ASSESSING THE INFLUENCE OF DIGITAL MODULATION METHODS ON LTE OVER FIBER FOR 5G SYSTEMS IMPLEMENTATION

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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2024

DECLARATION

I declare that this report entitled "Assessing the Influence of Digital Modulation Methods on LTE over Fiber for 5G Implementation" is the result of my own work except for quotes as cited in the references.

Signature : ....

Author : MUHAMMAD DANIEL AZROR BIN MOHD ADENAN

Date : 28 JUNE 2024

APPROVAL

I hereby declare that I have read this thesis, and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours

Signature : ....

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Date : 28 JUNE 2024

DEDICATION

I dedicate this work to my creator, my strong pillar, my source of inspiration, knowledge, and understanding. He was the source of all things during this task. To my precious father and mother, Mohd Adenan Bin Md Som and Azilah Binti Md Sahat, my dedicated lecturers especially my supervisor, Dr. Siti Khadijah Binti Idris @ Othman, also, my supportive friends. This is dedicated to each one of you. May Allah continue to bless you all.

ABSTRACT

Fiber optic is used extensively in telecommunications for both backhaul and fronthaul purposes. LTE over fiber in a 5G system refers to the utilization of fiber optic networks to transport signals, ensuring high-speed, low-latency connectivity that supports both LTE and 5G services. Investigating various digital modulation techniques in the context of 5G system is essential for enhancing efficiency, reliability, and performance. It addresses the needs for higher data rates, better signal quality, and supports a diverse range of applications to meet current and future demands. This research is to simulate mmW 5G system with QAM and QPSK digital modulation techniques using Optisystem software. The output signal was observed in terms of eye diagram, BER and Q-factor. The performance is evaluated based on modulation of QPSK, 16 QAM, 64 QAM and 256 QAM over bit rates of 10 Gbps and 40 Gbps, wavelength of 1550 nm and 1310 nm and distance from 5km to 100km respectively. The optimum performance is set following ITU standard at BER of 10E-12 and Q-factor greater than 8. QPSK shows robustness over long distances up to 80km and 50 km for 1550nm and 1310nm wavelength at 10Gbps respectively. 16QAM demonstrates better BER and Q-factor than 64QAM and 256QAM due to wider constellation spacing. Overall, 10 Gbps modulation performs better than 40GBps, meeting UTU standards with lower dispersion and attenuation issues.

ABSTRAK

Gentian optik digunakan secara meluas dalam telekomunikasi untuk tujuan backhaul dan fronthaul. LTE melalui gentian dalam sistem 5G merujuk kepada penggunaan rangkaian gentian optik untuk mengangkut isyarat, memastikan sambungan berkelajuan tinggi, yang menyokong kedua-dua perkhidmatan LTE dan 5G. Menyiasat pelbagai teknik modulasi digital dalam konteks sistem 5G adalah penting untuk meningkatkan kecekapan, kebolehpercayaan dan prestasi. Ia menangani keperluan untuk kadar data yang lebih tinggi, kualiti isyarat yang lebih baik, dan menyokong pelbagai aplikasi untuk memenuhi permintaan semasa dan masa hadapan. Penyelidikan ini adalah untuk mensimulasikan sistem mmW 5G dengan teknik modulasi digital QAM dan QPSK menggunakan perisian Optisystem. Isyarat keluaran diperhatikan dari segi rajah mata, BER dan faktor Q. Prestasi dinilai berdasarkan modulasi QPSK, 16 QAM, 64 QAM dan 256 QAM atas kadar bit 10 Gbps dan 40 Gbps, panjang gelombang 1550 nm dan 1310 nm dan jarak dari 5km hingga 100km masing-masing. Prestasi optimum ditetapkan mengikut piawaian ITU pada BER 10E-12 dan faktor Q lebih besar daripada 8. QPSK menunjukkan keteguhan pada jarak jauh sehingga 80km dan 50 km untuk panjang gelombang 1550nm dan 1310nm pada 10Gbps masing-masing. 16QAM menunjukkan BER dan faktor Q yang lebih baik daripada 64QAM dan 256QAM disebabkan jarak buruj yang lebih luas. Secara keseluruhan, modulasi 10 Gbps berprestasi lebih baik daripada 40GBps, memenuhi piawaian ITU dengan isu serakan dan pengecilan yang lebih rendah.

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First and foremost, I thank my supervisor, Dr. Siti Khadijah Binti Idris @ Othman, for her expertise, mentorship, and unwavering support. Her feedback and encouragement have significantly shaped this project.

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In conclusion, this project represents the culmination of dedicated effort, mentorship, and institutional support. I am grateful for the privilege to undertake this research at Universiti Teknikal Malaysia Melaka (UTeM), within the inspiring framework provided by the faculty.

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LIST OF SYMBOLS AND ABBREVIATIONS

G	:	Generation
IoT	:	Internet of Things
ITU	:	The International Telecommunication Union
VR	:	Virtual Reality
AR	:	Augmented Reality
mmW	:	Millimeter Wave
EHF	:	Extreme High Frequency
ELF	:	Extreme Low Frequency
ROF	:	Radio over Fiber
ROI	:	Return of Investment
QPSK	:	Quadrature Phase Shift Keying
QAM	:	Quadrature Amplitude Modulation
BER	:	Bit Error Ratio
FDM	:	Frequency Division Multiplexing
SMS	:	Short Messaging Services
MMS	:	Multimedia Messaging Services
TDMA	:	Time Division Multiple Access
CDMA	:	Code Division Multiple Access
OFDMA	:	Orthogonal Frequency Division Multiple Access

VoLTE	:	Voice over Long-Term Evaluation
AM	:	Amplitude Modulation
PM	:	Phase Modulation
FM	:	Frequency Modulation
ASK	:	Amplitude Shift Keying
FSK	:	Frequency Shift Keying
NDSF	:	Non-Dispersion Single Fiber
3GPP	:	3rd Generation Partnership Project
EVM	:	Error Vector Magnitude
PRBS	:	Pseudo Random Bit Sequence Generator

CHAPTER 1

INTRODUCTION

The evolution of the previous wireless generation from 1G to 5G has made a great impact in a transformative era. Each of the improvements of wireless generation has been improvised in terms of data speed rate, attenuation, and enhanced the coverage of the signal at certain places such as rural areas. This paradigm shift has not only enabled seamless communication of voice, video, and data but has become the lifeblood of connectivity across diverse sectors and applications in our modern society. 5G aims to improve and expedite wireless experiences by offering ultra-low latency, vast network capacity, and increased multi-Gbps data speeds.

1.1 Background of Project

1.1.1 5G Network

The fifth generation (5G) network is the latest wireless technology and it is the most advanced version of communication technology. 5G networks are possible to support a wide range of new applications and services as it offers highest faster speeds and ultra-low latency compared to the previous generations of mobile technology.

Some of the key features of 5G technology include:

i. High speeds: 5G networks significantly have faster data speeds compared to the previous network generations. Therefore, it enables the users to experience faster response times for applications and services, quicker download and upload speeds, and experience smoother streaming.

ii. High Network Capacity: A significantly higher number of linked devices may be supported simultaneously by 5G networks. This is especially crucial on the Internet of Things (IoT) era, as many devices, ranging from connected cars to smart appliances.

iii. Low Latency: There is less delay while sending and receiving data because of 5G networks' far lower latency than earlier generations of mobile technology. Applications like Virtual Reality (VR), Augmented Reality (AR) and remote control that demand real-time communication should take note of this.

5G technology is anticipated to have a significant impact on a wide range of sectors and applications. It can completely transform the way we communicate and access information.

1.1.2 Millimeter Wave (mmW)

mmW is a type of band with 30GHz to 300GHz and has a wavelength between 1mm to 10mm. The International Telecommunication Union (ITU) refers to mmW as the extremely high frequency (EHF) band. Frequencies higher than 24 GHz are especially useful for 5G wireless communication, among other things. These higher frequencies can help 5G networks achieve their high-speed and low-latency goals by providing better data transfer rates and bandwidth. mmW have shorter propagation distances and the signal can be easily distorted by the obstacles around such as building, or weather conditions, Hence, the advanced technologies such as beamforming is used to overcome these obstacles and improve mmW based communication systems performance.

1.2 Problem Statement

In this modern era, the speed of the data transfer from the transmitter to the receiver is one of the most important for the users to exchange information with each other efficiently. Low latency and huge bandwidth with high spectral efficiency are needed to accommodate 5G applications in areas such as hospitals, especially in critical surgery situations, smart transportation, security and many more. The choice of digital modulation methods is important to ensure the transmitted signal is received with minimal attenuation and maximum integrity. One of the primary issues in this context is to determine the most effective modulation method to be used to guarantee optimal performance. This challenge is compounded by the need to accurately simulate and predict real-world performance and virtual environments such as Optisystem platform.

1.3 Objectives

There are two objectives set for this project and are listed below.

1. To design and simulate mmW 5G system with QAM and QPSK digital modulation techniques.
2. To evaluate the performance of digital modulation techniques on 5G implementation based on BER, Q-factor and eye diagram.

1.4 Scope of Work

This project exclusively utilizes software through Optisystem, focusing on various modulation techniques such as QPSK, 16QAM, 64QAM, and 256QAM. The optical fiber transmission distance ranges from 5km to 100km was tested. The study involves testing the results of 5G system communication signals at wavelengths of 1310nm and 1550nm while the bit rates involved are 10Gbps and 40Gbps. The output signal is analyzed using metrics such as Bit Error Rate (BER), Q-Factor, and Eye Diagrams.

