Passive Optical Network Performance Analysis
Using Dijkstra's Algorithm

تحليل أداء الشبكات الضوئية الغير فعالة باستخدام خوارزمية الدايجسترا

Thesis Submitted in Partial Fulfilment to the Requirements for the award of the Degree of M.SC. In Electronics Engineering (Communications)

Presented by:
Laila Osama Mubarak

Supervised by:
Dr. Mudathir Abdallah Osman Fagiri

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قال تعالى:

"قَالُوْا سُبْحَانَكَ لا عَلَمَنَا إِلَّا إِلَامَعَتَكَ إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ"

صدق الله العظيم

(سورَة البقرة: الآية 32)
Acknowledgement

I extend my thanks to all who stood with me to achieve this research which it came because of grace of God and reconcile.

I would like to give special thanks to my supervisor, Doctor Mudather Fajri, for his great help and support.

And my teachers that gave me information and all staff in Sudan University.

Finally yet importantly I dedicate this project for everyone that helped me to be at the place that I am today.
Dedication

Dedication to my mother…
With warmth and faith…

Dedication to my father…
With love and respect…

Dedication to my friends…
Whom we cherish their friendship

Dedication to my special people
Who mean so much to me…

Dedication to all my teachers…
In whom I believe so much…
Abstract

A fiber optic communication system has been employed using 2.5G (downstream) next generation passive optical network architecture. The problem is the shorter range possible commonly no more than 20 km, that reason of study and analysis the optimal requirements, configurations and parameters that can used to design and implement an XG-PON downstream Network. The simulation was done using Matlab. The results have been compared for non-return to zero and return to zero formats for downstream data in terms of quality factor value. It has been observed that return to zero modulation format is superior compared to conventional on-return to zero modulation and the distance has been increased to 80km.
المستخلص

تم استخدام نظام اتصالات الألياف البصرية باستخدام معمارية الشبكات الضوئية الغير فعالة من الجيل التالي 2.5 قيفة (المصب). والمشكلة هي المدى الأقصر الممكن و الذي لا يزيد عادة عن 20 كم، وهذا سبب دراسة وتحليل المتطلبات المثلى، والتكوينات والمعاملات التي يمكن استخدامها لتصميم وتنفيذ شبكة الضوئية الغير فعالة من الجيل التالي (المصب). تم إجراء المحاكاة باستخدام ماتلاب، وتمت مقارنة النتائج بالنسبة إلى صيغ عدم العودة لصفر العودة للصفرليبيات النهائية من حيث قيمة معامل الجودة، ول sonra أن صيغة العودة لصفر أفضل من عدم العودة لصفر التقليدية، وتمت زيادة المسافة إلى 80كم.
**Abbreviations**

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<tr>
<td>AWGN</td>
<td>Additive White Gaussian Noise</td>
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<td>AON</td>
<td>Active Optical Network</td>
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<td>BER</td>
<td>Bit Error Rate</td>
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<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CO</td>
<td>Central Office (telephone switching center)</td>
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<tr>
<td>CWDM</td>
<td>Coarse Wavelength Division Multiplexing</td>
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<td>dB</td>
<td>Decibel</td>
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<tr>
<td>DWDM</td>
<td>Dense Wavelength Division Multiplexing</td>
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<td>DBA</td>
<td>Dynamic Bandwidth Assignment</td>
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<td>DS</td>
<td>Down Stream</td>
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<tr>
<td>3DTV</td>
<td>Three Diminutions Television</td>
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<tr>
<td>Erfc</td>
<td>Complementary Error Function</td>
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<td>EPON</td>
<td>Ethernet Passive Optical Network</td>
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<td>FSAN</td>
<td>Full Service Access Network</td>
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<tr>
<td>FTTx</td>
<td>Fiber To The X</td>
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<tr>
<td>FAX</td>
<td>Far Away Xerox(xerographic printer)</td>
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<tr>
<td>FTTB</td>
<td>Fiber To The Building</td>
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<tr>
<td>FTTC</td>
<td>Fiber To The Curb</td>
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<tr>
<td>FTTCab</td>
<td>Fiber To The Cabinet</td>
</tr>
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<td>FTTH</td>
<td>Fiber To The Home</td>
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<td>FTTCell</td>
<td>Fiber to the Cell</td>
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<tr>
<td>G-PON</td>
<td>Gigabit Passive Optical Network</td>
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<tr>
<td>Gbps</td>
<td>Gigabit per Second</td>
</tr>
<tr>
<td>HDTV</td>
<td>High Definition Television</td>
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<tr>
<td>ITU-T</td>
<td>International Telecommunication Union–Telecom sector</td>
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IEEE Institute of Electrical and Electronics Engineers
IP Internet Protocol
IPTV Internet Protocol Television
InGaAs Indium Gallium Arsenide
LR-PON Long-Reach PON
LTE Long Term Evolution
MTU Multi-Tenant Unit
MDU Multi Dwelling Unit
NG-PONs Next Generation Passive Optical Networks
NRZ Non Return To Zero
NS-3 Network Simulator 3
nA Nano Ampere
OMNET Objective Modular Network Tested
OLT Optical Line Terminal
ONUs Optical Network Units
ODN Optical Distribution Network
ODSM Opportunistic and Dynamic Spectrum Management
OFDMA Orthogonal Frequency Division Multiple Access
OCDMA Optical Code Division Multiple Access
OMCI Optical Network Termination Management and Control Interface
ONT Optical Network Terminal
OOK On-Off Keying
PSTN public Switching Telephone Network
PBX Private Branch Exchange
P2MP Point-To-Multipoint
<table>
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<th>Abbreviation</th>
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<td>PONs</td>
<td>Passive Optical Networks</td>
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<td>P2P</td>
<td>Point To Point</td>
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<td>Q-factor</td>
<td>Quality Factor</td>
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<tr>
<td>ROI</td>
<td>Return On Investment</td>
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<tr>
<td>RMS</td>
<td>Root Mean Square</td>
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<td>RZ</td>
<td>Return To Zero</td>
</tr>
<tr>
<td>SBU</td>
<td>Single Business Unit</td>
</tr>
<tr>
<td>SFU</td>
<td>Single Family Unit</td>
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<tr>
<td>SNR</td>
<td>Signal-To-Noise Ratio</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>US</td>
<td>Upstream</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice Over Internet Protocol</td>
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<tr>
<td>WDM</td>
<td>Wavelength Division Multiplexing</td>
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<tr>
<td>WDMA</td>
<td>Wavelength Division Multiple Access</td>
</tr>
<tr>
<td>WIFI</td>
<td>Wireless Fidelity</td>
</tr>
<tr>
<td>WIMAX</td>
<td>Worldwide Interoperability For Microwave Access</td>
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<tr>
<td>XG-PON1</td>
<td>Next Generation Passive Optical Network</td>
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CHAPTER ONE

INTRODUCTION

1.1 Preface

In telecommunications, the term asymmetric (also asymmetrical or non-symmetrical) refers to any system in which the data speed or quantity differs in one direction as compared with the other direction, averaged over time. Asymmetrical data flow can, in some instances, make more efficient use of the available infrastructure than symmetrical data flow, in which the speed or quantity of data is the same in both directions, averaged over time[1].

