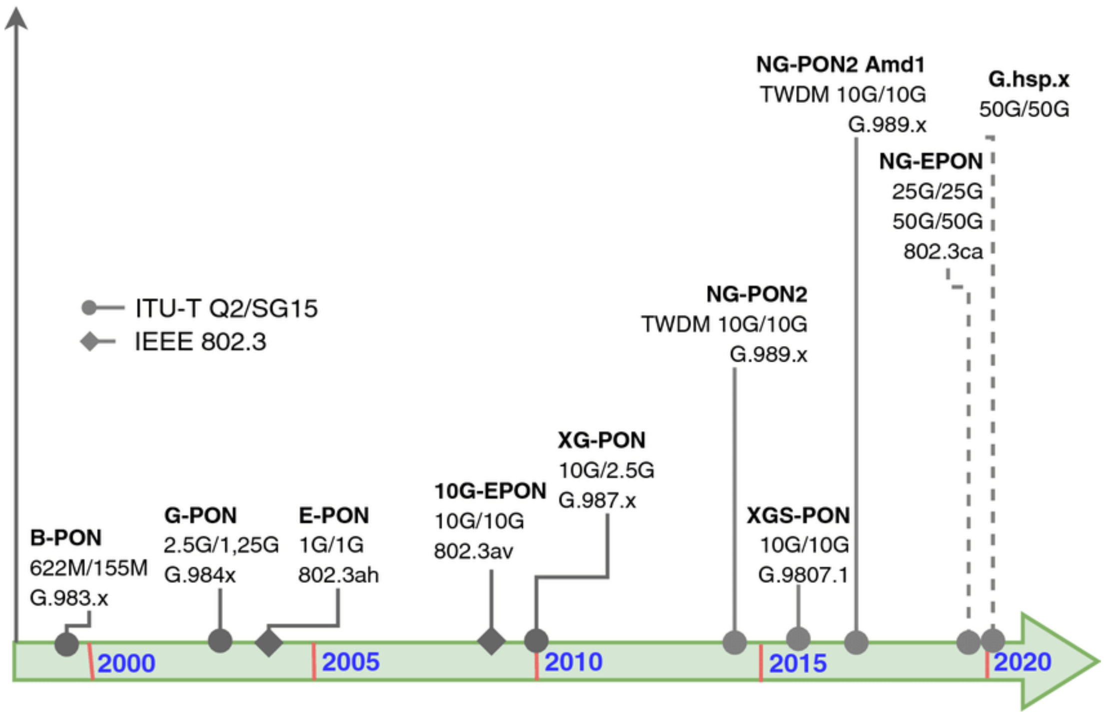


Figure 2-8 PON evolution and standards [9]

2.1.5 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 [10]. It can transport not only Ethernet, but ATM and TDM traffic by using GPON encapsulating method (GEM), the main characteristics of the GPON are:

• 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 the central commonly uses is 1490 nm and 1260-1360 nm for upstream direction with 1310 nm central wavelength. GPON standard uses line transmission rates 2.488Gbps for downstream and 1.244Gbps for upstream directions.[10] Figure 2-9 illustrates GPON Architecture.

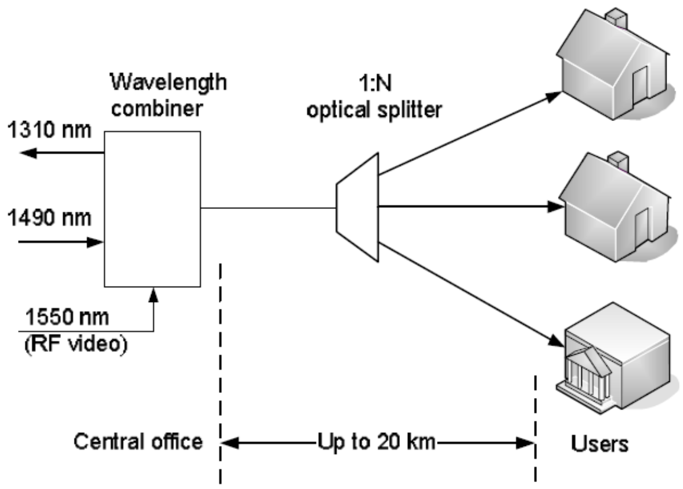


Figure 2-9 GPON Architecture

To separate upstream / downstream signals of multiple users over a single fiber, GPON adopts two multiplexing mechanisms:

• Downstream traffic is broadcasted by the OLT to all ONTs. Each of these processes the traffic which is assigned to it through an address contained in the header of the Protocol Data Unit (PDU). Data is broadcast in downstream direction. ONTs receive the desired data according to GEM port IDs.

- Upstream traffic uses Time Division Multiple Access (TDMA) mechanism under control of the OLT located at the CO which assigns time slots to each ONT 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 2-9 and Figure 2-10 illustrates broadcast and TDMA modes

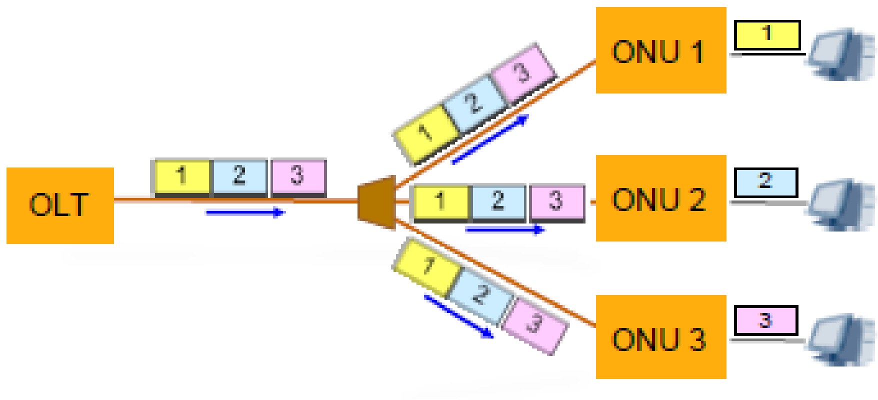


Figure 2-10 Downstream -Broadcast mode

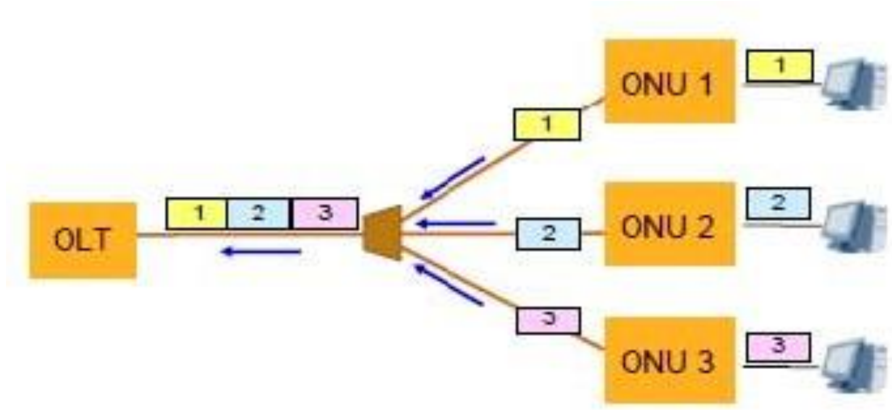


Figure 2-11 upstream- TDMA mode

2.1.6 GPON Transmission

Media Access Control (MAC) layer control protocol is needed to coordinate the traffic transmission such as the collision between traffic from different ONTs can be avoided.[3]. 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. [10]

2.1.6.1 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 ONT filters the downstream GEM frames based on their GEM Port IDs and processes only the GEM frames that belong to that ONT. [3]

2.1.6.2 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 number of bytes with different transmission rates; the higher the rate, the bigger the frame.

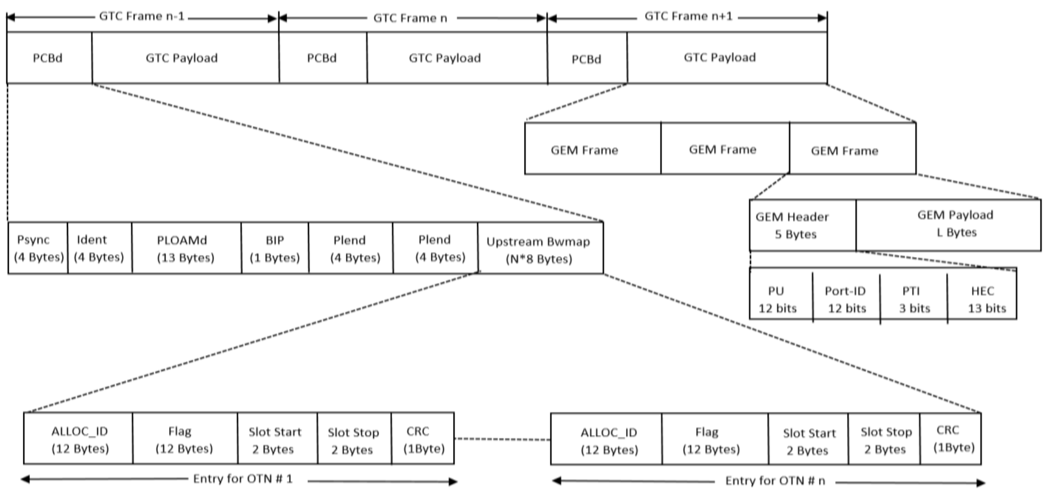


Figure 2-12 Downstream GTC Frame Format [11]

Downstream traffic is broadcasted from the OLT to all ONTs in TDM manner. Every ONT 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. [3] 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. GPON downstream frame structure is shown in Figure 2-13 , the frame is 125 micro second and 38880 bytes long.

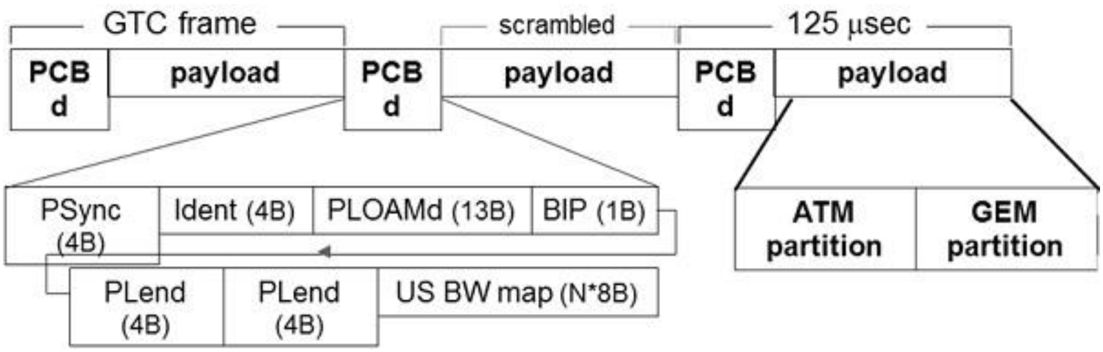


Figure 2-13 Downstream GPON Frame [12]

2.1.6.3 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 ONTs. The traffic-bearing entities of ONT are identified by their allocation IDs (Alloc-IDs). The bandwidth allocations to different Alloc-IDs are multiplexed in time as specified by the OLT in the bandwidth maps (BW Maps) transmitted downstream. Within each bandwidth allocation, the ONT uses the GEM Port-ID as a multiplexing key to identify GEM frames that belong to different upstream logical connections [3].