CHAPTER 2

BACKGROUND STUDY

This chapter reviews every related project from the past that shares some parallels with the current endeavor. It is possible to develop additional improvements and extract more ideas to improve the project by comprehending other prior efforts. A few thesis also include recommendations for the project's future direction, which would be very helpful in directing the project as it attempts to improve in areas where no one has previously attempted to do so.

2.1 Overview

The advent of the fifth generation of wireless technology, commonly known as 5G is the latest technology in telecommunication. Building upon the foundation laid by its predecessors, 5G offers many improvements compared to the previous network. Unlike its predecessors, 5G is not merely an incremental upgrade but a transformative force that promises to reshape the way we communicate and interact with the digital world.

At its core, 5G represents a significant evolution in mobile networking, designed to meet the growing demands of our increasingly interconnected society. The key pillars of 5G innovation include enhanced data transfer rates, lower latency, improvised energy efficiency [1], and can support diverse applications ranging from AR and autonomous vehicles to the IoT. This next-generation network is set to empower industries, improve user experiences, and catalyze innovations that were once deemed beyond the realm of possibility.

The development of new network technology, which is 5G, is very important because it uses different kinds of frequencies to connect devices. There are low, middle, and high frequencies which is the range from 30GHz to 300GHz. With the different level of frequency range, 5G works well in busy cities and faraway places. It means fast internet for crowded areas and good coverage in remote ones.

2.2 Evolution and Impact of Wi-Fi Technology and Applications

Cellular communication keeps evolving due to the high demand for better quality of data rates transfer, services and lower latency. The path of network signal evolution consists of several generations which is from 1G, 2G, 3G, 4G and the latest generation that still ongoing is 5G. For the first generation (1G), it was introduced in the early 1980s. This generation supported only voice calls as it used analog signals. It has poor quality in coverage, low bandwidth, no security and has limited voice capacity. The multiple access technique used by 1G was Frequency Division Multiple Access (FDMA) [1]. After that, second generation (2G) of mobile networks is launched in the 1990s. There are many changes in terms of voice quality and capacity as the second generation already used digital signals and supported voice and data services such as Short Message Service (SMS) and Multimedia Message Service (MMS). Compared to 1G, 2G had better quality, higher bandwidth and the security is improved. Multiple access technique used by 2G was Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) [2].

Then, in 2000s, Third Generation (3G) was launched. It offered faster data transfer rates for mobile internet, improved multimedia services and global roaming. 3G also introduced video calling and mobile broadband. Furthermore, it also supported online gaming and web browsing. The multiple access technique being used by 3G is Wide CDMA (WCDMA) and Orthogonal Frequency Division Multiple Access (OFDMA) [3]. In the 2010s, Fourth Generation (4G) was introduced. There was a lot of improvement in terms of speed of date rates transfer, latency and seamless connectivity compared to 3G signal. With the improvement that has been made, it enabled high-definition video streaming, cloud computing, social networking, and voice quality Voice over LTE (VoLTE) [4].

Finally, in 2020s, Fifth Generation (5G) was introduced. 5G network is the latest communication network signal and offers many improvements such as ultra-high data rates, ultra-low latency, and massive capacity. 5G also supports many applications such as AR, VR and IoT. Multiple access technique being used by 5G signal is mmW and beamforming.

2.3 Transmission Media: Analysis of the Guided and Unguided Media

Transmission medium can be divided into guided and unguided media as shown in Figure 2-1. Guided media use physical conductors such as optical fiber cable, coaxial cable and twisted pair cable to transmit signal while unguided media does not use physical conductor, but it uses free space to transmit the signals to the receiver. An example of free space medium is infrared waves, radio waves and microwaves.

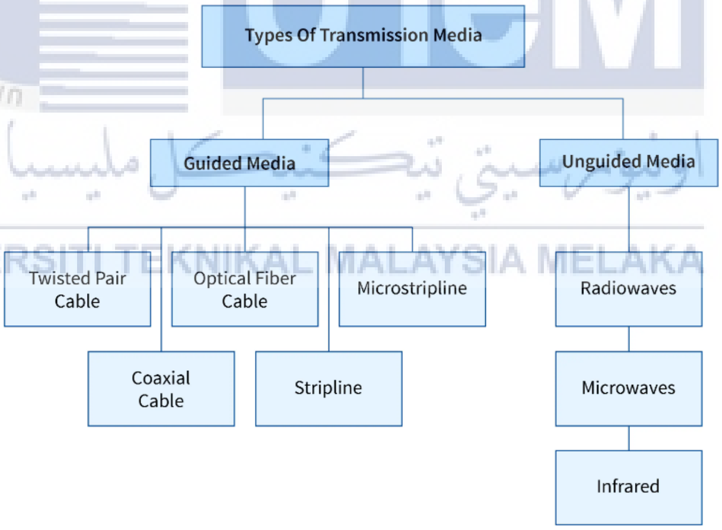


Figure 2.1 Types of Transmission Media

The twisted pair as in guided media has many advantages and disadvantages. The advantages of twisted pair cable are the cable can be installed easily, can carry both analog and digital data and if some part of twisted pair cable is damaged, it cannot affect the entire network. For the disadvantages, it has low durability as it can be damaged easily, poor security and has high attenuation [5].

For the fiber optic cable, is made of silica glass. Fiber optic can transmit data with the ability of reflecting the light in a way through the glass. There are many advantages of using fiber optic cable which are fiber optic cable can transmit the data at very high speed, cheaper than copper wire in terms of installation, and it has less signal lost compared to copper wire [6].

Unguided media such as microwaves transmission, operates by using microwave devices to transform electrical energy into electromagnetic energy and wirelessly transmit that energy through a transmitting antenna into space. Microwave wireless power transmission technology transforms electromagnetic energy into electric energy, which is then supplied to the electric load after being rectified, filtered, and subjected to other transformations [7].

2.4 Type of Modulations

Modulation is the process of varying a carrier signal in order to transmit information. This process is fundamental to communication systems, enabling the transmission of data over various types of media. Signal modulation is when the properties of a carrier signal are varied in accordance with the information signal. This enables the transmission of data over various mediums, such as optical fiber, radio waves, and coaxial cables. Modulation can be classified into analog and digital. Figure 2-2 shows the modulator with modulating signal or information signal and carrier signal are the input signal. Modulated signal refers to a carrier signal that has been modified or altered in some way to carry information.

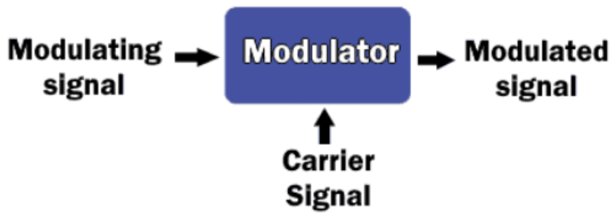


Figure 2.2 Block Diagram of Modulation

2.4.1 Analog Modulation

Analog Modulation has three types which are Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM).

2.4.1.1 Amplitude Modulation (AM)

AM is a form of analogue modulation where the modulating signal's instantaneous amplitude changes in relation to the high-frequency carrier signal's amplitude. Referring to Figure 2-3, carrier signal remains constant while message signal or information signal will keep changing instantly in relation to the modulating signal amplitude. Therefore, the carrier signal's amplitude holds the information [8].

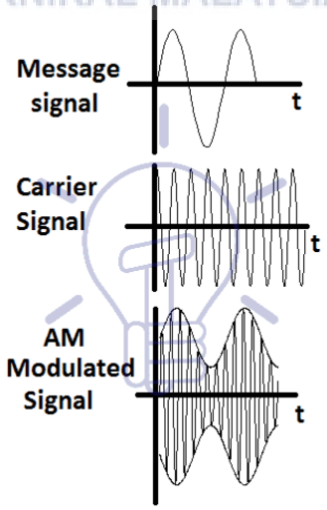


Figure 2.3 AM Signal

2.4.1.2 Frequency Modulation (FM)

FM is a type of analogue modulation in which the carrier signal's frequency changes in response to the message signal. For FM, the amplitude and phase of carrier signal or wave remain constant, but the frequency will change due respect to the changing of the frequency. Therefore, the FM modulated signal's frequency contains the information. The amplitude of modulating signal is directly proportional to the carrier signal's frequency [9].

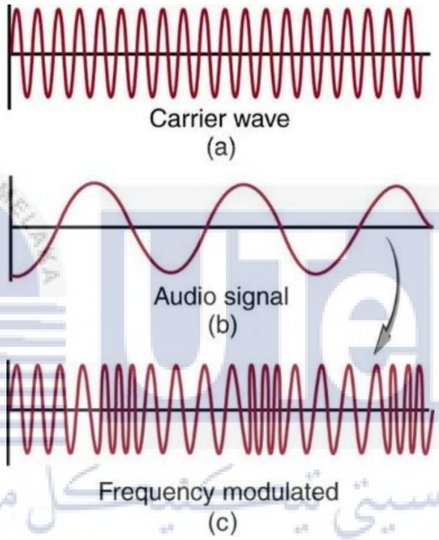


Figure 2.4 FM Signal

2.4.1.3 Phase Modulation (PM)

Phase Modulation (PM) is a type of analog modulation used in communication systems to change the carrier signal's phase in proportion to the message signal's instantaneous amplitude [10]. Figure 2-5 shows signal modulated based on phase changes in positive and negative axis.