Increasing demand of bandwidth due to rapid growth of P2P, HDTV, 3DTV and Cloud Computing creates new challenges to bandwidth deployment and operation. Passive optical networks (PONs) are the most important class of fiber access network in the world today. A PON is a point-to-multipoint optical network, where an Optical Line Terminal (OLT) at the Central Office (CO) is connected to many Optical Network Units (ONUs) at remote nodes through one or multiple optical splitters. The network between the OLT and the ONU is passive i.e., it does not require any power supply [1][2]. The direction of PON evolution is a key issue for the telecom industry. As the users’ demands for bandwidth are ever increasing, next generation passive optical networks (NG-PONs) are being standardized by ITU-T and IEEE standards. Furthermore, the future access network requires increased bit rates up to 10 GB/s to satisfy the increasing traffic demands. Two stages of NG-PON evolution have been planned by Full Service Access Network (FSAN) group: NG-PON1 and NG-PON2. NG-PON1 extended from the existing G-PON standards and compatible with the current optical
distribution network (ODN). NG-PON2 is a long-term solution with an entirely new optical network type. In contrast, NG-PON1 is a mid-term upgrade from the G-PON system with backward compatibility to the existing fiber deployments. NG-PON1 is also called XG-PON1. XG-PON1 features asymmetric transmission of 10 GB/s downstream and 2.5 GB/s upstream [3]. 10Gb/s is selected for downstream transmission, as a cost effective way to transmit large amounts of data. In the upstream direction, 10 Gb/s burst mode time division multiple access (TDMA) is a challenging issue for its high data rate. The difficulty of designing and manufacturing such components prohibits using 10 Gb/s in the upstream direction. Thus 2.5Gb/s is selected as an economical and practical upgrade solution [4].

XG-PON2 is a symmetric system with the bidirectional rate of 10 GB/s. To ensure the smooth upgrade from GPON to XG-PON coexistence of both systems is mandatory and it can be done with wavelength division multiplexing [5]. A coexisting XG-PON and GPON can be very cost effective as the system shares common infrastructure and reduces the number of central offices (CO). As early as the year 2009, PONs began appearing in corporate networks. Users were adopting these networks because they were cheaper, faster, lower in power consumption, easier to provision for voice, data and video, and easier to manage, since they were originally designed to connect millions of homes for telephone, Internet and TV services[6].

Passive Optical Networks (PON) provide high-speed, high-bandwidth and secure voice, video and data service delivery over a combined fiber network. In the United States, Europe, and several Asian countries, because residential customers require high-bit-rate connections for broadband services.
This demand for bandwidth has exceeded recent predictions, driven mostly by a number of factors, including the huge success of Internet video streaming services such as YouTube, the unanticipated success of high-definition television (HDTV), and the growing popularity of online social media sites where people meet, collaborate, and, more important, exchange photographs, video, and audio content with each other[7]. The number of users demanding high bandwidth continues to increase at a rapid pace. Consequently, many service providers are planning networks capable of offering 50 Mb/s, 100 Mb/s, or higher bandwidth per customer. In contrast to many existing broadband technologies, such as digital subscriber line (DSL) and wireless access, fiber access can easily fulfill such bandwidth requirements, on a per customer basis, while still being capable of offering higher capability in the future. Several fiber access network architectures have been developed, such as point-to-point (P2P)[8]. Active optical network (AON) and passive optical network (PON) Furthermore, there are three main types of PONs utilizing different resource sharing technologies: time-division multiplexing (TDM) PON, wavelength-division multiplexing (WDM) PON, and hybrid WDM/TDM PON. It has been examined that the feasibility of RZ format in XG-PON system is not available as such in the literature and thus is explored here to investigate the performance of 10G/2.5G asymmetric XG-PON system for NRZ and RZ data formats [9].

1.2 Problem Definition

The primary problem of passive optical network is the shorter range possible, commonly no more than 20 km.
1.3 Objectives
The aim of this research is to Design and analysis a downstream XG-Passive optical Network (PON). Moreover increase the distance of fiber optical.

1.4 Methodology
Study and analysis the fiber optic communication system based on 10G(down- stream) XGPON architecture. Evaluate the performance of the system for non-return-to-zero (NRZ) and return-to-zero (RZ) data formats by varying the length of the fiber for XG-PON system.

1.5 Thesis Outline
This thesis is divided into five chapters, in chapter two represents the literature review and related works, in the third chapter the project methodology along with the scenarios and parameters used in the simulation was represented while Chapter Four includes the results and discussions in chapter five: Conclusion and Recommendations, in last of the thesis References.
CHAPTER TWO
BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

In this chapter an introduction to the passive optical network was included with a brief notes on their structures and characteristics, and the coverage area along with the components of the network, moreover a summary of related works was included.

2.1.1 Passive Optical Network

A passive optical network (PON) features a point-to-multi-point (P2MP) architecture to provide broadband access. The P2MP architecture has become the most popular solution for Fiber To The X (FTTx) deployment among operators. PON-based FTTx has been widely deployed ever since 2004 when ITU-T Study Group 15 Q2 completed recommendations that defined GPON system (ITU-T series G.984)[10]. As full services are provisioned by the massive deployment of PON networks worldwide, operators expect more from PONs. These include improved bandwidths and service support capabilities as well as enhanced performance of access nodes and supportive equipment over their existing PON networks. The direction of PON evolution is a key issue for the telecom industry[11]. Full Service Access Network (FSAN) and ITU-T are the PON interest group and standard organization, respectively. In their view, the next-generation PONs are divided into two phases: NG-PON1 and NG-PON2. Mid-term upgrades in PON networks are defined as NG-PON1, while NG-PON2 is a long-term solution in PON evolution. Major requirements of NG-PON1 are the coexistence with the deployed GPON systems and the reuse of outside plant. The aforementioned requirements were tested in the recent Verizon field
trials. Optical distribution networks (ODNs) account for 70% of the total investments in deploying PONs[12]. Therefore, it is crucial for the NGPON evolution to be compatible with the deployed networks. With the specification of system coexistence and ODN reuse, the only hold-up of the migration from GPON to NG-PON1 is the maturity of the industry chain. Unlike NG-PON1 that has clear goals and emerging developments, there are many candidate technologies for NG-PON2. The selection of NG-PON2 is under discussion. However, one thing is clear, NG-PON2 technology must outperform NG-PON1 technologies in terms of ODN compatibility, bandwidth, capacity, and cost-efficiency. This paper describes the design principles and prospective technologies for NG-PONs. It introduces Huawei’s views of NG-PON evolution, focusing on the discussion and evaluation of various technologies. All of the discussion follows the FSAN and ITU-T framework of NG-PON recommendations[13].