2.1.6.4 Upstream GPON Frame Format

Upstream GTC frame duration is also 125 micro second and 19440 Bytes long. Upstream traffic uses TDMA under control of the OLT located at the CO which assigns variable time slots to each ONT 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 ONT may begin and end its upstream transmission so only one ONT 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. [3] 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. [10] A diagram of the upstream frame structure is shown in Figure 2-14. The frame length is the same as in the downstream for all rates. Each frame contains a number of transmissions from one or more ONTs. The BW Map dictates the arrangement of these transmissions. During each allocation period according to the OLT control, the ONT can send from one to four types of PON overheads and user data [10].

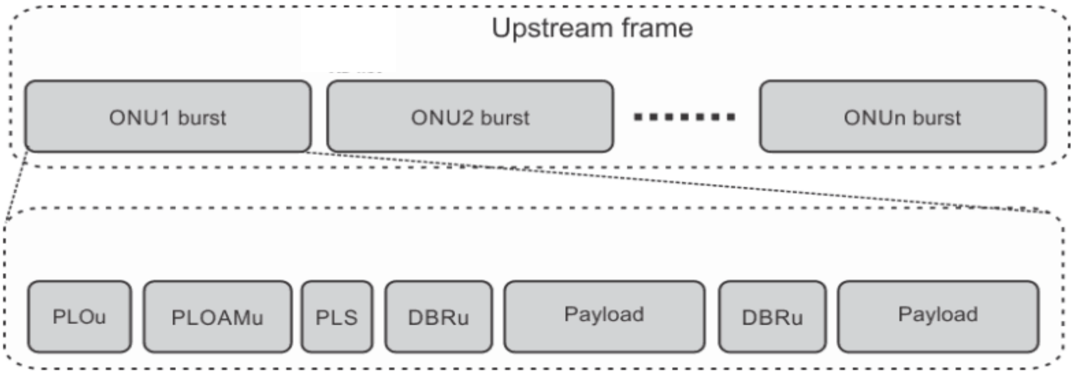


Figure 2-14 Upstream GPON Frame [10]

2.1.7 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 ONT can be supported, as well as higher number of splits per a single PON tree [3].

2.1.8 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 ONTs and allows the negotiation of access to the medium through the exchange of control messages. The

MPCP specifies mechanism between an OLT and ONTs connected to a P2MP PON segment to allow efficient transmission of data in the upstream direction [13].

2.1.9Security in GPON

Downstream data are broadcasted to all ONTs and every ONT has allocated time when data belongs to it. Because of that, some malicious user can reprogram its own ONT and capture all downstream data belonging to all ONTs 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. [14]

2.1.10 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.

2.1.11 Performance Parameters in GPON Network

2.1.11.1 Bit Error Rates

Bit 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.
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[15].

2.1.11.2 Eye Signal 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[17]. Figure 2-15 illustrates interpretation of the eye diagram.

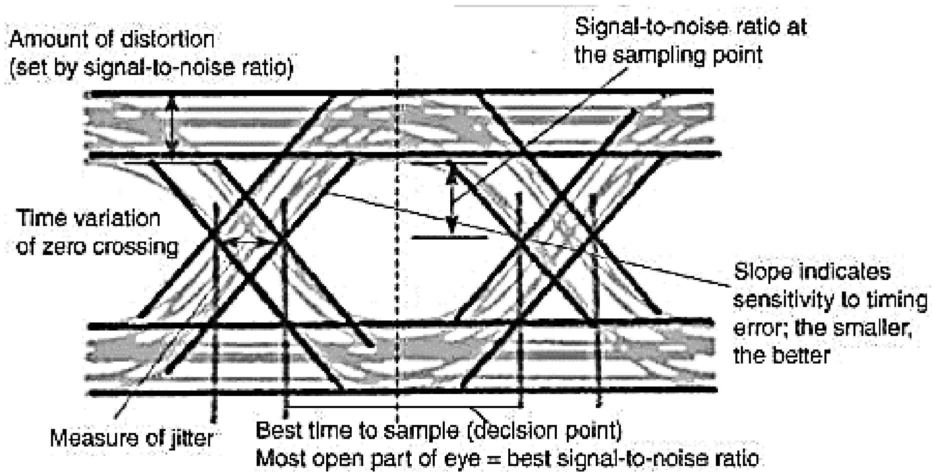


Figure 2-15 Eye Diagram interpretation [17]

2.1.11.3 Q Factor

The Q factor or quality factor represents the loss in energy of the signal. Maximum Q factor has less loss of energy-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. [17] Figure 2-16 illustrates the relationship between Q factor and bit error rate.

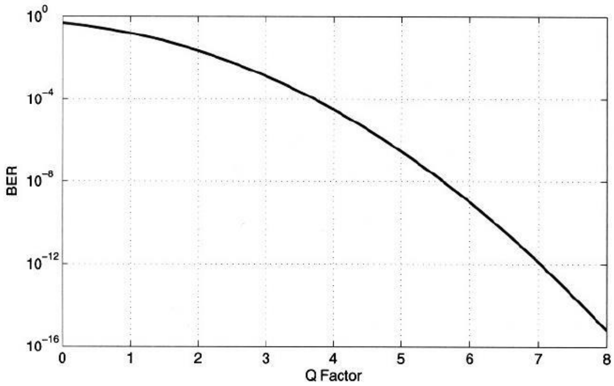


Figure 2-16 BER vs Q factor [18]

2.1.12 Concept of FTTx citation

Fiber-to-the-x includes mainly fiber-to-the-home (FTTH), fiber-to-the-curb or cabinet (FTTC), fiber-to-the-building or businesses (FTTB) and fiber-to-the-node (FTTN), these types are showed in Figure 2-17

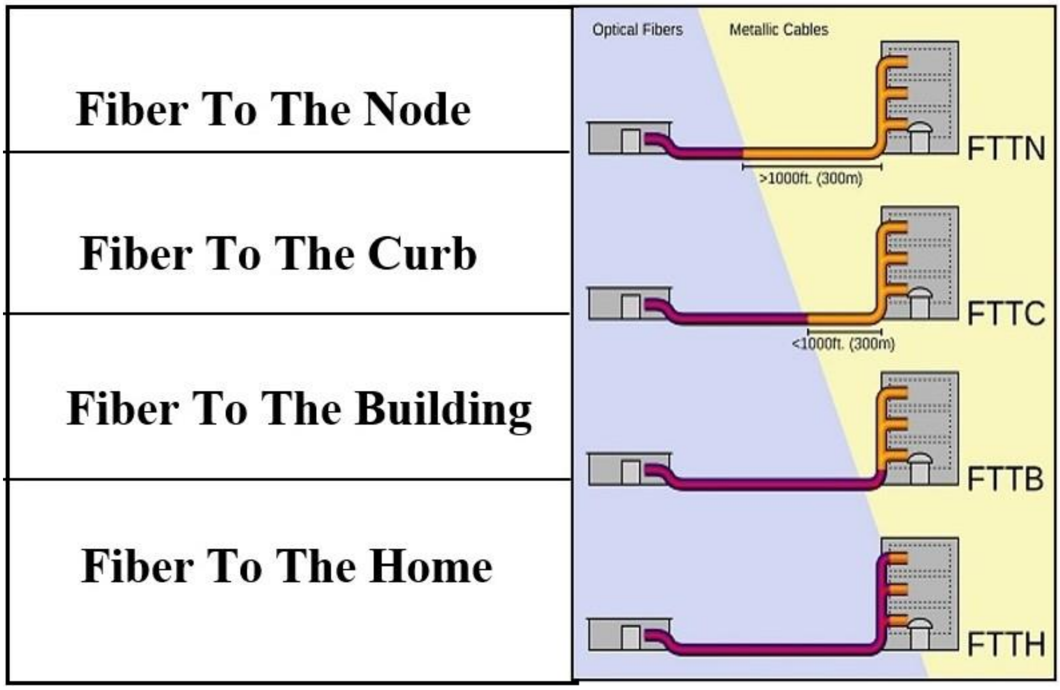


Figure 2-17 FTTx types [8]

• FTTH

FTTH Network connects large number of installations at the end users' homes 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.

• 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 end-users and the building switch often are by Digital Subscriber Line Access Multiplexer (DSLAM) that is installed in the building that with copper cable.

- FTTC

Fiber to the curb (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.

- FTTN

Fiber to the node or neighborhood (FTTN) is a telecommunication architecture based on fiber-optic cables run to a cabinet serving a neighborhood. End-users typically connect to this cabinet using traditional coaxial cable or twisted pair wiring. The area served by the cabinet is usually less than one mile in radius and can contain several hundred users.

2.1.13 Pros of GPON

2.1.13.1 Less physical equipment required

It’s obvious that GPON reduces the reliance on and cost of physical equipment in the fiber distribution network. No physical switches are necessary, and because a single fiber can be split into many different signals, less fiber is required in the network. A GPON network is thus cheaper and quicker to construct. As an illustration, the cabling and splitters of a typical GPON costs 40-50% less than copper access lines.

2.1.13.2 Lower maintenance requirements

Allied to the above point is the fact that having less physical equipment means that the network is less susceptible to physical equipment failure, and requires less physical equipment maintenance. There is less that can go wrong with a network that mostly relies on completely passive components.

2.1.13.3 More bandwidth, delivered more efficiently

GPON offers higher bandwidth delivery – it has a 2.488 Gbps downstream capacity and a 1.244 Gbps upstream capacity. It uses larger, variable length packets to transmit data and employs frame segmentation to give higher quality for voice and video traffic. The passive optical splitters provide higher efficiency by allowing each fiber optic strand to be split into 32 signals that can serve up to 128 end ports.

2.1.13.4 Easier network management

One of the design specifications of GPON was ease of troubleshooting. Because of the number of passive components, it lends itself more easily to centralized management, compared to an active Ethernet network. It is also easier to make high volume moves, changes and additions, with less field technician support required.

2.1.13.5 Limitations/cons of GPON

The cons of GPON can be attributed to the fact that the fiber-optic cable is quite sensitive to kinks, therefore it is categorically not recommended to lay it around the apartment, put it in the baseboards. In this case, the cable may break or its bandwidth may decrease, on the other hand the P2MP design what used in PON makes the link between CO and ODN is single point of failure, so there is a high risk if get down all network will be out of service, even the backup/diversity design need more cost, also now adays still 10G considered not enough bandwidth for the gluttonous users and the great evolution of digital services and IoT.

2.1.14 The Future of PON

Following the publication of 40 Gbps NG-PON2,in 2015 FSAN and ITU-T studying with the name “future optical access systems" with peak transmission rates above 10 Gbps. among possible nominal line rates of 20, 25, 50, and 100 Gbps per wavelength, they selected 50 Gbps as the next generation after 10 Gbps to provide a sufficiently large increment to network, the future researches should dig more about this next generation, applying a simulation model starting from 25Gbps in optiwave newer versions.