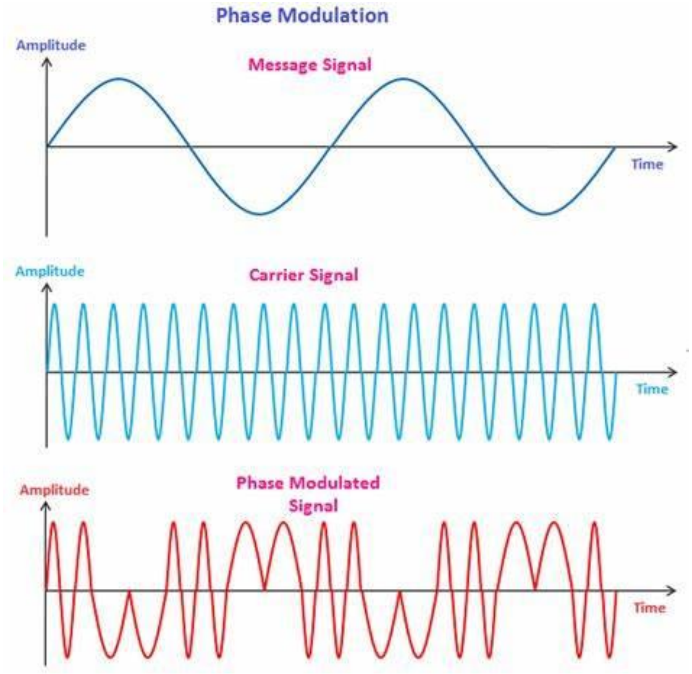


Figure 2.5 PM Signal

2.4.2 Digital Modulation

Digital Modulation has four types which are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM).

2.4.2.1 Amplitude Shift Keying (ASK)

ASK uses carrier signal amplitude variation to express distinct bits or symbols. While the carrier signal's frequency and phase are fixed, its amplitude is changed to represent binary 1 and binary 0 data inputs. The advantages of ASK are it can transmit digital data via optical fiber, it offers high bandwidth efficiency, and it has simple design of receiver. For the disadvantage is it has low power efficiency [11]. Figure 2-6 shows ASK signal based on binary input sequence signal.

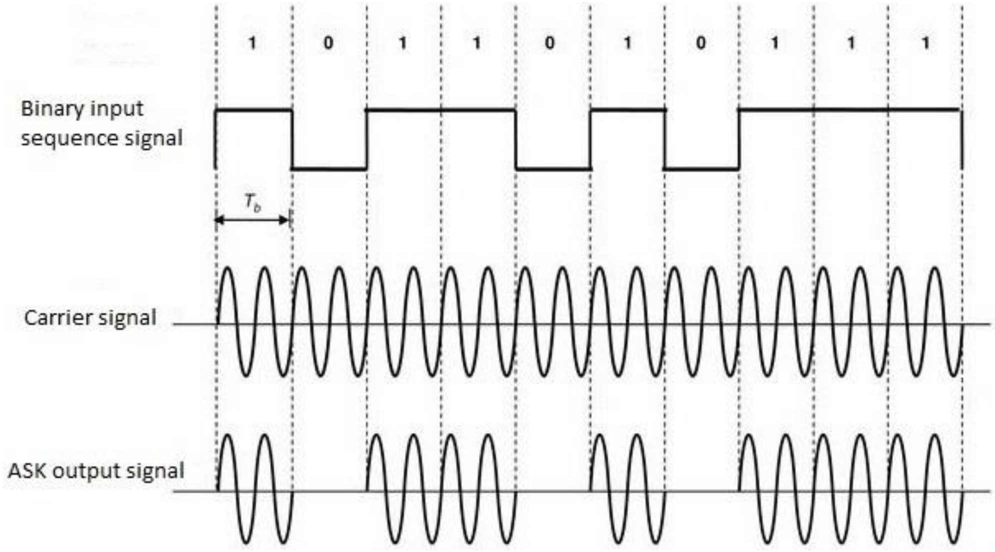


Figure 2.6 ASK Signal Frequency

2.4.2.2 Frequency Shift Keying (FSK)

FSK is a digital modulation technique which shifts the frequency of the carrier with respect to binary data signal. Binary data (0 and 1) are represented by two distinct carrier frequencies in the FSK modulation process. The advantage of using FSK is compared to AM or ASK. It was found that FSK is less susceptible to amplitude changes. Therefore, it has the resistance to changes in attenuation via channel [12]. Figure 2-7 shows the data, carrier and modulated signal based on FSK signal.

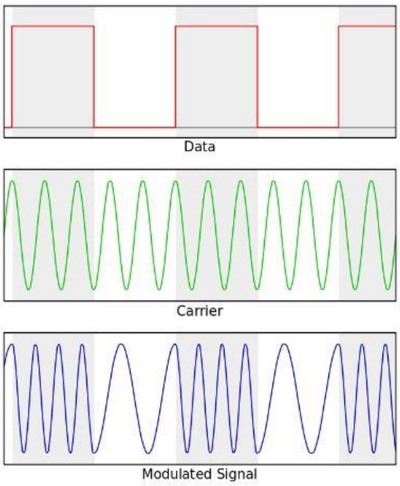


Figure 2.7 FSK Signal

2.4.2.3 Phase Shift Keying (PSK)

PSK is one of the digital modulations that transmits data by varying the carrier signal's phase. PSK can be classified into two types which are Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). BPSK can transmit one data or bit per symbol while QPSK can transmit two bits per symbol. Hence, QPSK has twice as much data rate compared to BPSK, but it required more complex transmitters and receivers than BPSK [13]. Figure 2-8 shows the message and carrier signal, phase modulated, carrier and modulated signal based on FSK signal.

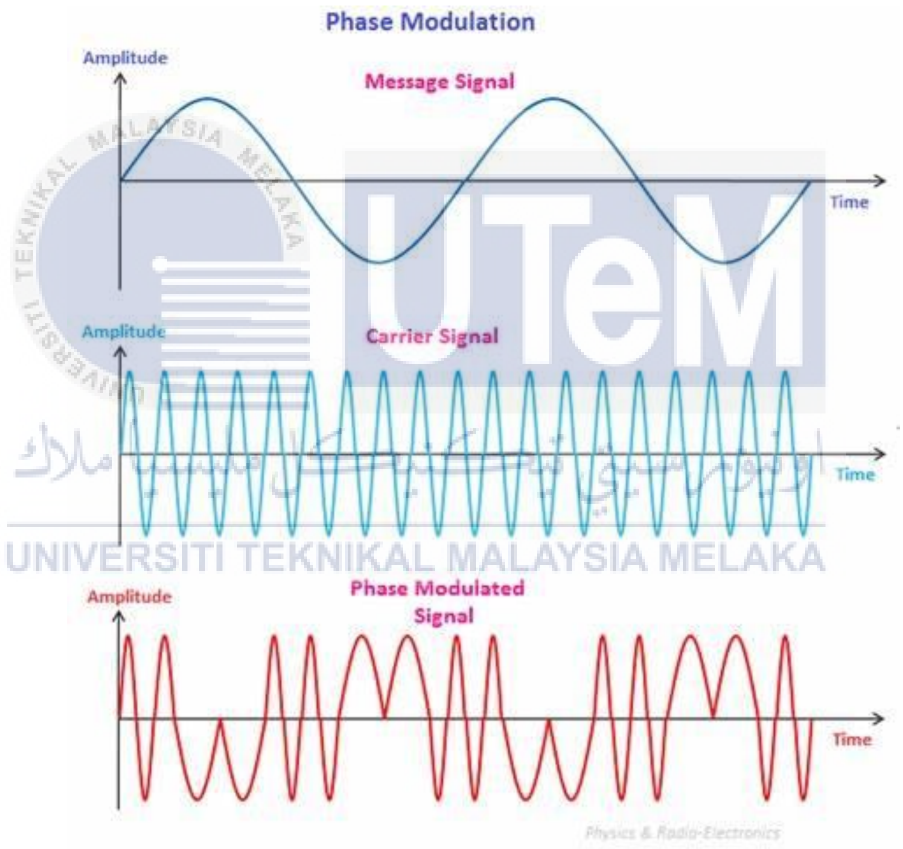


Figure 2.8 PSK Signal

2.4.2.4 Quadrature Amplitude Modulation (QAM)

QAM is a technique that combines amplitude and phase modulation signals into a single channel. By using this method, its effective bandwidth is doubled. Quadrature name is from using two carrier signals with same frequencies but differing in phase by 90 degrees [14].

2.5 Frequency Spectrum Range

The range of electromagnetic waves that can be utilized for communication or other purposes is known as the frequency spectrum. Wavelength, frequency, and energy are among the qualities that vary among the different regions of the spectrum. Bands including radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma-ray are among those that make up the spectrum. There is a particular range of frequencies and wavelengths for each band as depicted in Figure 2-9.

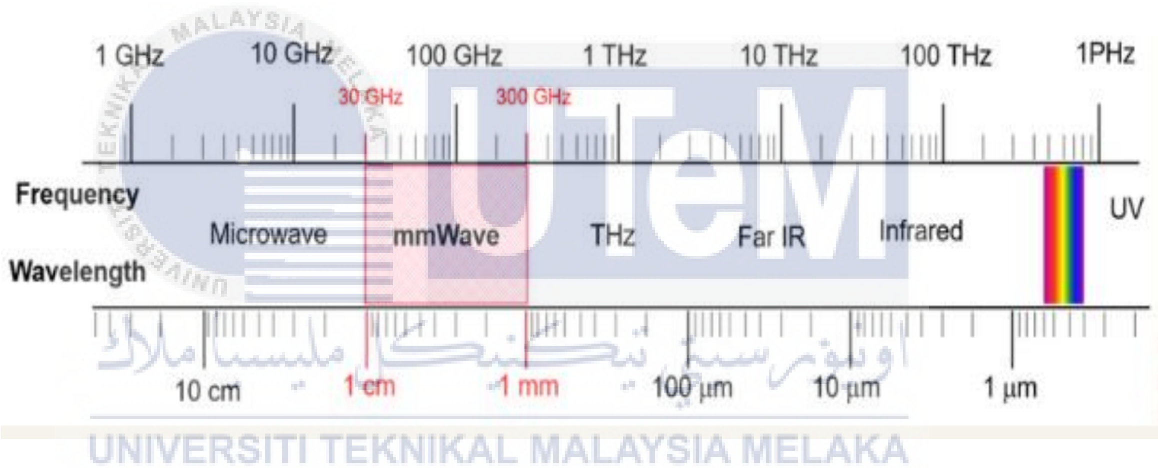


Figure 2.9 Frequency Spectrum Range

Extreme Low Frequency (ELF) has a very long wavelength, so it is suitable to transmit the data at long distance, but it has low frequency range, which is at range 0.3 Hz to 0.3 kHz, resulting in limited bandwidth. In comparison to higher-frequency bands, this restriction limits the total capacity for information transmission as well as the number of concurrent channels [15]. mmW is known as Extreme High Frequency (EHF) as it has 30GHz to 300GHz ranges of frequencies. Therefore, mmW has a very short wavelength which is from 1mm to 10mm. Hence, it can transmit a large amount of data in a short period of time [16].