2.1.2 Active Optical Network

An Active Optical Network (AON) utilizes electricity powered switching equipment like routers or a switch aggregator, repeaters, or shaping circuits to manage signal distribution and direction to the correct end users. These switches open and close to ensure that the outgoing and incoming messages are going in the right direction. Subscribers have a dedicated fiber optic strand. AON networks can cover a range to about 100 km, a PON is typically limited to fiber cable runs of up to 20 km it is also higher building cost as active networks requires more fiber[13].
2.2 PON Evolution

The evolution of passive optical network start from G-PON until NG-PON. In the view of Full Service Access Network (FSAN) and ITU-T, the nextgeneration PONs are divided into two phases: NG-PON1 and NG-PON2. Mid-term upgrades in PON networks are defined as NG-PON1, while NG-PON2 is a long-term solution in PON evolution [10].

2.2.1 Basic Principles

Ultra broadband and co-existence with existing technologies are the general requirements from network operations to direct PON evolution. Operators worldwide are seeking to increase revenue by developing bandwidth-consuming services. An exemplified service is HDTV, which requires about 20 Mbit/s per channel. In the near future, new business models, such as home video editing, online gaming, interactive E-learning, remote medical services, and next-generation 3D TV will dramatically increase bandwidth demand. The deployment of PON generally implies considerably initial investments and slow return on investment (ROI). ODN deployment accounts for 76% of the total investments in green field FTTH networks, while optical network units (ONUs) account for 21% Protecting investments by leveraging existing ODNs is essential to operators[13].

2.2.2 Evolution Path

After GPON Recommendations were done, FSAN and ITU-T continued the study of NG-PONs and defined the first phase of NG-PONs as systems that offer low costs, large capacity, wide coverage, full service, and interoperability with existing technology. FSAN and ITU-T members also agree that long term PON evolution will be driven by new scenarios if coexistence with legacy systems is not required. In addition to time-division
multiplexing (TDM) PONs, other technologies for NG-PON could also be taken into account. Based on the current application demands and technological maturity, As indicated in Figure (2.1), FSAN divide NG-PON evolution into NG-PON1 and NG-PON2. NG-PON1 is a mid-term upgrade, which is compatible with legacy GPON ODNs. NG-PON2 is a long-term solution in PON evolution that can be deployed over new ODNs, independent of GPON standards. The selection of NG-PON1 in FSAN is a trade-off between technology and cost. Operators require that NG-PON1 systems have a higher capacity, longer reach, larger bandwidth, and more users. Operators also require that NG-PON1 should leverage the use of existing GPON ODN to control cost. Moreover, driven by services, the downstream bandwidth demands will outpace upstream bandwidth demands for a long period[13].

![Figure (2.1) NG-PON roadmap by FSAN](image-url)
Therefore, FSAN decided to define NG-PON1 as an asymmetric 10G system with rates of 10G downstream and 2.5G upstream. The selected NG-PON1 system is essentially an enhanced TDM PON from GPON. Unlike NG-PON1, there are several types of prospective technologies that can be adopted for NG-PON2. Among the prospective technologies, a suggested baseline is to improve the rate to 40G from 10G by following the TDM technology. The second method is the employment of wavelength division multiplexing (WDM) PON to achieve 40G access. The possible multiplexing schemes can be coarse wavelength division multiplexing (CWDM) or dense wavelength division multiplexing (DWDM). The ODSM PON topology based on TDMA+WDMA is also suggested, which dynamically manages user spectrum without modifying the ODN and ONU$s. The third prospect is OCDMA-PON. OCDMA-PON uses code division multiple access (CDMA) to encode ONU signals, thereby avoiding the timeslot assignment for data transmission required by a time division multiple access (TDMA) systems. The O-OFDMA PON topology is an option that uses orthogonal frequency division multiple access (OFDMA) technology to differentiate ONU$s, thus effectively improving bandwidth usage. However, most of these technologies are still in the research phase. More study and test are highly desired to promote them as industry standard[13].

2.2.3 Smooth Evolution Based on Coexistence: NG-PON1

A general requirement of NG-PON1 is to provide higher data transmission rates than GPON. In addition, operators expect NG-PON1 to leverage existing optical deployments. Hence, FSAN and ITU-T specified the NG-PON1 backward compatibility with legacy GPON deployments to protect the initial GPON investments of operators. The specified NG-PON1 system
is called XG-PON1. In an XG-PON1 system, the upstream rate is 2.5G and the downstream rate is 10G. Therefore, the downstream bandwidth of XG-PON1 is four times of that of GPON, while the upstream bandwidth of XG-PON1 is twice as that of GPON. Particularly, the ODN in XG-PON1 entirely inherits that of GPON, implying that optical fibers and splitters in legacy GPON systems can be reused in XG-PON1. After a 10G interface board is added to the OLT, smooth evolution from GPON to XGPON1 can be achieved, which completely leverages the value of GPON ODN[13].

Figure (2.2) XG-PON1 standardization developments

As an enhancement to GPON, XG-PON1 inherits the framing and management from GPON. XG-PON1 provides full-service operations via higher rate and larger split to support a flattened PON network structure. The baseline XG-PON1 standards have been completed. In October 2009, ITU-T consented general requirements and physical layer specifications of XG-PON1 and published them in March 2010, announcing the NG-PON era. In June 2010, the transmission convergence (TC) layer and optical network termination management and control interface (OMCI) standards for
XGPON1 were consented in the general meeting of ITU-T SG15, and these standards will be published soon[13].

2.3 Network Architecture, Coexistence and Evolution

XG-PON1 is an enhancement to GPON. It inherits the point-to-multipoint (P2MP) architecture of GPON and is able to support diverse access scenarios, such as fiber to the home (FTTH), fiber to the cell (FTTCell), fiber to the building (FTTB), fiber to the curb (FTTCurb), and fiber to the cabinet (FTTCabinet). The application scenarios of XG-PON1 are shown in Figure (2.3)[13].

![XG-PON Network Architecture](image)

**Figure (2.3) XG-PON Network Architecture**

2.4 XGPON Application Scenarios

There are many applications of passive network such as fiber to the home (FTTH) fiber to the building (FTTB), fiber to the cell (FTTCell) and fiber to the cabinet.
2.4.1 The application of digital FTTH family

XGPON Application Scenarios The application of digital FTTH family Due to the service development, bandwidth requirements are raised. GPON will be replaced by XGPON technology which provides 10G/2.5G bandwidth. Through the smooth upgrade from GPON to the XGPON, the old network structure can be reserved, which means the ODN network needn’t be changed and the user’s bandwidth can be raised 4 times than in GPON access network. Via the big split ratio such as 1:128 and long distance coverage supporting 60km transmission and other advantage features, XGPON not only provides high bandwidth, but also covers more subscribers and regions. OLT cover scale and transmission distance can be expanded further by means of 1G OLT cascading 10G OLT[14].