2.2 Related works

The authors in [18] consider the design of GPON in nine floors building. Their design proves the allocation of maximum number of users for a multi dwelling buildings with tolerable power budget and cost. Their design was also capable to incorporate future services like IPTV and provides Dynamic Allocation of Bandwidth (DAB) according to the user requirements. They used INAS EMS software to show the active ports, and the methods used are OTDR and LSPM. Optical Time Domain Reflectometry (OTDR) launched the light into the network and it used to measure the total length of the fiber, loss of fiber, connector, splice, bent positions and break point detection by using any one of the following output traces, table and summary. It can’t be used for power measurement. Light Source and Power Meter (LSPM) testing is a type of testing which used the light source as laser and power meter to test the loss and power in the equipment, diagnose the issues by fire alarm settings, physical / logical topological configuration support etc. after the network implementation. The design was included the steps involved in the initial stage of FTTH network design, splitter allocation design to each floor, overall FTTH network from OLT to an ONT, Power budget calculation, link loss, calculation, cost calculation, power meter testing results at initial checking stage. Power budget, the calculation of the link loss has been done by using the following equations: Rx power at ONT = Tx power at OLT – (all losses along the path from OLT to ONT). Link loss = total length of fiber x attenuation (dB/km) + no. of splices x splicing loss + no. of connector x connector loss. While the total loss = Link loss + safety margin (3 dB). The results of received power were between -18.1~ -23.6 dbm along all floors, the power in each ONT is within the tolerable value. The INAS EMS shows the active GPON OLT ports with green light indication. Their results showed the design of FFTH network based on GPON technology was an optimum design which has tolerable power budget and the cost of implementation of this particular design is comparatively low than the other network designs. But it was proven that the design missed the versions of technology and services like IPTV.

In [20]'s authors stated that the large-scale adoption of Internet of Things (IoT) has ushered the need for reliable broadband links for swift and easy distribution of IoT devices and these challenges have led many varieties of research and industries to examine and vigorously study alternative designs based on passive optical network devices to provide low price, scalable, long distance, energy efficient, and high-speed networks. Their paper proposed a simulation of the Gigabit Passive Optical Network (GPON) standard of the fiber-To-The-Home (FTTH) in order to deliver a reliable connection to 64 subscribers, they used Optisystem over a distance of 50 km. Optical amplifiers were announced to extend the reach of GPON beyond the 20 km mark in order to achieve a high-performance working system. They used a top-down approach and the architecture of the GPON implementation covers a total of 64 ONTs using a single bidirectional optical fiber extended with optical amplifiers what used on both downstream and upstream part of the fiber link. Bidirectional single fiber WDM-PON were reduced the use of fiber links, as well as the number of network equipment, and hence reduce energy consumption and the cost. The configuration was used for various applications. It includes voice, video, and it used an optical splitter to distribute connections from the OLT with multiple ONTs. The work implemented P2MP architecture with 1:64 splitter, In the downlink, an optical transmitter was used on the 1490 nm wavelength with 10 dBm out power with a data rate of 2.5 Gbps; the optical amplifier is placed before the splitter owing to the fact that it was observed a significant amount of power was lost at the splitter.

The ONT is made up of the receiver and the uplink transmitter. In the uplink, an optical transmitter is used on the 1310 nm wavelength with 0 dBm power with a data rate of 1.25 Gbps to transmit signal from the ONT to the OLT.Their results has a value of Q-factor (24.993 downstream, 17.943 upstream) and 0 for BER in both up and down stream. They were acceptable results, but still they had a limitation in the area of optical power values in ONT side as it should be more than what they implemented.

The authors in [21]were based on how they can design and analyze the optical fiber communication system and their network topology was simulated using Optisystem The model used, was designed from the data that has been obtained from PT. Telkom. Their main tests were to evaluate the performance of the system using two factors, optical power and distance, they test more than ten scenarios in deferent values of optical power and fiber length. As a results and conclusion, based on the simulation on OptiSystem obtained the value of power budget link on the downstream configuration of $2.99513e^{-12}$ and for upstream of 0. for the Q-Factor in the downstream configuration of 6.87953 and for upstream of 41.9221. So, it can be concluded that both values were meet the minimum value of Q-Factor is 6 and also both values were meet the minimum value of BER is 10^{-9}.But the research open issues were the areas of bit rates and wavelength value which is very important to tests in GPON systems. In [10]'s authors stated that, their main aim of the paper is to review the standardization evolution of PON to next generation passive optical network (NG-PON. Also, it presented the possible challenges in NG-PON alongside their strengths and weakness in different techniques. BPON and E-PON (ITU-T G.983.1-G.983.5 and IEEE 802.3ah standard respectively) were the first generation of PON, the ideal for Internet access services at 1/1Gbps data rates over 10 or 20 km transmission distance with 16 ONTs per OLT. EPON has gained success in East Asia. Then to carried packetized traffic more natively, GPON (ITU G.984 series) was selected at 1.25/2.5 Gbps data rates. GPON became popular Europe and some Asian countries. Although, the "over the top" service EPON systems replaced the cable modem or digital subscriber line (DSL) to eliminate the copper wiring issues, but also raises the fiber cabling potential trouble inside end-user's home. GPON systems deployed for full service to become the users complete home networking device. NG-PON or XG-GPON has characteristics which are similar to the deployed GPON with some divergences in the physical layer that provide considerable performance improvements. The XG-GPON is divided into two classes: (

XG-GPON1 provides an asymmetrical transmission with 10/2.5Gbps data rates and XG-GPON2 which provides 10Gbps symmetrical transmission. In particular, the XG-GPON1 physical layer has been defined in ITU-T G.987.2 series. According to the ITU G.987.1, for XG-GPON1 recommendation, two scenarios have been proposed to enable migration from GPON to XG-GPON1. The first scenario was a green-field migration, which is the replacement of the copper connection into premises with an optical connection. The other option was the PON migration scenario, which is an up gradation of the existing GPON system. This includes the replacing or upgrading some network components such as ONT units or OLT modules. NG-PON2 or XG-PON2 is defined in ITU-T G.989 series. It was a successor standard of EPON, GPON, and NG-PON1. It supports the multiple wavelengths per direction and compatibility over ODNs. NG-PON2 has various multiplexing technologies PON e.g., WDM-PON, TDM-PON, orthogonal frequency division multiplexing passive optical network (OFDM-PON), optical code division multiplexing passive optical network (OCDM-PON) and their combinations such as TDM/WDM-PON, OCDM/WDM-PON, OFDM/WDM-PON, OCDM/TDM-PON, OFDM/TDM-PON etc.

GPON and NG-PON technologies are competing for low bit rate, low capacity and high cost because of TDM multiplexing technique which have limited time slots, inefficient use of scalability and limited capacity for end users. Hence, GPON and even NG-PON do not meet the rapid increase of high Internet services and high bandwidth capacity. The basic optical multiplexing techniques are lacking in performance such as WDM-PON lacking in inefficient bandwidth usage and high cost; OCDMA-PON lacking in dependence of network performance on designed address code, Multi Access Interface (MAI) noise and structure of a receiver in the presence of various noises and OFDM-PON lacking in complex receivers, optical beat noise, frequency offset and high cost. The increase in signal dispersion loss, signal nonlinearities such as self-phase modulation (SFM) cross phase modulation (XPM) and four-wave mixing (FWM) appears as the low bandwidth and low transmission capacity risk in c GPON and NG-PON. They stated that,in the competitive networks, the information privacy is one of the main concerns due to context information exchanged among different nodes. The cost of ONTs in NG-PON1/2 is high because of use of complex optical and electronic components. Thus, these challenges motivate towards some preferable hybrid WDM/OCDM, WDM/OFDM and OCDM/OFDM etc. multiplexing techniques in NG-PON.

CHAPTER THREE

SIMULATION AND ANALYSIS

Chapter Three

Simulation and Analysis

This chapter gives a deep sight and describes the detailed implementation of transmission stage of PON 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.

3.1 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. To carry out research simulations, Optisystem-Optiwave version7.0 used.

3.2 Network Setup and Design

This part describes the simulation setup in Optisystem where all necessary parameters based on the GPON standardized properties. Figure 3-1 shows the schematic diagram for transmission of GPON system.

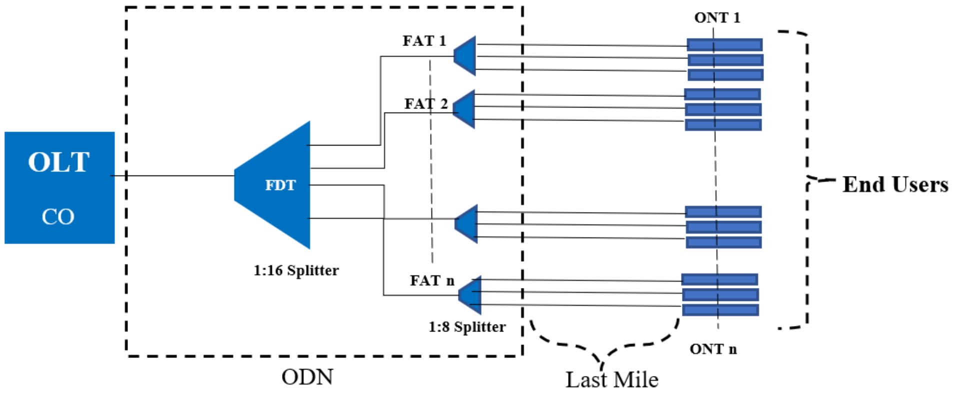
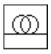


Figure 3-1 schematic diagram for GPON transmission

There are three areas of the network as shown above, first is the Central Office (CO) of the service provider where the OLT located, then ODN is the outsider optical transmission channel between the OLT and ONT, it is usually found in the streets and roads it consists of the passive components (splitters) that 1:16 splitter (FDT) and cascaded to 8 ONTs via another 1:8 passive optical splitter (FAT) as well as optical fiber cables, and the third are the ONTs what based at the end-user's premises. There are many components used in the simulation model, the description of the all these components used in simulation illustrated in Table 3-1

Table 3-1 list of components used in simulation

#	Component	Symbol	Description
1	Optical Transmitter		Converts electrical signal to an optical signal and transmit it through fiber network
2	Optical Fiber		Allows optical signals to travel in both directions at the same time
3	Optical Power Meter		Measures the optical power in different ports
4	BER Analyzer		Measures the performance of the system based on the signal before and after the propagation
5	Optical Attenuator		Attenuates the optical signal power
6	Optical Receiver		Convert the optical signal back into electrical form and recover the data transmitted through the system
7	Optical Splitter 1: N		Splits the signal into required number of signal streams to transmit it to ONTs

The main components in simulation are transmitter and receiver, inside 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 side, the inner components are Avalanche Photodiode (APD) what 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. To analyze the performance of the signal in both downstream and upstream directions the network constructed illustrated in Figure 3-2 and Figure 3-3 respectively.