2.6 Summary of Literature Review

Error! Reference source not found. shows the summarized research related to the influence of digital modulation on LTE over fiber and BER and Q-Factor measurements after being tested with different types of modulation techniques.

Table 2.1 Literature Review Table

Author	Title	Summary	References
Pham Tien Dat, Atsushi Kanno, and Tetsuya Kawanishi	A High-Speed QPSK/16-QAM 1-m Wireless Link with a Tunable 220-260 GHzLO Carrier in SiGe HBT Technology (2018)	This paper theoretically analyzes and experimentally demonstrates the transmission of 3GPP LTE signal over a seamlessly integrated radio-over-fiber and millimeter-wave wireless link1.	[17]
A. Bahrami, et al	Radio over Fibre Transmission Using Optical Millimeter Wave in Nonlinear Fibre Propagation (2022)	This paper examines how well the optical mmW-RoF system performs in comparison to wireless RF signals operating at 5 GHz while accounting for the Rayleigh fading channel. Comparing the optical mmW-RoF to the wireless RF system, improvements ranged from 40% to 64%. When compared to a wireless RF system across a	[18]

		Rayleigh fading channel, the power penalty values of the optical mmW-RoF system improved by 64% and 50% at 10 km, 50% and 41% at 30 km, and 46% and 43% at 50 km.	
John Park, et al	1550-nm Transmission of Digitally Modulated 28-GHz Subcarriers Over 77 km of Non dispersion Shifted Fiber.	The technique used in this paper is transmitting multiple digital modulation channels over non-dispersion shifted fiber up to at least 77 km in length without optical amplification and without being limited by dispersion effects at 1550 nm. Without the need for optical amplification, a QPSK modulated carrier at 28.00 GHz was successfully delivered over 76.7 km of NDSF.	[19]
J S Ojo and F O Dare	Analysis and impact of digital modulation techniques on LTE over fibre for 5G systems applications (2021).	Simulated a system consisting of Transmitter and Receiver where the input data signal was modulated using QPSK. 16QAM, 64QAM and 256QAM. BER and Eye Diagram output is observed and analyzed. This paper also	[20]

		evaluated the performance of different modulation techniques such as QPSK, 16QAM, 16QAM and 256QAM with BER and Eye Diagram by using Optisystem. Thus, the paper provides insights into the impact of digital modulation techniques on the transmission of RF signals over fiber for 5G systems applications	
K. H. Shakthi Murugan and M. Sumathi	BER and Eye Pattern Analysis of 5G Optical Communication System with Filters (2019)	The paper focused on various digital modulation techniques such as QPSK, 16 QAM, 64 QAM, and 256 QAM for LTE systems. The authors designed a QPSK-based Radio over Fiber (RoF) system and a QAM-based RoF system. The system is analysed with various optical filters like Bessel optical filter, Trapezoidal optical filter, Gaussian optical filter and Fabry Perot optical filter. By using the various types of filters, the performances of BER and Eye	[21]

		Diagram can be seen improved. It can also be observed that the Bessel filter shows a better performance compared to the other filters being used, which are Trapezoidal, Gaussian and Fabry Perot filter.	
Nabila Syadzwina Effendi, Yus Natali and Catur Apriono	Design of Radio over Fiber System with 16-QAM Modulation for 5G Fronthaul Network Implementation in Indonesia	This paper investigates RoF by considering amplifier placement and different Bit Rate with 16-QAM modulation for Indonesia's 5G Fronthaul Network Implementation. This journal designed the system by using preamplifier and amplifier booster. The result is observed and analysed by using BER. The preamplifier scenario has a BER value of 0 and a maximum transmission distance of 15 km while for booster amplifier scenario, the maximum transmission distance is 20 km, and the BER value is $2e^{-4}$.	[22]

Rasha Al-Dabbagh and Hamed Al-Raweshidy	Millimeter-Wave Transmission Technologies over Fiber/FSO for 5G+ Networks (2021)	This paper combines fiber and free space optical (FSO) backhaul connection communication system based on hybrid millimeter-wave transmission technology. The BER obtained is $1.5e^{-13}$ and Q-factor is 7.1 on transmission of a 64GHz mmW over hybrid Fiber/FSO.	[23]
Abdullah Al-Mamun Bulbul, Md. Tariq Hasan, et al	128-QAM Based MMW Communication (5G) Architecture (2021)	This paper used QPSK, 16QAM and 128QAM as modulation techniques. Implemented Single-carrier frequency-division multiple access (SC-FDMA) and orthogonal frequency-division multiple access (OFDMA) have been proposed for the uplink and downlink multiple access respectively. OFDMA and SC-FDMA has enhanced the system capacity. 128QAM has the highest data rate which is 9.2Gbps compared to 16QAM and QPSK at 2km distance between transmitter and receiver.	[24]

Sining An, Zhongxia Simon He, el at	A Synchronous Baseband Receiver for High-Data-Rate Millimeter-Wave Communication Systems (2019)	This paper proposed synchronous baseband receiver utilizes a carrier recovery subsystem implemented in an analog-digital hybrid manner. The CR subsystem comprises a low-speed digital signal processing platform, a bandpass filter (BPF), a digital-to-analog converter (DAC), and a single-sideband (SSB) mixer. The receiver has demonstrated successful transmissions of 9Gbps 64-QAM and 16Gbps QPSK signals, with error vector magnitudes (EVM) of 6.22% and 29%, and bit error rates (BER) of $1.3e^{-4}$ and $2.7e^{-4}$.	[25]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explored tactics connected to advancing this investigation via each step. Methodology is the collection of techniques utilized by researchers to complete their work of explaining, describing, defining, and forecasting events. The subsequent section will provide an overview of the work procedure, followed by a detailed explanation. Throughout the digital modulation methods on LTE over fiber for 5G systems implementation, this project requires the theoretical concept and experimental method. To meet the purpose stated in Chapter 1, the flowchart in Figure 3.1 is modified to illustrate the study's process.

3.2 Flowchart

The flowchart is essential since it illustrates in further detail how this study is conducted in each stage and route. It describes in detail what will be done, how it will be done, and what steps should have been followed to achieve the study's objectives.

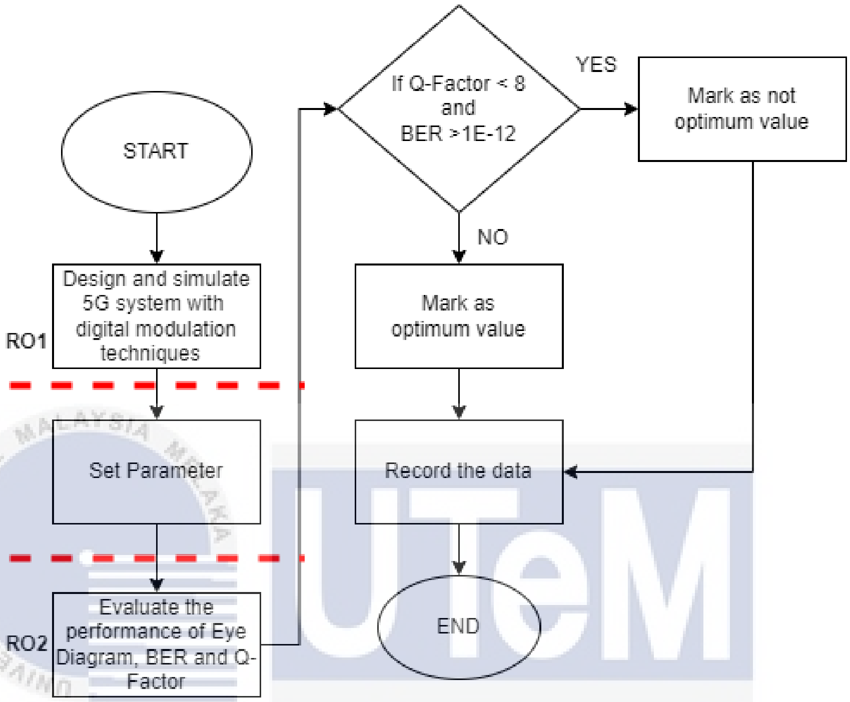


Figure 3.1 Project Flowchart

Among the first steps in this research is to design and simulate a 5G system with digital implementation. The circuit design is a crucial part to ensure that the data that has been transmitted to be received by the receiver. The acceptable received data is clarified by the Eye Diagram, BER and Q-Factor obtained and observed at the output. After completing the design, the parameters are set into PRBS, optical fiber, and electrical modulator. The parameters that are inserted need to comply with the ITU standard to ensure the result can be acceptable [26]. Then, the design is simulated, and the output is observed. The output performance of the eye diagram, BER and Q-Factor is evaluated and recorded into the table. After that, all the data is compared with the optimum value of BER and Q-Factor. If BER has lower than $1e^{-12}$ and Q-Factor is higher than 8, the data will be marked as passed the optimum value while if BER has higher than $1e^{-12}$ and Q-Factor is lower than 8, the data will be marked as not passed the optimum value. Finally, the data is recorded and plotted into the graph and table.