Figure(2.4) XGPON FTTH typical network topology

2.4.2 The Application of FTTO Enterprise

Enterprise users are faced with online video conference, video telephone and other senior business needs. More and more cities have already hewed out special high-tech industrial parks, which characteristic is the distribution of
many office buildings and factories, and distribution within the building companies. In order to realize the fiber to the office (FTTO), the PBX switches hung bellows the ONU and other equipment’s, and provide the leased line access, it should firstly choose the appropriate point along the main road. For example, the optical splitter can placed in the engine room, and then set the secondary branching unit and ONU according to the branch distribution again, and the ONU are set in the company in a general way. In this simulation multistage splitter structure can be used to save cable laying at the most[15].

2.4.3 The application of FTTC

FTTC solution is very similar as traditional MSAN technology. MDU with DSL and POTS service card will be placed in outdoor cabinet around 1km away from subscribers. In the FTTC structure, operators only need to lay optical distribution network (ODN) to each curb, and the rest from curb to the end-user is running on the existing copper. So FTTC Solution can be
used in the scene where it is difficult to lay the fiber to the users such as in some old buildings. Also Telkom can reduce the cost with using the existing cable to connect MDU/ONU to the users[15].

Figure (2.6)XGPON FTTC typical network topology

GPON Smooth Upgrade Compared with GPON, XGPON specifications is improved. XGPON optical module’s optical power exceeding 30 dBm, means that it can support further transmit distance and the split ratio of 1:128 further exceeding GPON 1:64. That is why XGPON has access to more subscribers. Also Bandwidth of XGPON is largely increased to the 10G/2.5G. In the FTTH scenario; each subscriber can obtain 4 times bandwidth than GPON. In the FTTB/O scenario, MDU can provide the GE interfaces to meet the enterprise high bandwidth requirements. As known, FTTH solution by using GPON technology can provide more than 100M bandwidth to the users which can meet long term demand. But in FTTC
solution, there are still some bandwidth troubles. However if the GPON platform can be smoothly upgraded to XGPON, the troubles will be solved[15].

![Smooth Evolution from GPON to XGPON](image)

**Figure (2.7) Smooth Evolution from GPON to XGPON**

As seen in figure (2.7), there are five steps to complete the smooth evolution: Cut off the main optical fiber, and add WDM1 components ONU must use narrow spectrum transceiver, if not, WBF1 components are needed. Upgrade GPON platform to XGPON platform by adding XGPON OLT line cards Reconfiguring network management and resource system data Add New XGPON ONUs XGPON coexists with GPON over the same ODN to protect the investments of operators on GPON. As indicated in XGPON physical layer specifications, the upstream/downstream wavelength of
XGPON is different from that of GPON. Compatibility between XGPON and GPON is achieved by implementing WDM in the downstream and WDMA in the upstream. That is, a WDM1r is deployed at the central office (CO) and a WBF is deployed at the user side (could be located inside an ONU, between aONU and an optical splitter, or in an optical splitter) to multiplex or demultiplexer wavelengths on multiple signals in downstream and upstream directions. As above topology shown in an XG-PON&GPON coexisted system, the ODN in XG-PON entirely inherits that of GPON, implying that optical fibers and splitters in legacy GPON systems can be reused in XG-PON. After a 10G interface board is added to the unified OLT platform, smooth evolution from GPON to XGPON can be achieved, which completely leverages the value of GPON ODN and the CO device[15].

2.5 Related Works

Although simulation has been used to study PON, the existing work cannot be used directly or extended easily to study the performance issues arising with the deployment of XG-PON. In [16], the authors developed their own simulator to study dynamic bandwidth assignment (DBA) algorithms when the physical reach is much longer than the current PON networks. This simulator has limited functions and there is no Internet protocol stack, which is needed to study many research topics. EPON and GPON had also been studied with OPNET and several models have been implemented by different authors. However, these EPON/GPON models are not available to the public. Furthermore, OPNET simulates too many details (CPU of a router, etc.) and the simulation speed is slow even when the simulated network bandwidth is lower than 1 GB/s. Since OPNET is not an open-source simulator, its core cannot be changed to simulate a 10 Gb/s XG-PON network with a reasonable simulation speed.
In [17,18], one simple EPON module has been developed for OMNeT++ and the code is available to the public. Since there are a lot of between EPON and XG-PON, the code of this EPON module may not be very helpful to implement one XG-PON module for OMNeT++. Considering the good points of NS-3 discussed above, it should be better to develop one XG-PON module from the scratch for the NS-3 network simulator.

In [19] XG-PON module is designed and implemented for NS-3. With such an XG-PON module, a simulation can be done to XG-PON and study its own performance. With the more realistic Internet protocol stack of NS-3, a study of the performance experienced by users/applications in XG-PON networks can be done. With the existing NS-3 modules for various wireless networks (WiFi, WiMAX, LTE, etc.), also a study of the integration between XG-PON and wireless networks, which is the trend of the future Internet access networks. In summary, with this XG-PON module, NS-3 will become a good platform for studying the next generation Internet access networks composed by XG-PON and wireless networks. Not only XG-PON, the XG-PON module can be extended to study Long-Reach PON (LR-PON), an evolution of XG-PON with a larger number of users, symmetric data rate (10 Gb/s in both upstream and downstream), and longer reach (100 km) [20,21].

In [22,23] the aim of LR-PON research group is to initially build LR-PON from the XG-PON standard, while identifying the required modifications and improvements.

In [24] the authors explained how to design and planning of a passive optical network (PON) and consists of deploying a WDM GPON from a central telecommunications to different areas where end users will enjoy the services that only optical fiber network can provide. It Supply all materials
and components necessary to deploy a passive optical infrastructure of an FTTx network, which includes from OLT to the optical jack (ONT) in the house. In [25] the authors explained how to design of WDM-PON network, the simulation and analysis of transmission parameters in the OptiSystem 7.0 environment for bidirectional traffic. In this study two transmitters at the OLT with bit rate 2.5 GB/s, the two transmitters are transmitted with two different wavelengths, Each transmitter section consists of continuous wave. And used Q-factor to measure the signal quality for determining the BER.