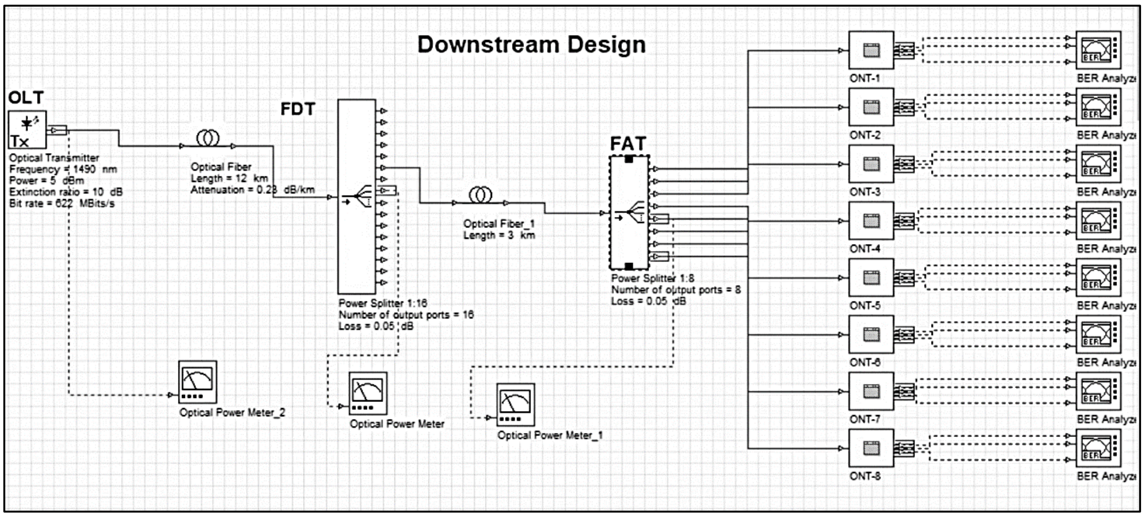


Figure 3-2 Downstream Simulation design

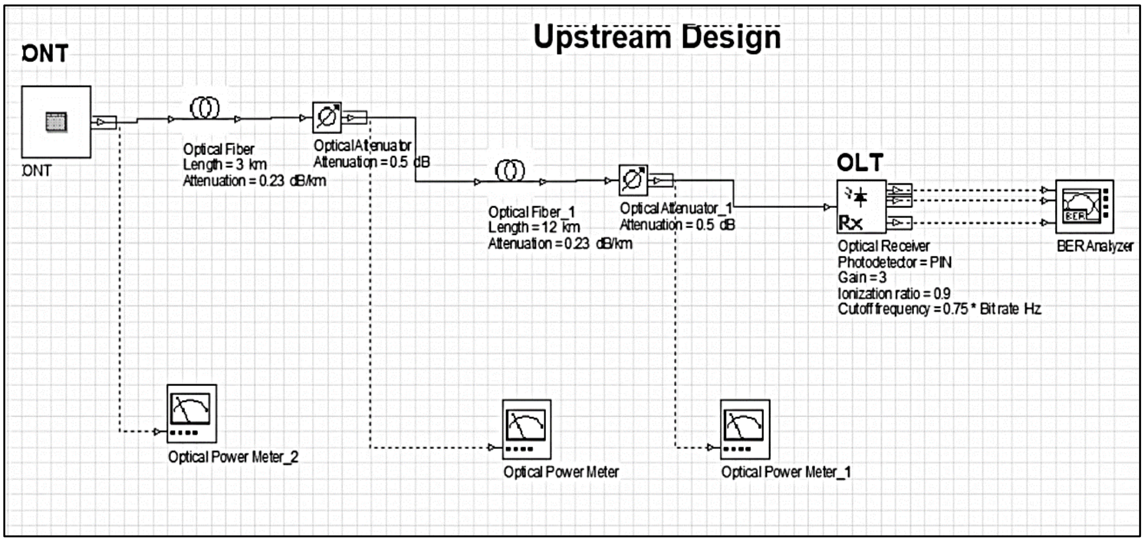


Figure 3-3 Upstream Simulation design

Based on components types, the network can be divided to active and passive components

3.2.1 Active Components

The two main active components used in PON, are OLT and ONT

3.2.1.1 Optical Line Terminal (OLT)

As shown in Figure 3-2 and described in details in section 3.2, the OLT is the transmitter what sending the optical signal through the network, it is the most important part of the network, where the electrical signal from the service provider's equipment is converted into optical signals and given to the feeder network. it is the ultimate network manager and controls all of the GPON network traffic, in the form video, data and voice signals, and sends them downstream to the ONTs on the other end. The OLT also receives these signals from the end user's ONT, and sends them on their way to their destination over the Internet.

Vendors uses different specifications for their OLT products in such as boards (service and control), GPON ports, switching capacity, in the research case study, the vender uses an equipment with board configuration two slots for both service and control,32 GPON ports and 720 Gbps switching capacity.

In this part of simulation, the important parameters what should be changed every stage of the evaluation scenarios are: frequency (wavelength ƛ) in nm, optical power in dbm and bit rate in bit/seconds.

3.2.1.2 Optical Network Terminal (ONT)

ONTs are the active components that located at the end-user premises, The ONT provide conversion of GPON signals from optical to electrical for delivery to the end device. ONTs also works as a router and access points through the WIFI, also it has multiple ethernet ports for connection to the user devices, phone sockets, the operator in the research case study uses the specifications: two phone sockets (POTS-RJ11), 4 Gigabit Ethernet ports (output ports), and one GPON class B+ port (input port).

3.2.2 Passive Components

The passive components have no electrical power needs, it carries the traffic signals contained within specific optical wavelength, the idea of the PON is to use them as no OAM for this port of network.

3.2.2.1 Optical Splitters

The Passive Optical Splitters are the components that splits the fiber and its signal. A signal from the OLTs is sent along a run of fiber. When it reaches the splitter, mirrors and glass in the component split the light into many fiber strands., As shown in Figure 3-2, there are two splitting ratios in the simulation, FDT (1:16) and FAT (1:8), the both splitters are distributing the signals a long distance, but FDT located in ODN area in a form of cabinets, while FAT closed to the user's premises.

3.2.2.2 Optical Fiber

In optical fiber part, the values of attenuation/km, optical power losses and the distance of fiber length should modify and check the results in each scenario.

3.2.3 Measurement Tools

In simulation model, some measurement tools are used to measure the optical power and quality of service.

3.2.3.1 Optical Power Meters

As shown in Figure 3-2, the optical power meters are located after every stage of the transmission design to measure the optical power before and after the main components of the network, thus can calculate the loss and attenuation, so the adjustment of power can be done to reach to the acceptable result, it measures in dbm or dbm units.

3.2.3.2 BER Analyzer

The BER analyzer is putted at the last stage to analyze and read the results of the simulation which should be evaluate the performance of PON design, the main parameters what will be focused in results are Q-factor, eye diagram, BER and the shape of eye diagram.

3.3 Performance Evaluation Scenarios

The parameters and values in the simulation scenarios are selected based on PON standards as shown in table 3-2

Table 3-2 show the simulation parameters for the five scenarios

# Scenario	PON	Bit Rate (B/s)	Wavelength nm	Optical Power dbm	Distance km
1	BPON	622M/155M	1490/1310	5/-3	15
2	EPON	1G/1G	1490/1310	5/-3	18
3	GPON	2.5G/1.25G	1490/1310	5/-3	20
4	10G-PON	10G/2.5G	1577/1270	10/1.5	60
5	XG-PON	10G/10G	1577/1270	10/1.5	60

3.4 Performance Evaluation Parameters

3.4.1 BER

$$\text{BER}= \frac{\boldsymbol{E}}{\boldsymbol{N}} \qquad 3.1$$

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:

$$\text{BER}= \frac{1}{2}(1-ref)\sqrt{Eb/NO} \qquad 3.2$$

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)

3.4.2Q Factor

Q factor defined according to the following formula:

$$Q= (I1-I0) / (\alpha1+\alpha0) \qquad 3.3$$

Where I1 is a logic level “1“, I0 is a logic level “0”, α1 is a standard deviation of a logic level “1”, α0 is a standard deviation of a logic level “0”. And the acceptable Q factor is > 6.

CHAPTER FOUR

RESULTS AND DISCUSSION

Chapter Four

Results and Discussion

This chapter shows the implementation details for the simulation and obtained results. Also discusses the results and some problems or concepts had met during the implementation of the system.

3.5 Simulation Scenarios

3.5.1 Scenario One (622M/155M)

Refer to what mentioned in Table 3.2 about the simulation scenarios based on PON standards, the first simulation (BPON) parameters and results were:

Table 0-1 shows results of scenario one:

Bit Rate (B/s)	**Wavelength (nm)**	**Power (dbm)**	**Distance (km)**	**Q-Factor**	**BER**
622M/155M	1490/1310	5	15	Up: 37.1708	Up: $6.227467\text{x}10^{-303}$
				Down :8.97995	Down: $1.31573x10^{-19}$

As mentioned in 3.4.2 the acceptable Q factor usually > 6, so, the results of scenario one what shows in Table 4-1 gives acceptable quality level of downstream (about 8.9) while upstream is quality is 37.1 (very high), BER values in upstream and downstream are near to zero for both, Figures 4-1 and 4-2 respectively represent the results of scenario one.

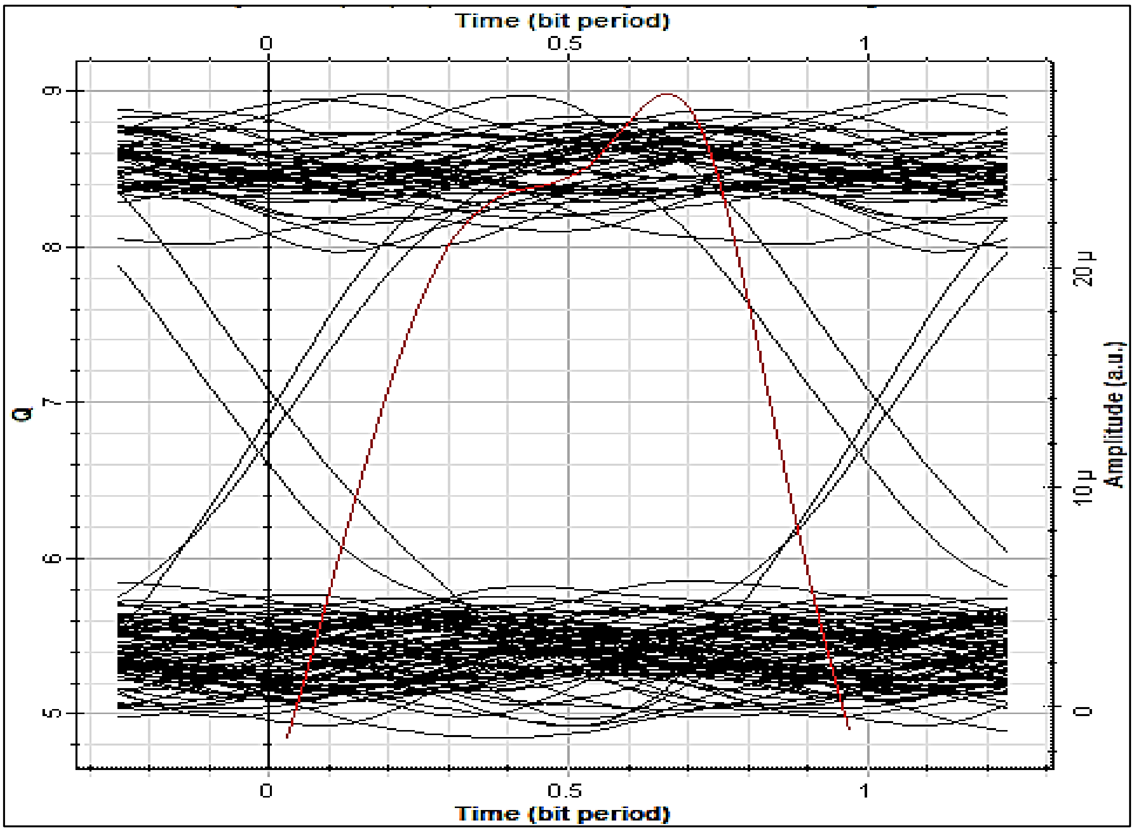


Figure 0-1 Downstream scenario one (622M/155M)