3.3 Simulation Software

Optisystem software is software that can design and simulate optical telecommunication systems based on real-time scenarios [27]. This software is very useful for educators, students, engineers and designers to develop knowledge about fiber optics. Optisystem can adjust many parameters such as the length of the single fiber optic, type of modulators, etc. It also offers many components pre-built in such as laser, modulators, amplifiers, and repeaters. With Optisystem software, the user also can analyse the output signal while simulating the result without extra cost. So, it really can save the cost before constructing the real-time environment and organization can allocate their budgets more effectively.

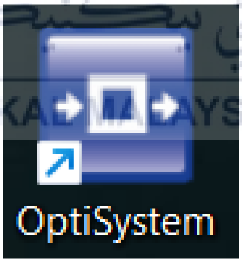


Figure 3.2 Optisystem software

Therefore, using Optisystem can really help the users to analyse improve the system's efficiency due to its wide list of features.

3.3.1 Performance Parameter

In this project, the signal analyzer such as Q-Factor, BER and Eye Diagram is used to monitor the performance of digital modulations with different parameters as variables such as bit rates, wavelengths and the distance of optical fiber cable.

3.3.2 Eye Diagram

To measure the quality of the signal output, the eye diagram is used in this project. Eye Diagram is a tool to an indicator to measure the quality in high-speed data transmission [28]. It visualized an eye pattern to indicate the performance of signal output strength. When the Signal to Ratio (SNR) is higher it indicates a better eye opening while when the SNR is low, the eye diagram displayed narrower eye opening. When the eye opening is narrow, it means that the signal output has high value of Q-Factor and BER.

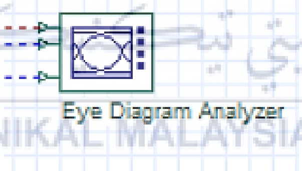


Figure 3.3 Eye Diagram Analyzer

3.3.3 Bit Error Ratio (BER)

BER Analyzer is used to measure the rate at which errors occur while transmitting the data stream [29]. BER analyzer icon on Optisystem is depicted in Figure 3-4.

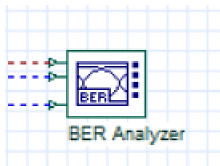


Figure 3.4 BER Analyzer

When the value of BER is lower than the optimum value which is at $1e^{-12}$, it indicates a better performance. As if the value of BER is higher than $1e^{-12}$, it indicates a poor performance of the signal. Formula below shows how the BER is calculated:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right)$$

This formula is used to calculate BER as erfc is the complementary error function defined as $erfc(x) = 1 - erf(x)$ with $erf(x)$ being the error function [30].

3.3.4 Q-Factor

Q-Factor is an analyzer that is used to measure the quality of the signal [31]. If the Q-Factor value is higher than 8, it means that the signal output has better quality performance. Below is the formula that being used to calculate the Q-Factor:

$$Q = \frac{\mu_1 - \mu_2}{\sigma_1 - \sigma_0}$$

Referring to the formula above, μ is the mean current values for bit ‘1’ and bit ‘0’ respectively while σ is for standard deviations which is noise levels associated with these bits [30].

3.4 Proposed System

This project evaluates how different digital modulation techniques (QPSK, 16QAM, 64QAM, and 256QAM) perform in transmitting 5G signals across varying distances and communication technologies. This begins with defining the research problem and conducting a literature review for background knowledge. This project use OptiSystem software to create a simulation that replicates real-world scenarios, configuring the transmitter, creating 5G frequency range (30GHz to 300GHz), and setting up transmission channels, the wavelength (1310nm and 1550nm) including optical fiber. After that, BER, Q Factor and eye diagrams are set up on the receiver to observe the signal output and compare the result obtained for every modulation scheme. The comparisons consider a few variables, including the optical fiber medium and varying distances from 5 to 100 km. Based on the finding, the best modulation technique is crucial to determine as to find the most efficient modulation technique on 5G MMW that is being tested with 1310nm and 1550nm of wavelength.

3.4.1 Transmitter Section

In this project design, the optical transmitter consists of three subsystems. The first subsystem is the PRBS generator. This subsystem represents the information or data to be transmitted [31]. The second subsystem is Electrical Modulator which is QAM and QPSK. This subsystem is used to convert electrical signals into modulated optical signals suitable for transmission [32]. The third subsystem in the optical transmitter is CW (continuous wave) laser. A CW laser used as light sources in fiber-optic communication systems [33]. Figure 3-5 shows the component in transmitter section.

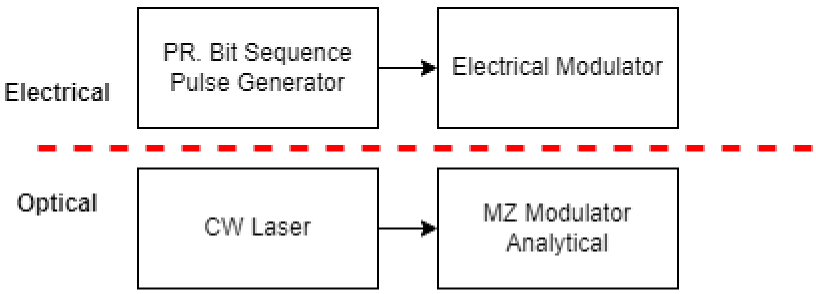


Figure 3.5 Transmitter Section

3.4.2 Receiver Section

Referring to Figure 3-6, the optical receiver consists of PIN Photodiode converts the optical signal into electrical signal followed by a low pass filter [34]. A Low Pass

Bessel Filter is used to allow the signal that lower than the cut-off frequency (f_c) and attenuate the signals that has higher frequency than the cut-off frequency [35-36]. 3R Regenerator is used to Re-shaping, Re-timing and Re-amplifying the signal output. Lastly, to observe the signal output, BER Analyzer, Q-Factor and Eye Diagram is used to measure the quality of output signal.

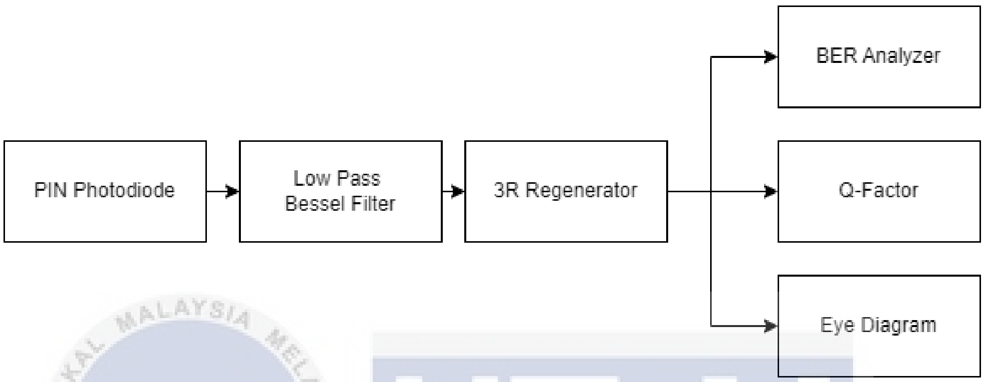


Figure 3.6 Receiver Section

3.5 The Construction of 5G System on LTE over Fiber

To find the output signal that will be generated and observed by the eye diagram, the circuit of fiber communication system modulated by QPSK and QAM is constructed as in Figure 3-7 and Figure 3-8.

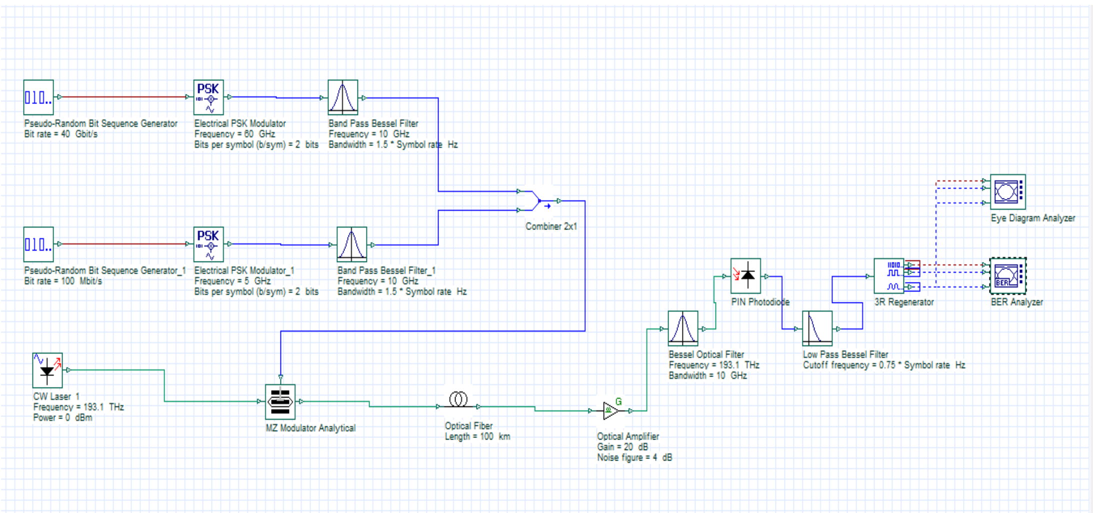


Figure 3.7 Optical Communication Circuit for QPSK

Figure below shows the 5G system by using Electrical QAM modulator.