In [26] the authors investigated and compared the performance of different modulation formats like Non Return to Zero (NRZ), Return to Zero (RZ) and On-Off Keying (OOK) for bi-directional passive optical networks (PON). The PON architecture is implemented by using a wavelength re-modulated scheme which in downstream optical signal is re-modulated as a carrier for upstream transmission. This modulation scheme issued to make the system cost effective by removing the laser source from Optical Network Unit (ONU). For NRZ, 10 Gbps data is successfully transmitted to 32 ONUs with acceptable Q-factor of 7.11 for downlink and 2.5 Gbps data is received with Q-factor of 6.83 for uplink. Data successfully transmitted with Q-factor of 6.83 with NRZ, 6.11 with RZ and 5.25 with OOK at 150 km at OLT side and Q-factor of 7.01 with NRZ, 6.71 with RZ and 5.99 with OOK at ONU side at same distance. It has been observed that the most suitable data format for PON network is NRZ.

In [27], a fiber optic communication system has been employed using 10G/2.5G asymmetric XGPON architecture. In this system bidirectional optical fiber has been employed for upstream and downstream data transmission. The system performance has been investigated for
non-return-to-zero (NRZ) and return-to-zero (RZ) data formats by varying the length of the fiber for co-existed GPON and XG-PON system. The results have been compared for NRZ and RZ formats for upstream and downstream data in terms of Q value and eye opening. It has been observed that RZ modulation format is superior compared to conventional NRZ modulation. The potential of NRZ and RZ signal transmission for co-existed GPON and XG-PON system has been analyzed over a transmission distance of 80km. It is found that the faithful transmission distance covered by XG-PON is greater than 80km for both upstream and downstream transmission in RZ format. It is concluded that for this co-existed system the RZ modulation format is superior to the conventional NRZ modulation scheme as it offers better immunity to fiber non-linearity's. Further, it is found that the performance of XG-PON deteriorates due to greater non-linear effects at higher Bit rate.

In [28], analysis and estimates the performance achieved by TDM PON and WDM PON using Different Coding Schemes, by the use of 16 users in Optical Network Unit (ONU) receiver side. Simulation work estimates the gain performance achieved up to 10Gbps in terms of data capacity per ONU and distance at 100 km in terms of system reach at the downstream direction in the receiver side. Results simulated using OptiSystem have confirmed that WDM PON network performance is better than TDM PON networks. This has been evaluated for different coding techniques for both TDM PON and WDM PON. Through simulation it is revealed that Manchester coding shows better performance through Min BER, Max Q factor, and Eye Diagram when compared with RZ and NRZ coding techniques. In the long reach enhanced system the data rates are compared using 1Gbps, 2.5Gbps, 4Gbps and 10Gbps.
CHAPTER THREE
METHODOLOGY

3.1 Introduction
In this chapter the project methodology is represented including the mathematical model, and the simulation scenario used to obtain the results.

3.2 Mathematical Model
In order to obtain results from the simulation the following parameter should be adjusted.

Table 3.1 simulation parameters set up

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>10Gb/s</td>
</tr>
<tr>
<td>RZ Bandwidth</td>
<td>10GHz</td>
</tr>
<tr>
<td>Fiber Attenuation</td>
<td>0.2 dB/km</td>
</tr>
</tbody>
</table>

3.2.1 Bandwidth Required For Bit Rate
The conversion of bit rate to bandwidth in hertz depends on the digital coding format used. When NRZ format (non-return-to-zero) is employed, the binary 1 level is held for the whole bit period $\tau$. In this case there are two bit periods in one wavelength. Hence the maximum bandwidth $B$ is one-half the maximum data rate $B=0.5 \times \text{bit rate}$. However, when a return-to-zero code is considered, the binary 1 level is held for only part (usually half) of the bit period. This is why $B=\text{bit rate} = 10 \times 10^9 = 10\text{GHz}$ [29].
3.2.2 Q Factor, S/N Ratio, and BER

\[ BER = \frac{1}{2} \text{erfc} \left( \frac{Q}{\sqrt{2}} \right) \]  

(3.1)

Since \( BER = 10^{-9} \) then from erfc the Q factor is equal to 6 dB (3.9810) linear value. Where erfc is the complementary error function[30].

\[ \text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp(-y^2) \, dy \]  

(3.2)

\[ Q = \frac{1}{2} \sqrt{\frac{\text{signal}}{\text{noise}}} \]  

(3.3)

\[ S/N(\text{dB}) = (Q \times 2)^2 = (6 \times 2)^2 = 12^2 = 144 = 2.5118 \times 10^{14} \text{(linear value)} \]

For \( BER \) of \( 10^{-9} \), \( Q=6 \) then \( S/N=144 \)

3.2.3 Fiber Attenuation

The transmission loss of optical fibers has proved to be one of the most important factors in bringing about their wide acceptance in telecommunications. As channel attenuation largely determined the maximum transmission distance prior to signal restoration, since the attenuation in single mode fiber is 0.2 dB/km and the link is 80 km long, then the total loss in the fiber will be 16.0 dB[31].

\[ \text{Fiber Loss} = \alpha_{\text{dB}} \times L \]  

(3.4)

\[ \text{Fiber Loss} = 0.2 \times 80 = 16.0 \text{ dB} \]

3.2.4 Fiber Dispersion

Dispersion of the transmitted optical signal causes distortion for both digital and analog transmission along optical fibers. When considering the major implementation of optical fiber transmission which involves some form of digital modulation, then dispersion mechanisms[32] within the fiber cause broadening of the transmitted light pulses as they travel along the channel and then it is cause ISI.
\[ \Delta_T = L \times \text{Dispersion/Km} \]  
\[ B = \frac{0.35}{\Delta_T} \]  

where \( B \) is bandwidth, \( \Delta_T \) total dispersion and \( L \) fiber length.

For \( B=10 \times 10^9 \) and \( L=80 \text{km} \)

From equ(3.6) \( \Delta_T = \frac{0.35}{B} = \frac{0.35}{10 \times 10^9} = 0.035 \times 10^{-9} = 0.035 \text{ ns} \)

Then \( \text{Dispersion/km} = \frac{\Delta_T}{L} = \frac{0.035 \times 10^{-9}}{80} = 4.375 \times 10^{-13} = 0.4375 \text{ps km}^{-1} \)

So the single mode fiber should have dispersion of 0.4375 p/km

### 3.2.5 Signal-to-noise ratio and capacity

Signal-to-noise ratio (abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels [33]. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. While SNR is commonly quoted for electrical signals, it can be applied to any form of signal. The signal-to-noise ratio, the bandwidth, and the channel capacity of a communication channel are connected by the Shannon–Hartley theorem [34].

\[ C = B \log_2 \left( 1 + \frac{S}{N} \right) \]  

Where \( C \) is channel capacity

\( B \) is Channel bandwidth which equal 10GHz

\( \frac{S}{N} \) is signal to noise ratio which is equal \( 2.5118 \times 10^{14} \) (linear value)

\[ C = 10 \times 10^9 \log_2 (1 + 2.5118 \times 10^{14}) = 10 \times \]

\[ 10^9 \times 48.319204 = 483.19 \text{Gbps} \]
Signal-to-noise ratio is sometimes used metaphorically to refer to the ratio of useful information to false or irrelevant data in a conversation or exchange. For example, in online discussion forums and other online communities, off-topic posts and spam are regarded as "noise" that interferes with the "signal" of appropriate discussion.