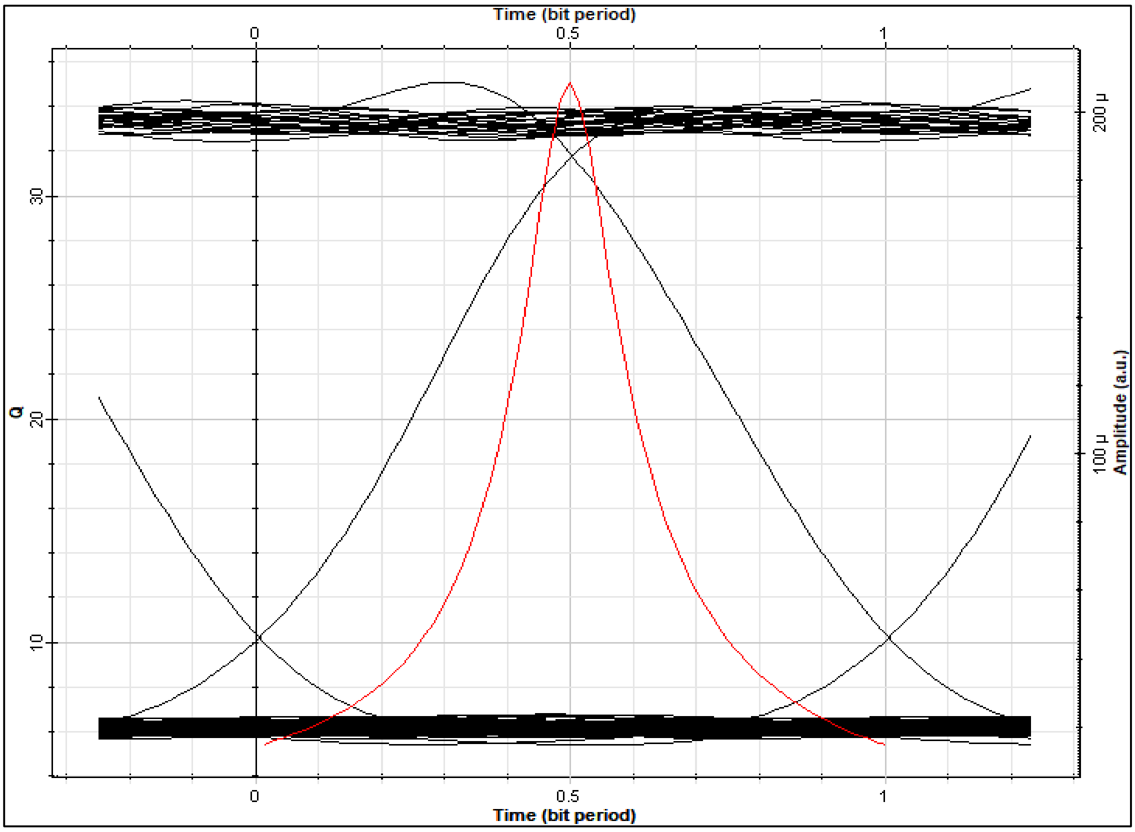


Figure 0-2 upstream scenario one (622M/155M)

3.5.2 Scenario Two (1G/1G) ″Symmetric″

In this scenario (EPON), change on bandwidth was done by upgrade upstream and downstream to 1G for both (increased), as well as the fiber length is increased to be 18 km instead of 15 km, as a result of that, it noticed that the Q-factor and BER were improved accordingly.

Table 0-2 shows result of scenario two

Bit Rate (B/s)	**Wavelength (nm)**	**Power (dbm)**	**Distance (km)**	**Q-Factor**	**BER**
1G/1G	1490/1310	5	18	Up: 38.473	Up: $4.94066\text{x}10^{-324}$
				Down: 13.8468	Down: $6.42994\text{x}10^{-44}$

From Table 4-2, the increase in bandwidth from 155/622M to 1/1G about 560% for upstream and 65% for downstream, this affects the results of downstream Q factor that increased from 8.9 to13.8 (55% better) and upstream improved from 37.1 to 38.4 (about 3% increase), for BER still near to zero without significant increase. The 3 kms increasing in fiber length from 15 to 18 doesn’t affect negatively in quality because 3 kms considered a minor value in PON systems, Figures 4-3 and 4-4 respectively represent the results of downstream and upstream.

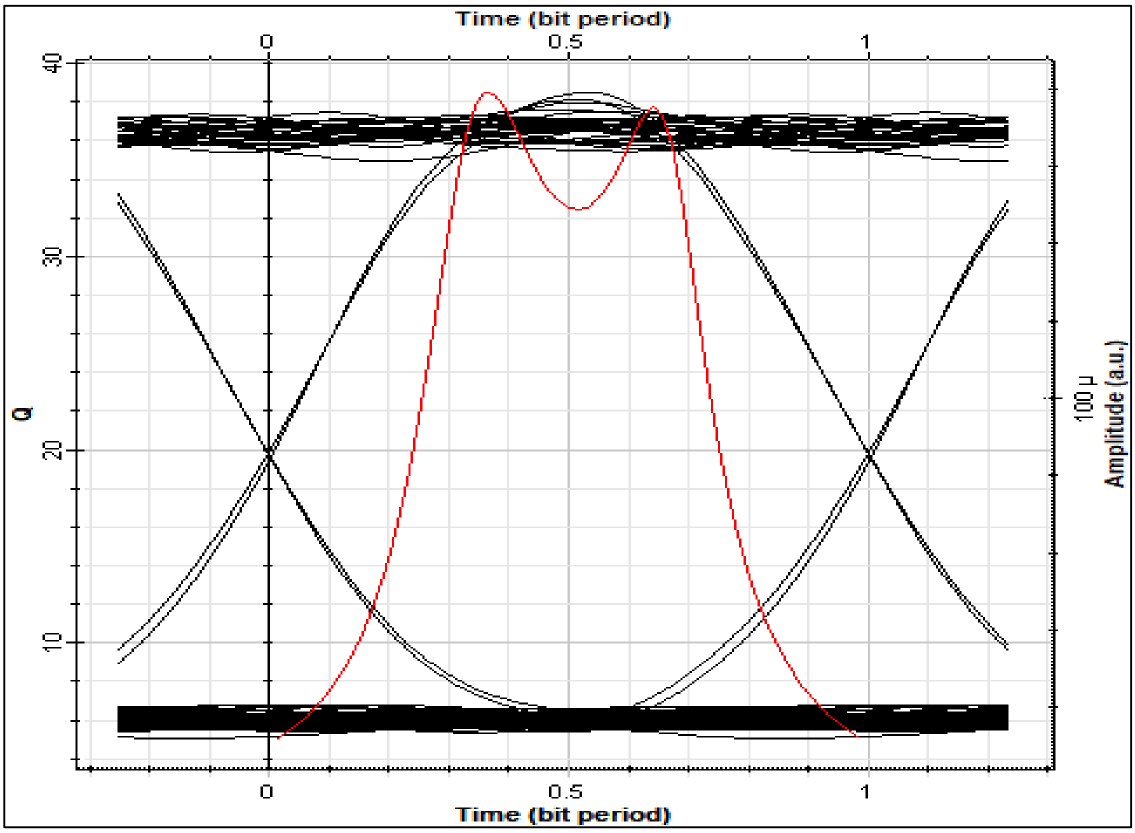


Figure 0-**3** downstream scenario two (1G/1G)

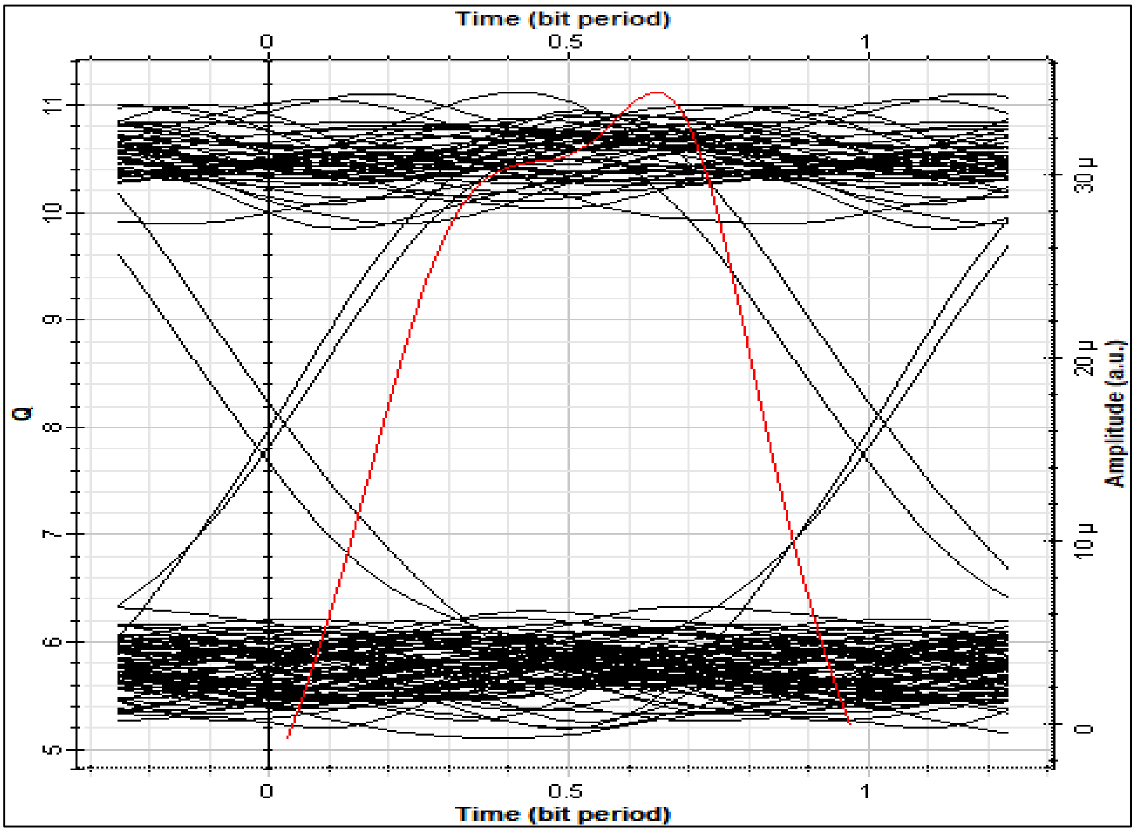


Figure 4-4 upstream scenario two (1G/1G)

3.5.3 Scenario Three (2.5G/1.25G)

In the third scenario, (GPON), which is the real scenario from case study as mentioned before, the upgrade in downstream and upstream to 2.5G/1.25 respectively, also the fiber length is increase to be 20 km, as a result of that, it noticed that the Q-factor and BER were improved accordingly.

Table 0-3 shows results of scenario three

Bit Rate (B/s)	**Wavelength (nm)**	**Power (dbm)**	**Distance (km)**	**Q-Factor**	**BER**
2.5G/1.25G	1490/1310	5	20	Up: 52.4806	Up: 0
				Down :18.6216	Down: $4.65053\text{x}10^{-77}$

In scenario three, what represent in Table 4-3 and Figures 4-5 and 4-6, the increase in bandwidth from 1/1G to 2.5/1.25G about (150% in downstream and 25% in upstream) ,also the fiber length increased 2 more kms to be 20 km (as per GPON standard for min length) ,reflect clear improvement in the results of Q factor specially in upstream value that increased about 51% better, also the BER in downstream improved from $6.42994\text{x}10^{-44}$ to be $4.65053\text{x}10^{-77}$ while it gives zero sharp bit error in upstream this time.