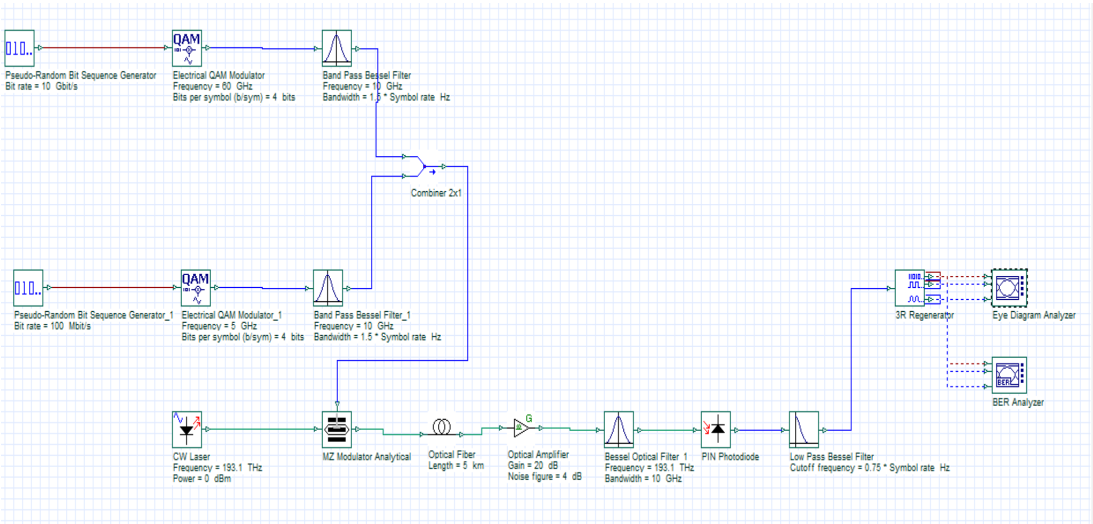


Figure 3.83-8 Optical Communication Circuit for QAM

Figure 3-7 and Figure 3-8 share the same circuit but the difference between the two circuits is the types of modulators that are being used.

3.6 Components Properties in Optisystem

Bit rates are a very important parameter to determine the performance of a communication system. Depending on application, the most used bit rate are 2Gbps, 10Gbps, 40Gbps and 100Gbps. PRBS is an essential tool in Optisystem and is used to generate binary sequence and set the bit rate for the system [37]. In this project, the system was tested and observed based on two different bit rates, 10Gbps and 40Gbps. Figure 3-9 shows the window in Optisystem platform to set the bit rate. This is where the bit rate is insert whether 10Gbps or 40Gbps.

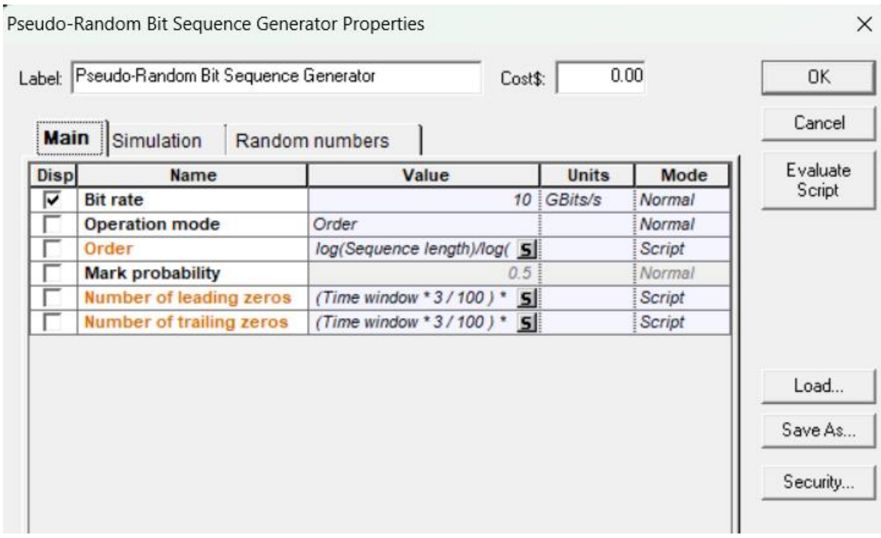


Figure 3.9 PRBS bitrate set up

In Figure 3-10, from the optical fiber setting, the wavelength is set to 1310nm and 1550nm, optical fiber length is set to 5km to 100km, and attenuation is set 0.2db/km for 1550nm while 0.35db/km for 1310nm.

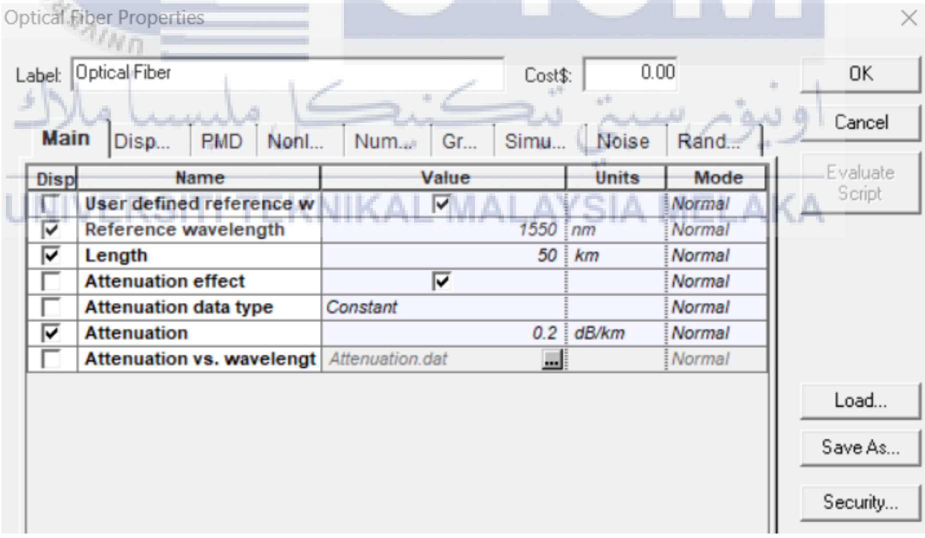


Figure 3.10 Optical fiber set up wavelength

Figure 3-11 shows the properties of electrical modulator bit per symbol and frequency set up. Electrical QPSK Modulator used 2 bits per symbol while Electrical QAM Modulator has 3 types of bits per symbol that are used in this project which is 24 (16 QAM), 26 (64QAM), 28 (256QAM) and in Figure 3.14, QPSK is set to 2 for the number of bits while both modulator frequency is set to 60 GHz.

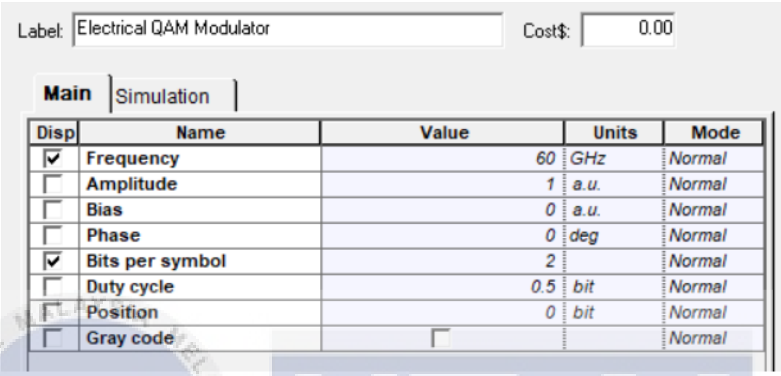


Figure 3.11: Electrical modulator set up

CHAPTER 4

RESULTS AND DISCUSSION

This chapter focuses on analyzing the output signal produced from the BER Analyzer. The important parameter observed are the BER value, the eye diagram, and the Q-factor. These analyses were conducted by varying a range of parameters in optical circuit such as the type of Electrical Modulator, the wavelength, the distance of optical fiber and the bit rate used based on the simulation conducted in Optisystem platform. Optisystem is a software that is widely used to design and test optical communication systems to examine the details of various components and configurations. The influence of various parameters is observed to find the optimum configuration for high performance communication links.

4.1 5G Systems Implementation by using Electrical Modulator

Referring to the network in Figure 3.7, the frequency is set to 60GHz at the electrical modulator. mmW has a range of frequency between 24GHz to 300GHz. So, 60GHz is complied with the mmW frequency specifications. The circuit is used to find the output signal at the receiver. The performance can be determined from the eye diagram, BER value and the Q-factor. PRBS is used to generate bit rates which are 10Gbps or 40Gbps. Two different communications wavelengths, which are 1550 nm and 1310nm with different attenuation was used. The distance varies from 5 km to 100 km and the acceptable output is when the BER in below 10e-12 and Q factor is greater than 8. This is based on ITU standard. Four different digital modulators namely QPSK, 16QAM, 64QAM and 256 QAM were simulated using this system setup. Table 4-1 summarize the parameters used to simulate the circuit.

Table 4.1 Simulation Parameters for QPSK and QAM

Component	**Specifications**
Optical Fiber Length	5km – 100km
Wavelength	1310nm, 1550nm
Attenuation	0.35db/km and 0.2db/km
Bit Rates	10Gbps, 40Gbps
Modulator Frequency	60GHz
Optical Amplifier Gain	20dB
Number of Base Station	2
Photodetector	PIN Photodiode
Photodetector Responsivity	1A/W
Electrical Modulator	QPSK, 16QAM, 64QAM, 256QAM
Fiber Optical Mode	Single Mode

4.2 Digital Modulator Performance for 5G System at 10Gbps

There are two different wavelengths tested with four different modulation techniques at bit rate of 10Gbps. The obtained data such as eye diagram, BER value and Q-factor were monitored and observed to justify the digital modulator performance. Each data was tabulated and classified as the following.