Signal-to-noise ratio is defined as the ratio of the power of a signal (meaningful information) and the power of background noise (unwanted signal).

\[
\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.8)
\]

Where \( P \) is average power. Both signal and noise power must be measured at the same and equivalent points in a system, and within the same system bandwidth. If the variance \( \alpha \) of the signal and noise are known, and the signal is zero-mean.

\[
\text{SNR} = \frac{\alpha^2_{\text{signal}}}{\alpha^2_{\text{noise}}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.9)
\]

If the signal and the noise are measured across the same impedance, then the SNR can be obtained by calculating the square of the amplitude ratio:

\[
\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} = \left(\frac{A_{\text{signal}}}{A_{\text{noise}}}\right)^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.10)
\]

Where \( A \) is root mean square (RMS) amplitude (for example, RMS voltage).

**3.2.6 Dijkstra's algorithm**

is an algorithm for finding the shortest paths between nodes in a graph, which may represent, for example, road networks. It was conceived by computer scientist Edsger W. Dijkstra in 1956 and published three years later [35]. The algorithm exists in many variants; Dijkstra's original variant found the shortest path between two nodes, but a more common variant fixes a
single node as the "source" node and finds shortest paths from the source to all other nodes in the graph. Let the node at which we are starting be called the initial node. Let the distance of node Y be the distance from the initial node to Y. Dijkstra's algorithm will assign some initial distance values and will try to improve them step by step as follow:

• Assign to every node a tentative distance value: set it to zero for our initial node and to infinity for all other nodes.
• Set the initial node as current. Mark all other nodes unvisited. Create a set of all the unvisited nodes called the unvisited set.
• For the current node, consider all of its neighbors and calculate their distances. Compare the newly calculated distance to the current assigned value and assign the smaller one. For example, if the current node A is marked with a distance of 6, and the edge connecting it with a neighbor B has length 2, then the distance to B (through A) will be $6 + 2 = 8$. If B was previously marked with a distance greater than 8 then change it to 8. Otherwise, keep the current value.
• When we are done considering all of the neighbors of the current node, mark the current node as visited and remove it from the unvisited set. A visited node will never be checked again.
• If the destination node has been marked visited (when planning a route between two specific nodes) or if the smallest tentative distance among the nodes in the unvisited set is infinity (when planning a complete traversal; occurs when there is no connection between the initial node and remaining unvisited nodes), then stop. The algorithm has finished.
• Otherwise, select the unvisited node that is marked with the smallest distance, set it as the new "current node", and go back to step 3.
Fig (3.1) XG-PON Network Configuration

3.3 Block diagram

The following block diagram represents a full construction of multiservice provided into next generation passive optical network.

1- Multiservice can be served using XG-PON, such as VoIP, PSTN.
2- Each services has a routing header.
3- Multiplexing of different services is done through different wavelength.
4- Add Additive white Gaussian Noise that may occurs during the transmission and receiving process into channel.
5- D-multiplexing is then used to split the services into different channels to serve users.
Figure (3.2) block diagram represent a full construction of multiservice provided into XGPON

3.3.1 OLT Transmitter
The following flowchart represents the OLT transmitter process from the combination of multiple services to the streaming.
Start

Create Nodes

Set IP address for Each Node

Set Label for Each Node

Set Number of Users

Set Wavelength

Generate Random Data for Different Services

Apply Multiplexing

Apply AWGN

Is the distance of destination node < the distance of the previous node? 

NO

End

Yes

Figure (3.3) OLT Transmitter
3.3.2 ONU Receiver

The following flowchart represents the ONU Receiver process from the combination of multiple services to the streaming.

![Flowchart of ONU Receiver process](image)

Figure (3.4) ONU Receiver
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction
The following chapter represents the results and discussion of the simulated work, a simulation was made using MATLAB programming and some parameters which are bit error rate, fiber attenuation, bandwidth and data rate.

4.2 Bit Error Rate and Quality Factor
It is clear from Fig (4.1), that BER decrease as Q-Factor increase.
For bit error rate equal to $0.986 \times 10^{-9} \approx 10^{-9}$ the Q-Factor is 6 dB.

![Fig (4.1) bit error rate vs. quality factor in dB](image)
4.3 Signal to Noise Ratio and Quality Factor

The Q-factor suggests the minimum signal-to-noise ratio (SNR) required to obtain BER = $10^{-9}$. In Fig (4.2) as Signal to noise ratio increase the Q-Factor increase. For Q-Factor equal to 6dB the minimum signal to noise ratio equal to 144dB.

**Fig (4.2) Signal to Noise Ratio vs. Quality Factor in dB**
4.4 Fiber Capacity and Signal to Noise Ratio

According to Shannon Hartley theorem as signal to noise increase the capacity of channel increase. In Fig(4.3) the maximum amount of error-free digital data that can be transmitted over a fiber is \( 4.783 \times 10^{11} \) Gbps when the signal to noise is 144 dB and BER = \( 10^{-9} \)

![Fig (4.3) capacity of fiber vs. signal to noise in dB](image)
4.5 Fiber Loss and Length of Fiber

It is clear from Fig (4.4) that fiber loss in dB is increased as distance increase the maximum length for fiber is 80 km for Q Factor 6dB so the dB 16fiber loss is .

![Fig (4.4) Fiber loss vs. length of fiber](image)
4.6 XG-PON Q-Factor down stream

In Fig(4.4), RZ is better than NRZ format for XGPON system. The Q-factor obtained is 10dB and 9dB at a distance of 50km and 70km respectively for XGPON in downstream transmission for RZ (0.6) format. It is clear from figure that Q-value decreases with increase in length of fiber.

![Diagram showing Q-Factor vs Length for XGPON with different formats](image)

**Figure (4.5) Length vs. Q-Factor of XGPON for NRZ and RZ formats for downstream transmission**
4.7 Summary

RZ modulation has become a popular solution for 10 GB/s systems because it has average peak power, a higher signal-to-noise ratio, lower bit error rate and RZ modulation is found to be less susceptible to inter-symbol interference (ISI) than NRZ encoding. It also offers better immunity to fiber nonlinear effects. The minimum required Q-value for faithful transmission is 6 dB at BER = $10^{-9}$. and typically achieves better performance compared to NRZ. Fig (4.5) shows the graphical representation of Q value as a function of Length for NRZ and RZ (with duty cycle = 0.6 and 0.8) data formats for XG-PON downstream data. The Q-factor obtained is 10 dB and 9 dB at a distance of 50 km and 70 km respectively in downstream transmission for RZ (0.6) format. The faithful transmission distance is up to 85 km in RZ (0.6) format.
CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion
The potential of NRZ and RZ signal transmission for XG-PON downstream system has been analyzed over a transmission distance of 80km. It is found that the faithful transmission distance covered by XG-PON is greater than 80km for downstream transmission in RZ format. It is concluded that for this system the RZ modulation format is superior to the conventional NRZ modulation scheme as it offers better immunity to fiber non-linearity.