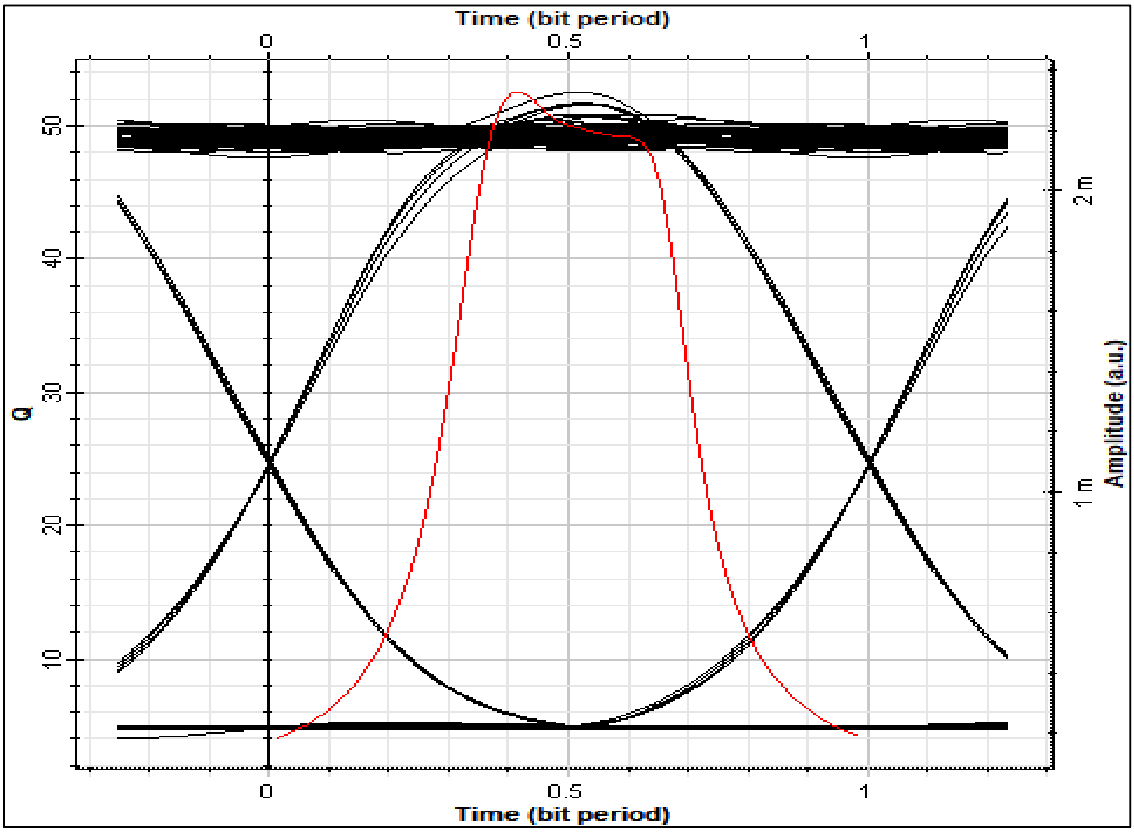


Figure 0-5 Downstream scenario three (2.5G/1.25G)

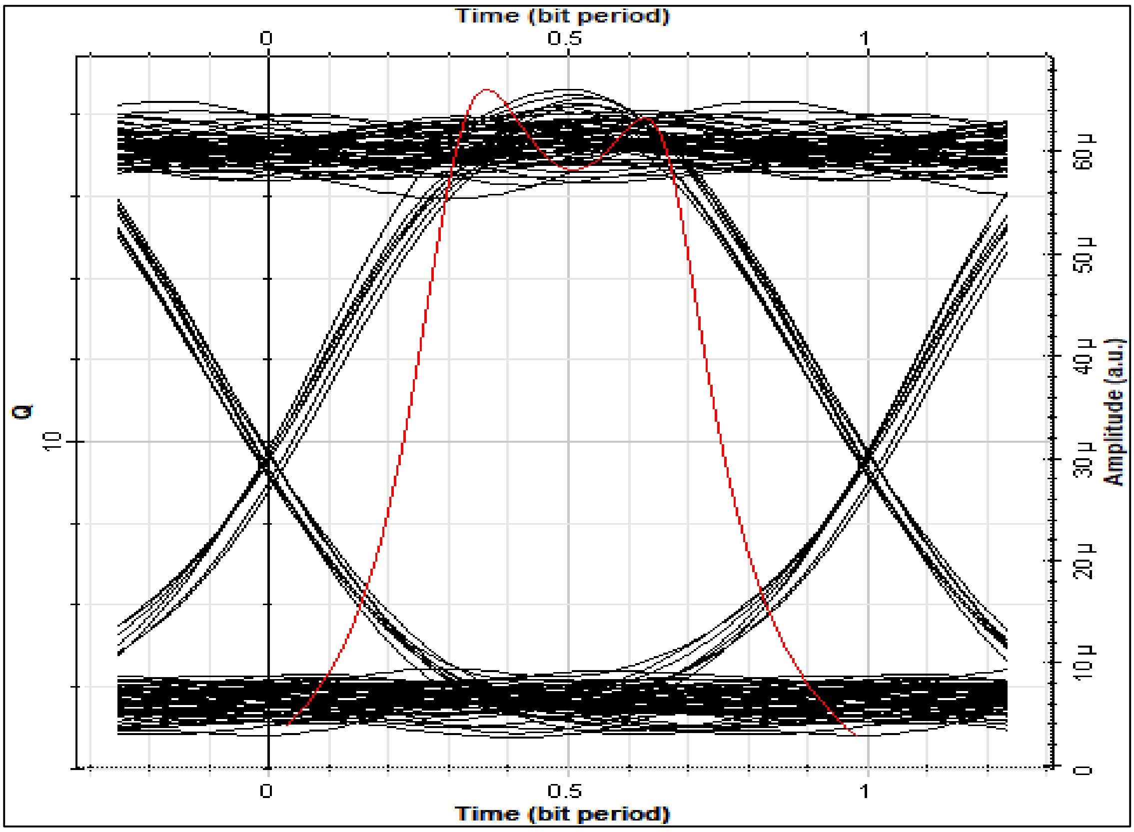


Figure 0-6 upstream scenario three (2.5G/1.25G)

3.5.4 Scenario Four (10G/2.5G)

In this scenario (10G-PON) the bit rates for downstream and upstream are 10G/2.5G respectively, also as per standard the wavelength of this scenario changed from 1490/310 to 1577/1270, and optical power increased from 5 dbm to 10 dbm, with no change in min fiber length.

Table 0-4 shows the results of scenario four

Bit Rate (B/s)	**Wavelength (nm)**	**Power (dbm)**	**Distance (km)**	**Q-Factor**	**BER**
10G/2.5G	1577/1270	10	20	Up: 80.4059	Up: 0
				Down :36.094	Down: $1.39249x10^{-285}$

As a results of these changes, as shown in Table 4-4 the Q-factor is jumped from 52.4806 to 80.4059 (about 55%) in the upstream, and clear improvement in downstream from 18.6216 to 36.094 (almost 100%), and this due to big increase in bit rate (400% and 100%) and optical power (100%) that also affect directly in downstream BER to be 1.39249 x 10^{-285} compare with $4.65053x10^{-77}$ in GPON what was a big jump in QoS. Figures 4-7 and 4-8 illustrates clear different in eye diagram shape.

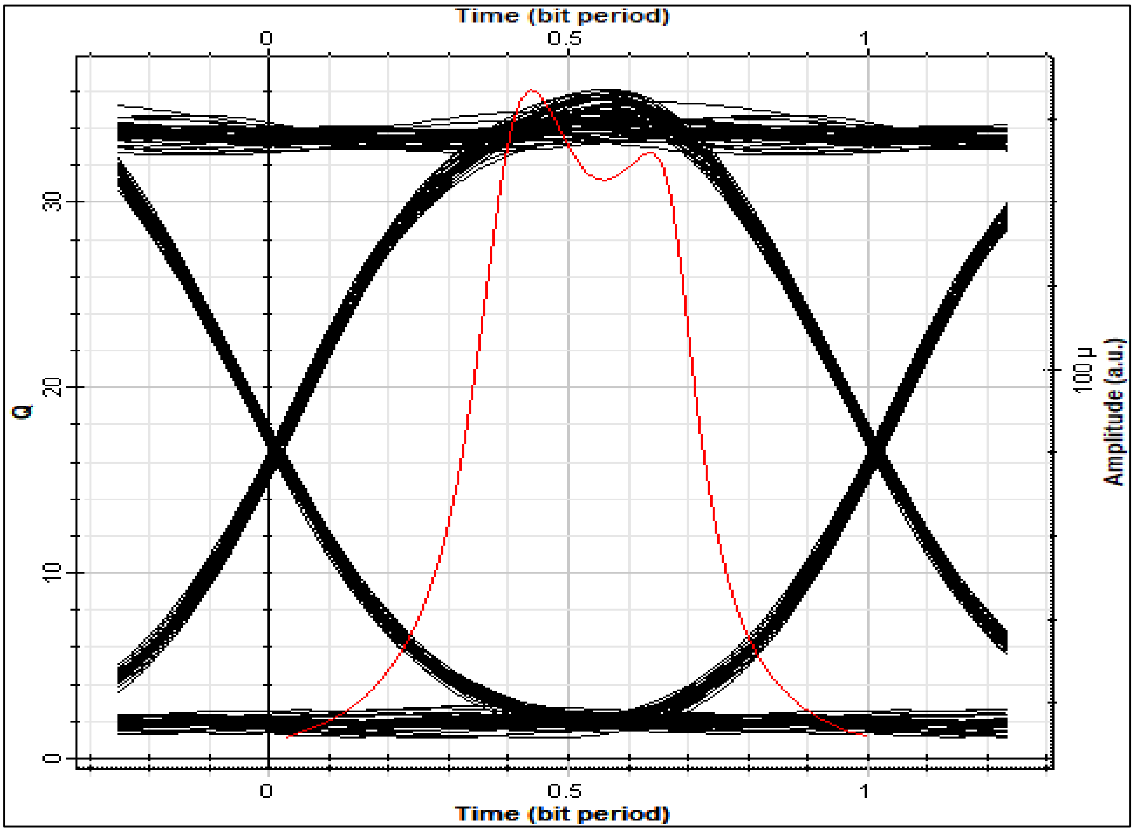


Figure 0-7 downstream scenario Four (10G/2.5G)