4.2.1 Eye diagram at 1550nm

Figures below show the eye diagram on 5km for QPSK, 16QAM, 64QAM and 256QAM at 1550nm.

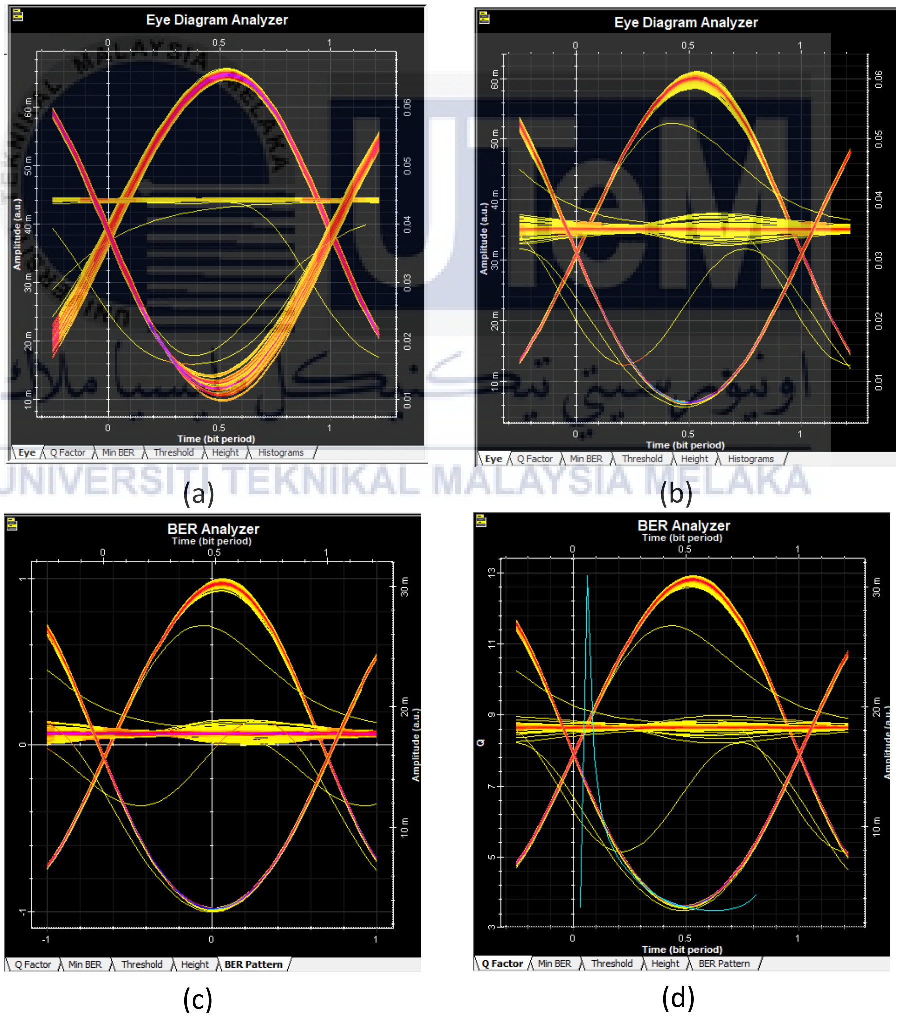
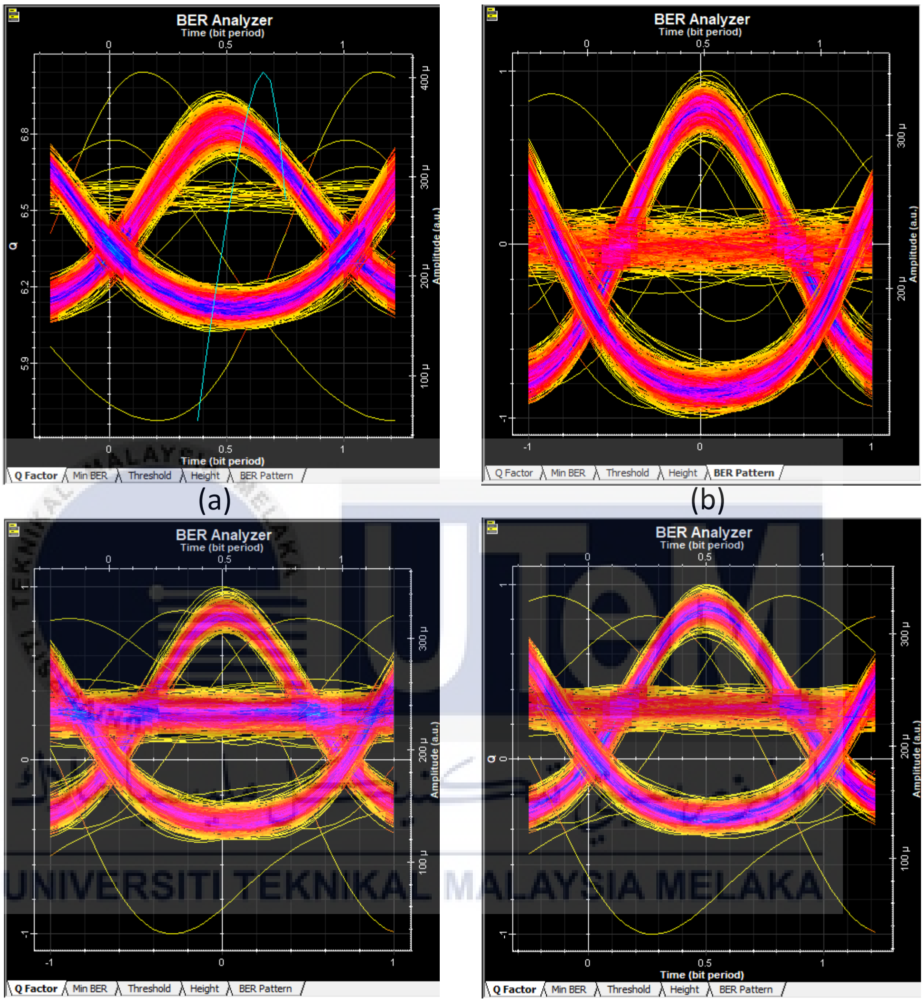


Figure 4.1 Eye diagram for 1550 nm at distance 5 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

By simulating the circuit in Figure 3.7 for QPSK and Figure 3.8 for QAM with different number of bits (16, 64, 256), the outputs are displayed in Eye Diagram just like an oscilloscope that can display electrical signal that changes over time. Good eye pattern in eye diagram can be produced when the BER and Q-Factor reach the optimum value or in other words when it has the least signal distortion. Low quality of eye diagram can be seen when the BER and Q-Factor is below than the optimum value as it happened because of Inter-Symbol Interference (ISI) and signal noise. This project operates in 1550nm and 1310nm of wavelengths. Both wavelengths operate at different wavelengths characteristics so the difference signal output produced when using both wavelengths can be observed and recorded.

At 10Gbps of bit rates, Figure 4.1 (a) QPSK (b) 16QAM (c) 64QAM (d) 256QAM shows the good eye opening as it shows the value of good BER and Q-Factor measurement. It is because the value of Q-factor is higher than 8 while the BER value is lower than $1e^{-12}$.

The figure below is at the maximum distance of optical fiber cable, 100km, the eye diagram produced the eye opening but with poor conditions as the BER and Q-factor value has poor quality.



(a) (b) (c) (d)

Figure 4.2 Eye diagram for 1550 nm at distance 100 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

Referring to Figure 4-2, after the distance of optical cable is increased to 100km, despite the presence of eye opening, the eye pattern are in a poor quality due to the high value of BER and lower value than 8 for the Q-factor. The same quality of the eye pattern is obtained at 1310nm of wavelength.

4.2.2 Eye diagram at 1310nm

By using different wavelength, 1310nm, the eye opening can be seen clearly at 5km for QPSK, 16QAM, 64QAM and 256QAM. The eye diagram in the figure below has asymmetrical eye crossing at 1310nm.