5.2 Recommendations
Comparison of different line coding schemes in XGPON, Apply bidirectional fiber in XGPON and analysis the performance of coexistence GPON-XGPON for both upstream and downstream transmission.
Reference


Appendix A

% XGPON downstream Simulation Program
%
% Four Routers Inside XGPON Network PE1,PE2,P1,P2
% Four Routers Linked TO XGPON Network CEA1,CEA2,CEB1,CEB2
% configured IP Address for the Network
% PE1 : 0.0.0.0
% PE2 : 0.0.0.0
% PE3 : 0.0.0.0
% CEA1: 0.0.0.0
% CEA2: 0.0.0.0
% CEB1: 0.0.0.0
% CEB2: 0.0.0.0
clear all;
close all;
clc;
%%Configuring Network Link %%
% PE1--> P1
% PE1--> P2
% P1--> P3
% P1--> P4
% P2--> P4
% P3--> PE2
% P3--> PE3
% P4--> PE3
% PE3--> PE2
% CEA1--> PE1
% CEA2--> PE1
% CEB1--> PE2
% CEB2--> PE3
%Assign IP Addresses%
P1_ip='192.168.0.2';
P2_ip='192.168.0.4';
P3_ip='192.168.0.5';
P4_ip='192.168.0.6';
PE1_ip = '192.168.0.1';
PE2_ip = '192.168.0.3';
PE3_ip = '192.168.0.7';
CEA1_ip = '10.0.0.10';
CEA2_ip = '10.0.1.20';
CEB1_ip = '20.0.0.10';
CEB2_ip = '20.0.1.20';
Assign Labels for Each Router

PE1_label = '20';
P1_label = '40';
P2_label = '10';
P3_label = '30';
P4_label = '50';
PE2_label = '60';
CEA1_label = '70';
CEA2_label = '90';
CEB1_label = '80';
CEB2_label = '100';
PE3_label = '110';

Viewing Labels

x=['Router PE1', ' ', P1_ip, ' ', 'Label', ' ', PE1_label];
disp(x);

x=['Router PE2', ' ', P2_ip, ' ', 'Label', ' ', PE2_label];
disp(x);

x=[ 'Router P1', ' ', P3_ip, ' ', 'Label', ' ', P1_label ];
disp(x);

x=[ 'Router P2', ' ', P4_ip, ' ', 'Label', ' ', P2_label ];
disp(x);

x=[ 'Router P3', ' ', PE1_ip, ' ', 'Label', ' ', P3_label ];
disp(x);

x=[ 'Router P4', ' ', PE2_ip, ' ', 'Label', ' ', P4_label ];
disp(x);

x=[ 'Router PE3', ' ', PE3_ip, ' ', 'Label', ' ', PE3_label ];
disp(x);

x=[ 'Router CEA1', ' ', CEA1_ip, ' ', 'Label', ' ', CEA1_label ];
disp(x);

x=[ 'Router CEA2', ' ', CEA2_ip, ' ', 'Label', ' ', CEA2_label ];
disp(x);

x=[ 'Router CEB1', ' ', CEB1_ip, ' ', 'Label', ' ', CEB1_label ];
disp(x);

x=[ 'Router CEB2', ' ', CEB2_ip, ' ', 'Label', ' ', CEB2_label ];
disp(x);

Bandwidth Settings

band1=512;
band2=1024;
band3=256;
band4=2048;
band5=3000;
band6=2800;
band7=1800;
band8=1000;
band9=2100;

% Link Cost Calculations
PE1_P1_cost =100000/band1;
PE1_P2_cost =100000/band2;
P1_P3_cost =100000/band3;
P2_P4_cost =100000/band4;
P1_P4_cost =100000/band5;
P4_PE3_cost =100000/band6;
P3_PE2_cost =100000/band7;
P3_P5_cost =100000/band8;
PE3_PE2_cost =100000/band9;

% Routing Cost Calculations
path1=PE1_P1_cost+P1_P3_cost+P3_PE2_cost;
path2=PE1_P1_cost+P1_P4_cost+P4_PE3_cost+PE3_PE2_cost;
path3=PE1_P1_cost+P1_P4_cost+P4_PE3_cost+P3_PE2_cost+P3_PE3_cost;
path4=PE1_P2_cost+P2_P4_cost+P4_PE3_cost+P3_PE2_cost;
path5=PE1_P2_cost+P2_P4_cost+P4_PE3_cost+P3_PE2_cost+P3_PE3_cost;
path6=PE1_P2_cost+P2_P4_cost+P4_PE3_cost+P3_PE3_cost+P3_PE2_cost;
path7=PE1_P2_cost+P2_P4_cost+P4_PE3_cost+P3_PE3_cost+P3_PE2_cost;
path8=PE1_P2_cost+P2_P4_cost+P4_PE3_cost+P3_PE3_cost;
path9=PE1_P2_cost+P2_P4_cost+P4_PE3_cost;
path10=PE1_P2_cost+P2_P4_cost+P4_PE3_cost;

% Transmitting Scenario
data_size =500;
% Wave Division Multiplexing
samples=1000;
% number of input Signals or Nodes
nos=8;
% modulating signal IN THZ
mfreq=[192.5 192.6 192.7 192.8 192.9 193.0 193.1 193.2];
% carrier wave allocated to the different users in THZ
cfreq=[300 600 900 1200 1500 1800 2100 2400];
% choose wave deviation
freqdev=10;
% generate modulating signal
t=linspace(0,1000,samples);
parfor i=1:nos
    m(i,:)=sin(2*pi*mfreq(1,i)*t)+2*sin(pi*8*t);
end
% Generate the modulated signal OLT
parfor i=1:nos
    y(i,:)=fmmmod(m(i,:),cfreq(1,i),10*cfreq(1,i),freqdev);
end
% pass the modulated signal through the channel
ch_op=awgn(sum(y),0,'measured'); % Add Adaptive White Gaussian Noise
if (path1<path2 && path1<path3 && path1<path4 && path1<path5 && path1<path6)
disp('Link Thorugh path1 is selected\n');
disp(path1);
costs=path1;
end
if (path2<path1 && path2<path3 && path2<path4 && path2<path5 && path2<path6)
disp('Link Thorugh path2 is selected\n');
disp(path2);
costs=path2;
end