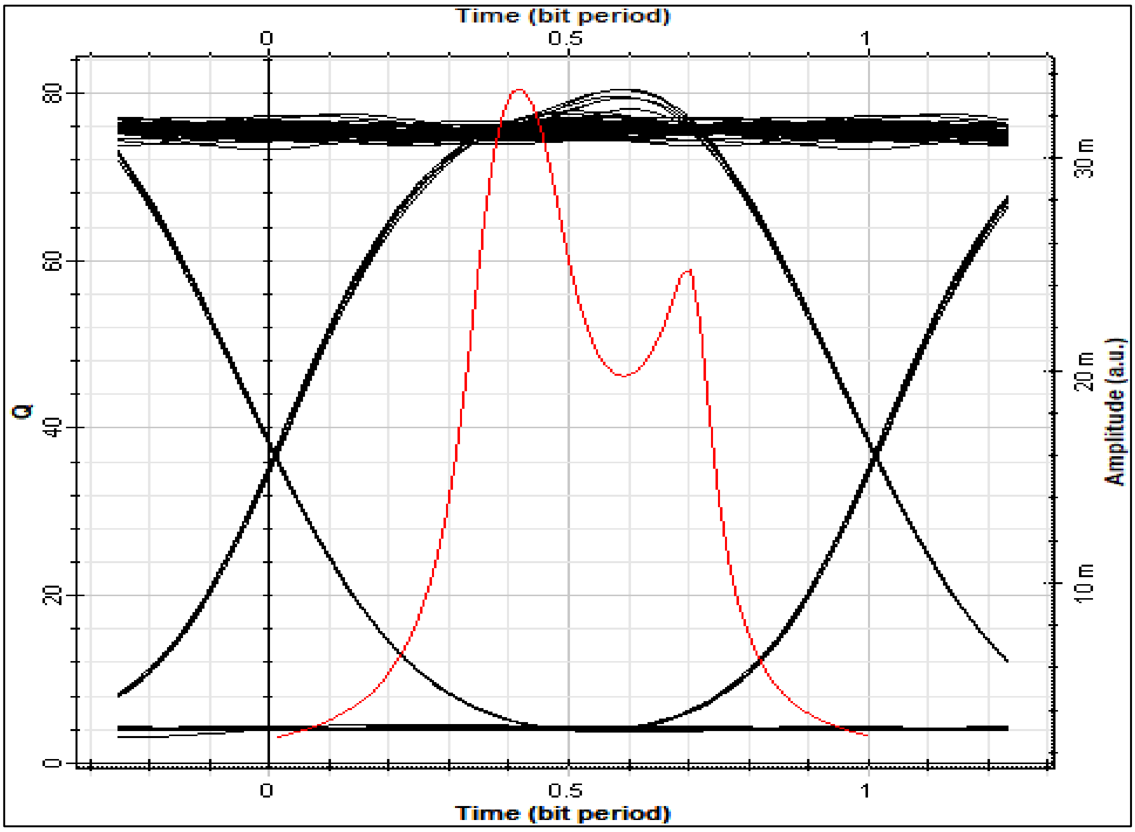


Figure 0-8 upstream scenario Four (10G/2.5G)

3.5.5 Scenario Five (10G/10G) ″Symmetric″

In the last scenario (XG-PON), for the bit rates just the upstream increased four times to be 10 G, to be symmetric, also the min fiber length doubled to be 40 kms as per standards.

Table 0-5 shows the results of scenario five

Bit Rate (B/s)	**Wavelength (nm)**	**Power (dbm)**	**Distance (km)**	**Q-Factor**	**BER**
10G/10G	1577/1270	10	40	Up: 115.518	Up: 0
				Down :36.094	Down: $1.39249x\ 10^{-285}$

In Table 4-5 and Figures 4-9 and 4-10, The change of bit rate in upstream is from 2.5G to 10G (300%), and although the min fiber length is increased 100% from 20 to 40 km what should affect in quality, but the Q-factor highly improved from 80.4 to 115.5, that indicates increasing with big value in bit rate is the most It is the most influential factor the fiber length even if it doubled.

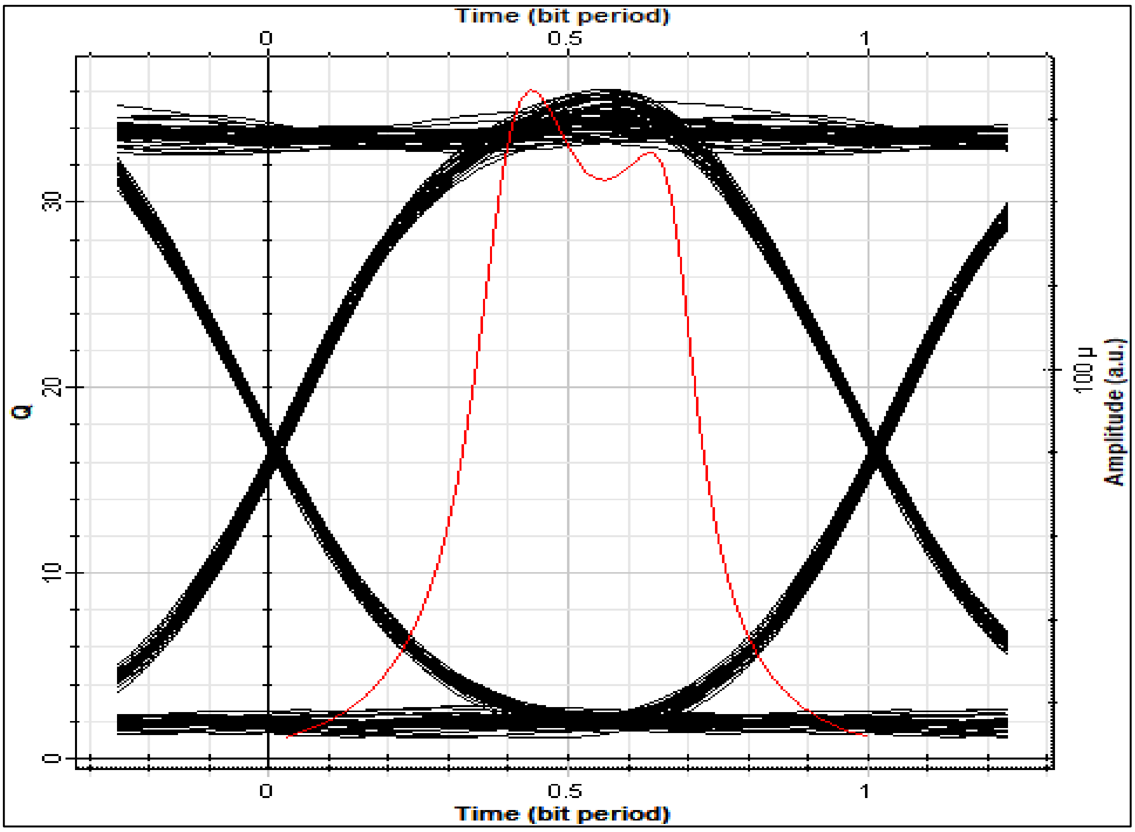


Figure 0-9 Downstream scenario five (10G/10G

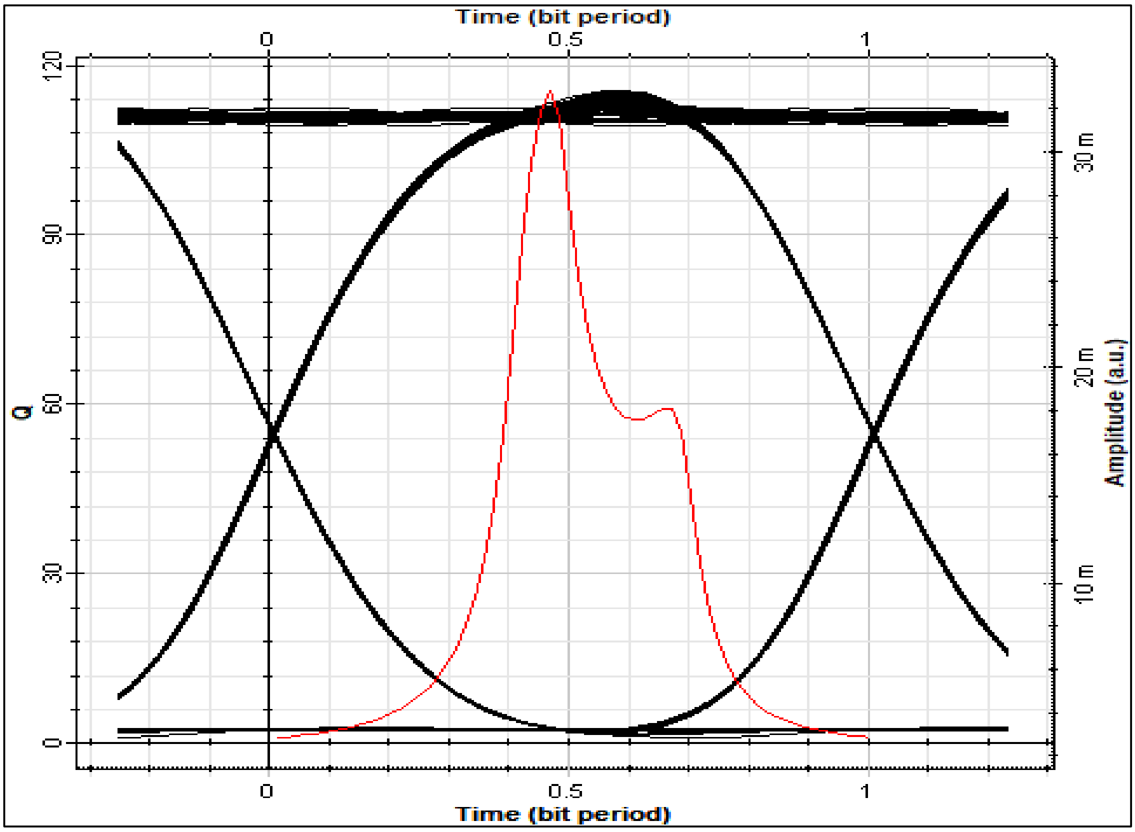


Figure 0-10 upstream scenario five (10G/10G)

3.6 Results Analysis and Discussions

The results for the all five scenarios illustrated in the below Table 4-6 what focus on bit rate changes among the scenarios.

Table 0-6 All simulation scenarios results:

# Scenario	Bit Rate (B/s)	Results			
		Q-Factor		BER	
		Upstream	Downstream	Upstream	Downstream
1	622M/155M	37.1708	8.97995	$6.227467\text{x}10^{-303}$	$1.31573\text{x}10^{-19}$
2	1G/1G	38.4730	13.8468	$4.94066\text{x}10^{-324}$	$6.42994\text{x}10^{-44}$
3	2.5G/1.25G	52.4806	18.6216	0	$4.65053\text{x}10^{-77}$
4	10G/2.5G	80.4059	36.0940	0	$1.39249\text{x}10^{-285}$
5	10G/10G	115.5180	36.0940	0	$1.39249\text{x}10^{-285}$

In the simulation, many variables were used to have a varied performance evaluation, but focused on optical power, fiber length and the main factor was bit rate as shown in Table 4-6. The evaluation will seek for higher Q-factor and lower BER.

3.6.1 Change of optical power

It has been noticed that, the higher optical power means better results, because its signal could travel over longer distance, in the research simulation, only two values of optical power were used, in scenario one, two and three the power was 5 dbm, but when the power is increased to be 10 dbm in fourth and fifth scenarios there was a great improvement in the result in terms of Q factor and BER. Note that the power can be modified and adjusted only in OLT part, while in ONT it is constant as specified by the manufacturer.

3.6.2Change of fiber length

As mentioned in 4.6.1, tables and figures of simulation, the effect of fiber length appears directly in the results, there is an inverse relationship between ″Q-factor, BER″ and fiber length, means the longer fiber gets fewer quality results unless other factors changed especially optical power, in scenario four and five although the increase in length to be 40 km in both, it has been noticed that the results have maintained their good performance, that’s due to optical power increasing.