if (path3<path1 && path3<path2 && path3<path4 && path3<path5 && path3<path6)
disp('Link Thorugh path3 is selected\n');
disp(path3);
costs=path3;
end

if (path4<path1 && path4<path2 && path4<path3 && path4<path5 && path4<path6)
disp('Link Thorugh path4 is selected\n');
disp(path4);
costs=path4;
end

if (path5<path1 && path5<path2 && path5<path3 && path5<path4 && path5<path6)
disp('Link Thorugh path5 is selected\n');
disp(path5);
costs=path5;
end

if (path6<path1 && path6<path2 && path6<path3 && path6<path4 && path6<path5)
disp('Link Thorugh path6 is selected\n');
disp(path6);
costs=path6;
end

if (path7<path8 && path7<path9 && path7<path10)
disp('Link Thorugh path7 is selected\n');
disp(path7);
costs=path7;
end

if (path8<path7 && path8<path9 && path8<path10)
disp('Link Thorugh path8 is selected\n');
disp(path8);
costs=path8;
end

if (path9<path7 && path9<path8 && path9<path10)
disp('Link Thorugh path9 is selected\n');
disp(path9);
costs=path9;
end

if (path10<path7 && path10<path8 && path10<path9)
disp('Link Thorugh path10 is selected\n');
disp(path10);
costs=path10;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%Using Dijkstra Algorithm%%%%%%%%%%%%%%%%%%%%%%%%
results=[];
for(i=1:3)
    for(n=2:10)
        randomMatrix = magic(n);
        tic;
        dijkstra(randomMatrix,1,2);
        DijkstraTime = toc;
        tic;
        bellmanford(randomMatrix,1,2);
        BellmanTime = toc;
        results(n,3*i-2) = n;
        results(n,3*i-1) = DijkstraTime;
        results(n,3*i) = BellmanTime;
    end
end
results

% %%%%%%%%%%%%%%%%%%%%%%%calculating %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% h = waitbar(0,'Please wait...');
% steps = 1000;
% for step = 1:steps
%     waitbar(step / steps)
% end
% close(h)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
b=10000000000; % Set the bandwidth
SNR_dB=1:200  % Set the range of SNR between 1 to 200 db
    SNR=10.^(SNR_dB/10);
    z=log2(1+SNR);
    c =b*z; % calculate the fiber capacity
figure (1)
plot(c);
grid on
title ('Capacity of fiber vs SNR');
xlabel('SNR (dB) ');
ylabel('Capacity');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%  BERvs Q
Qfact_dB=1:10;
    Qfact=10.^(Qfact_dB/10); % calculate Q
    BER=0.5*erfc(Qfact_dB/1.4142); % Calculates BER based on Q
figure (2)
semilogy(Qfact_dB,BER)
grid on
title ('Bit Error Rate vs Q Factor');
xlabel('Qfactor (dB)');
ylabel('BER');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%  BERvs Q vs SNR
Qfactsnr_dB=1:10;
SNRq=(2*Qfactsnr_dB).^2;
figure(3)
plot (SNRq);
grid on
title ('SNR VS Qfact ');
xlabel(' Q-factor (dB)');
ylabel('SNR(dB)');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% FIBER LOSS CALCULATION
A_dB=0.2;
L=1:90;
floss_dB=0.2*L;
figure (4)
plot(floss_dB);
grid on
title ('fiberlossvs fiber length');
xlabel('fiber length');
ylabel('fiber loss in dB');

% DISPERSION OF FIBER PER KM
DT=0.35/b;
L=80;
dispersion =DT/L;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Signal generation
x=0:.5:4*pi;                             % signal taken upto 4pi
sig1=8*sin(x);                           % generate 1st sinusoidal
signal
l=length(sig1);
sig2=8*triang(l);
figure(5)
% Display of Both Signal
subplot(2,2,1);
plot(sig1);
title('Sinusoidal Signal');
ylabel('Amplitude -->');
xlabel('Time -->');
subplot(2,2,2);
plot(sig2);
title('Triangular Signal');
ylabel('Amplitude -->');
xlabel('Time -->');
% Display of Both Sampled Signal
subplot(2,2,3);
stem(sig1);
title('Sampled Sinusoidal Signal');
ylabel('Amplitude -->');
xlabel('Time -->');
subplot(2,2,4);
stem(sig2);
title('Sampled Triangular Signal');
ylabel('Amplitude -->');
xlabel('Time -->');
l1=length(sig1);
l2=length(sig2);

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for i=1:l1
    sig(1,i)=sig1(i);                        % Making Both row vector to a matrix
    sig(2,i)=sig2(i);
end

% both quantize signal
tdmsig=reshape(sig,1,2*l1);
% Display of TDM Signal
figure(6)
stem(tdmsig);
title('Signals');
ylabel('Amplitude -->');
xlabel('Time -->');

% Demultiplexing of Signal
demux=reshape(tdmsig,2,l1);
for i=1:l1
    sig3(i)=demux(1,i);                % Converting The matrix into row vectors
    sig4(i)=demux(2,i);
end
% display of demultiplexed signal
figure(7)
subplot(2,1,1)
plot(sig3);
title('Recovered Sinusoidal Signal');
ylabel('Amplitude -->');
xlabel('Time -->');
subplot(2,1,2)
plot(sig4);
title('Recovered Triangular Signal');
ylabel('Amplitude -->');
xlabel('Time -->');

figure(8)
x=[40 50 60 70 80 90];
y1=[11 10 9 9 7 5 ];
y2=[10 9 8 7.8 6.9 3];
y3=[9 8.5 7 6.5 5 2.5];
p=pplot(x,y1,x,y2,'--',x,y3,'b--o');
grid on
hold on

title('Length Vs Q-Factor of XG-GPON downstream');
xlabel('Length of Fiber[Km]');
ylabel('Q-Factor db');
legend('RZ=0.6 XG-PON','RZ=0.8 XG-PON','NRZ XG-PON');

figure(8)
x=[40 50 60 70 80 90];
y1=[11 10 9 9 7 5 ];
plot(x,y1,'color','r','marker','.','Linewidth',0.5);
grid on
hold on
y2=[10 9 8 7.8 6.9 3];
plot(x,y2,'color','g','marker','.','Linewidth',0.5)
grid on
hold on
y3=[9 8.5 7 6.5 5 2.5];
plot(x,y3,'color','b','marker','.','Linewidth',0.5)
title('Length Vs Q-Factor of XG-GPON downstream');
xlabel('Length of Fiber[Km]');
ylabel('Q-Factor db');
legend('RZ=0.6 XG-PON','RZ=0.8 XG-PON','NRZ XG-PON');