3.6.3 Change of wavelengths

In principle, the energy associated with a wave is directly proportional to its frequency. hence, the higher the frequency, the shorter the wavelength and the higher the energy of the wave. So in the upstream direction it used 1310 and 1270 compare with 1490 and 1577 in downstream, as mentioned before in ONTs it could not change or adjust optical power, so it should select lower wavelength, note that the used wavelengths as ITU-T and IEEE standard (central wavelength) for all scenarios, it doesn’t changed in the first three scenarios (14910/1310), and then changed in scenario four and five to (1577/1270) , the effect of this changed is minor as showed in results.

3.6.4 Change of bit rate

In this research, the main focus is about the changes of bit rate and how it affects the performance, because the main factor in end-user side is the quality of service which is measures by the bit rate and BER, so as to standards ITU-T and IEEE, the five scenarios were illustrate the family of PON systems, and noticed that there is a direct correlation between the bit rate and best results, that higher bit rates gives better performance. For example, in scenario five 10Gbs gives Q-Factor ″115″ and ″0″ BER which the best performance ever in simulation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Chapter Five

Conclusion and Recommendations

4.1 Conclusion

The main aim of this research is to test the performance of PON systems uses shared fiber for both downstream and upstream data for a sample of eight end-users ONTs and one OLT and evaluate the final results. In this research network design was done in block diagrams and then simulated to five scenarios using Optisystem-Optiwave version7.0 software by taking different values of transmitted power, fiber cable length, operating wavelengths and focused on the bit rates values, then the results were evaluated based on BER, Q factor and eye pattern obtained. The five scenarios were BPON (622/155M), EPON(1G/1G), GPON (2.5G/1.25G),10G-PON (10G/2.5G) and XG-PON (10G/10G) respectively. Distance was changed from 15 km,18 km,20 km up to 40 km and the optical power changed once from 5 dbm to 10 dbm as well as one change in wavelength from 1490/1310 nm to 1577/1270 nm. The achieved results changed gradually from 37.1708 to 115.5180 for Q-factor that almost improved with 310 times, also the BER changes from $1.31573x10^{-19}$ reached to $1.392\,x10^{-285}$ that is near to 1500%. It observed that optical power and bit rate values changes effects directly at both upstream and downstream results comparing to fiber length and wavelength's changes.

4.2 Recommendations

The simulation of the research was done by Optiwave system v7.0, which has a limitation on its parameters values, many tries to put bit rate values of 25 Gbps and above (G.hsp.x) , but the performance analyzer didn't give any results for Q-factor and BER, even if the optical power was increased to 30 dbm, so it recommended that for coming researches to use a higher versions of Optiwave software (v.10 and above) that can manage higher values of optical power and bit rates and it can be more flexible and have a more techniques and more parameters values for simulation.

More tests and simulations in the areas of splitting ratios (1:32 and above) and to focus more in longer fiber length and higher optical power tests (30 dbm and above) with higher bit rates (25 G) and above as mentioned, are recommended, also extensive and deep study to by WDM and TWDM technologies.

References

[1] ″https://newwavedv.com/applications/telecommunications/what-is-epon/″ [Online].[Accessed 23/ 8 /2021]

[2] Ali, M., Design, develop and performance analysis of a gigabit passive optical network for quad play architecture. 2017.

[3] Lin, C., Broadband optical access networks and fiber-to-the-home: systems technologies and deployment strategies. 2006: John Wiley & Sons.

[4] ″https://www.fcc.gov/general/types-broadband-connections#satellite″ [Online].[Accessed 23/ 8 /2021]

[5] G. Keiser, "Optical Fiber Communications", McGraw-Hill, 2000.

[6] ITU-T, R.G., 989.1," 40-Gigabit-capable passive optical networks (NG-PON2): General requirements,". International Telecommunication Union, 2013.

[7] ″https://forum.huawei.com/enterprise/en/the-introduction-of-the-t-cont-type/thread/581658-100181″ [Online].[Accessed 25 8 2021]

[8] ″https://forum.huawei.com/carrier/en/thread-445979.html″ [Online].[Accessed 12 /9/ 2021]

[9] ″https://docplayer.net/86320980-Itu-t-pon-standards-progress-and-recent-activities-q2-sg15.html″[Online].[Accessed 10 /12 /2021]

[10] M. Kumari, R. Sharma, and A. Sheetal, “Passive Optical Network Evolution to Next Generation Passive Optical Network: A Review,” 2018 6th Ed. Int. Conf. Wirel. Networks

[11] ″https://images.slideplayer.com/11/3228074/slides/slide_16.jpg ″[Online].[Accessed 3 1 2022]

[12] ″https://www.tutorialspoint.com/ftth/ftth_gpon.htm″[Online].[Accessed 3/ 1/ 2022]

[13] Liu, X., et al., Multipoint control protocol with look-ahead for wavelength division multiplexed ethernet passive optical network. Journal of Optical Communications and Networking, 2014.

[14] Gutierrez, D., J. Cho, and L.G. Kazovsky. TDM-PON security issues: Upstream encryption is needed. in National Fiber Optic Engineers Conference. Optical Society of America. 2007.

[15] Xie, Y., et al. Crosstalk noise and bit error rate analysis for optical network-on-chip. in Design Automation Conference. IEEE. 2010.

[16] ″https://www.edn.com/eye-diagram-basics-reading-and-applying-eye-diagrams/″ [Online].[Accessed 3 /12 / 2021]

[17] Freude, W., et al. Quality metrics for optical signals: Eye diagram, Q-factor, OSNR, EVM and BER. in 2012 14th International Conference on Transparent Optical Networks (ICTON). IEEE 2012.

[18] ″https://www.researchgate.net/figure/BER-versus-Q-factor_fig1_229085615″ [Online].[Accessed 14 /1 /2022]

[19] Rose, F., S. Jacob, and R. Renjith, Design and implementation of FTTH network based on GPON technology. International Journal of Innovations in Scientific and Engineering Research, 2017.

[20] Al-Shammari, H.Q., et al. Energy efficient service embedding in IoT over PON. in 2019 21st International Conference on Transparent Optical Networks (ICTON). IEEE .2019.

[21] Hamza, M.E.-G. and K.B. Bugaje. Enhancement of gigabit passive optical highspeed network using fiber-to-the-home. in 2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE). 2018.

[22] Awalia, W. and A. Pantjawati. Performance simulation of fiber to the home (FTTH) devices based on optisystem. in IOP Conference Series: Materials Science and Engineering. IOP Publishing 2018.

[23] Gutierrez, D., et al. FTTH standards, deployments and research issues. in 8th Joint Conference on Information Sciences, Salt Lake City, Utah. Citeseer 2005.

[24] Alam, S.J., et al., Bit error rate optimization in fiber optic communications. International Journal of Machine Learning and Computing, 2011.

[25] Altabas, J.A., et al. 25Gbps quasicoherent receiver for beyond NG-PON2 access networks. in 2018 European Conference on Optical Communication (ECOC). IEEE .2018.

[26] Angilella, V., W. Ben-Ameur, and M. Chardy, Design of fiber cable tree FTTH networks. Electronic Notes in Discrete Mathematics, 2018.

[27] Ansari, N. and J. Zhang, Media access control and resource allocation: For next generation passive optical networks. Springer Science & Business Media 2013.

[28] Cale, I., A. Salihovic, and M. Ivekovic. Gigabit passive optical network-GPON. in 2007 29th International Conference on Information Technology Interfaces. IEEE. 2007.

[29] Chen, L., S. Dahlfort, and D. Hood. Evolution of Pon: 10G-Pon and Wdm-Pon. in Asia Communications and Photonics Conference and Exhibition. IEEE .2010.

[30] Effenberger, F.J., The XG-PON system: Cost effective 10 Gb/s access. Journal of lightwave technology, 2011

[31] Effenberger, F.J. PON standardisation status and future prospects. in 45th European Conference on Optical Communication (ECOC 2019). IET. 2019.

[32] Elbers, J.-P. Optical access solutions beyond 10G-EPON/XG-PON. in Optical Fiber Communication Conference. Optical Society of America 2010.

[33] Hernández, J.A., et al., Meeting the traffic requirements of residential users in the next decade with current FTTH standards: how much? how long? IEEE Communications Magazine, 2019.

[34] ITU-T, R.G., 989.1," 40-Gigabit-capable passive optical networks (NG-PON2): General requirements,". International Telecommunication Union, 2013.

[35] Jain, S., et al., World's first XG-PON field trial. Journal of lightwave technology, 2011.

[36] Jiang, J., M. Handley, and J. Senior, Dynamic bandwidth assignment MAC protocol for differentiated services over GPON. Electronics Letters, 2006.

[37] Keiser, G., Optical fiber communications. McGraw-Hill New York. 2000.

[38] Khotimsky, D.A., NG-PON2 transmission convergence layer: A tutorial. Journal of Lightwave Technology, 2016.

[39] Kim, J., H. Bang, and C.-S. Park, Design and performance analysis of passively extended XG-PON with CWDM upstream. Journal of lightwave technology, 2012.

[40] Kimura, S. WDM/TDM-PON technologies for future flexible optical access networks. in OECC 2010 Technical Digest. IEEE.2010.

[41] Kumara, S., G. Kumarb, and C. Kumar, Performance Evaluation of FTTH network for High Speed Application Services.2015.

[42] Lambert, S., et al. Power consumption evaluation for next-generation passive optical networks. in 2013 24th Tyrrhenian International Workshop on Digital Communications-Green ICT (TIWDC). IEEE .2013.

[43] Luo, Y., et al., Time-and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation PON stage 2 (NG-PON2). Journal of lightwave technology, 2012.

[44] Nesset, D., NG-PON2 technology and standards. Journal of Lightwave Technology, 2015.

[45] Penze, R.S., et al., Fiber powered extender for XG-PON/G-PON applications. Journal of optical communications and networking, 2014.

[46] Poon, K., D. Mortimore, and J. Mellis, Designing optimal FTTH and PON networks using new automatic methods. 2006.

[47] Safrianti, E., L.O. Sari, and D.P.R. Yuhana, Broadband Network Fiber to the Home (FttH) Design for Improving Performance of Information and Telecommunication Network in Riau University. International Journal of Electrical, Energy and Power System Engineering, 2018.

[48] Selmanovic, F. and E. Skaljo. GPON in telecommunication network. in International Congress on Ultra Modern Telecommunications and Control Systems. 2010.

[49] Skubic, B., A. Lindström, and S. Dahlfort. Power efficiency of next-generation optical access architectures. in 2010 Conference on Optical Fiber Communication (OFC/NFOEC), collocated National Fiber Optic Engineers Conference. 2010.

[50] Spruytte, J., et al. Joint-Rollout of FTTH and Smart City Fiber Networks as a Way to Reduce Rollout Cost. in 2019 CTTE-FITCE: Smart Cities & Information and Communication Technology (CTTE-FITCE). 2019.

[51] Straullu, S., S. Abrate, and R. Gaudino, Self-coherent reflective passive optical networks. Advances in Optical Fiber Technology: Fundamental Optical Phenomena and Applications, 2015.

[52] van Veen, D., et al. Options for TDM PON beyond 10G. in Access Networks and In-house Communications. Optical Society of America.2012.

[53] Weimann, P., et al. Design Considerations for Next-Generation Optical Drop Cables Using Bend-Optimized Fiber. in Proceedings of the 56th International Wire & Cable Symposium . 2007.