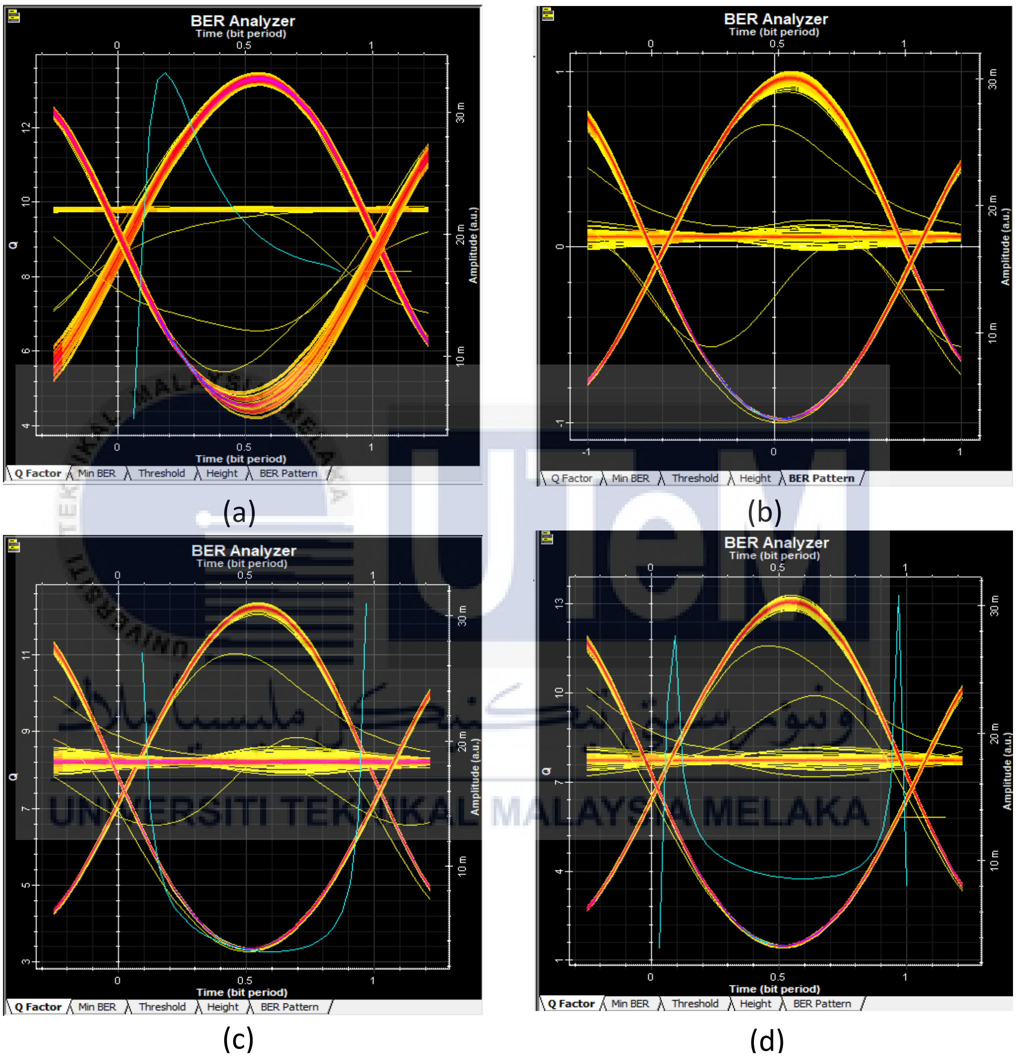


Figure 4.3 Eye diagram for 1310 nm at distance 5 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

The eye pattern produced in Figure 4-3 (a) QPSK (b) 16QAM (c) 64QAM (d) 256QAM can be seen clearly as the BER and Q-Factor is at optimum value. When the eye diagram is in excellent quality, it means that there's low attenuation and signal degradation occurred. The BER and Q-Factor obtained for (a) QPSK is $8.03e^{-20}$ and, 13.48, (b) 16QAM is $9.34e^{-20}$ and 9.02, (c) 64QAM is $2.06e^{-35}$ and 12.36 and (d) 256QAM is $1.09e^{-40}$ and 13.30.

The figures below show the eye diagram at which BER starts to drop below optimum value for QPSK, 16QAM, 64QAM and 256QAM.

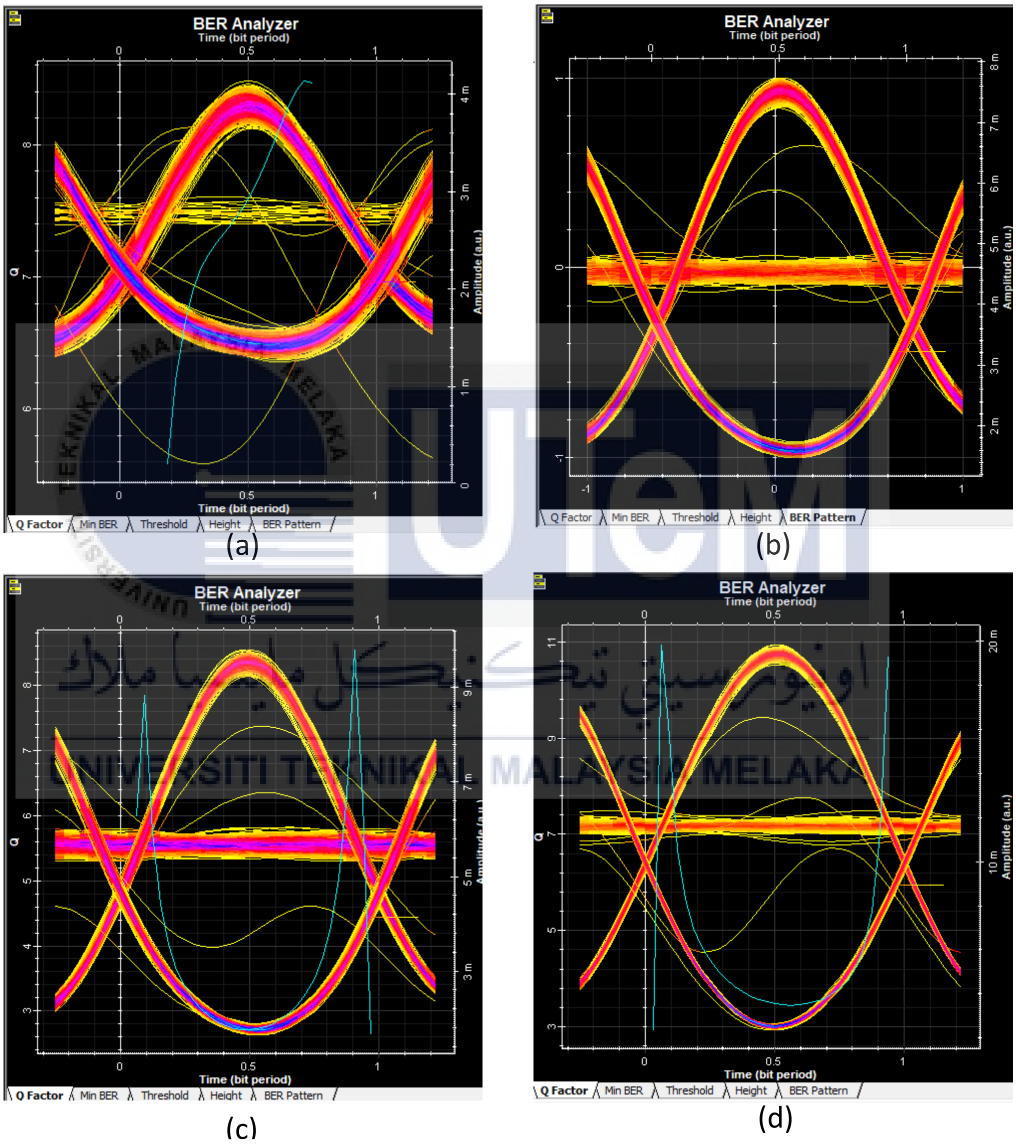
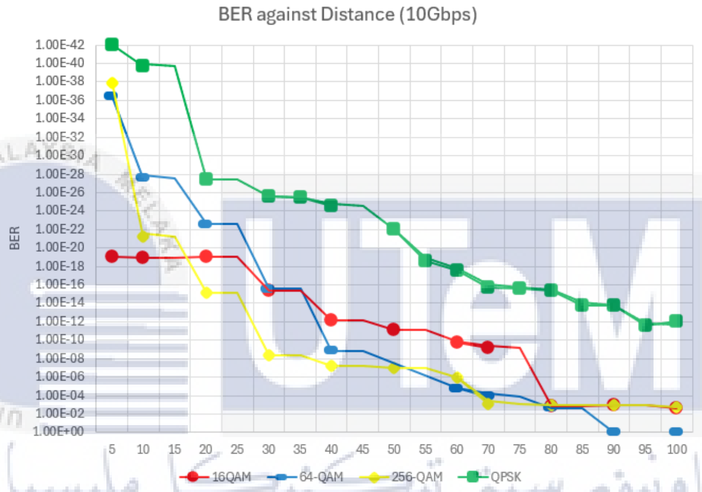


Figure 4.4 Eye diagram for 1310 nm at distance 15km to 50 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

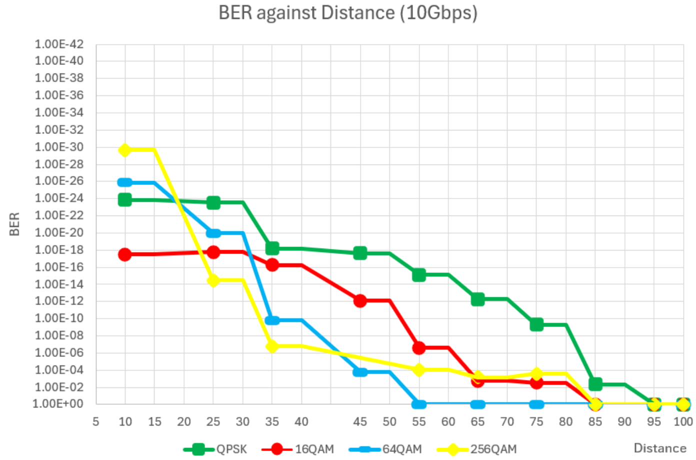
At Figure 4-4 (a) QPSK (b) 16QAM (c) 64QAM (d) 256QAM has shown the good eye diagram at 50km, 35km, 30km and 15km before the BER start to drop from optimum value. From the observation, the eye pattern starts to distort due to the BER and Q-factor being close to the optimum value and after the distance, the quality of the eye diagram is reduced as the signal degradation and attenuation is increased.

4.2.3 BER over distance

Figure 4-5 shows the graph of BER against distance at 1550nm and 1310nm. From the observation, the pattern of the graph for QPSK, 16QAM, 64QAM and 256QAM keep decreasing when the distance is increased to 100km.



(a)



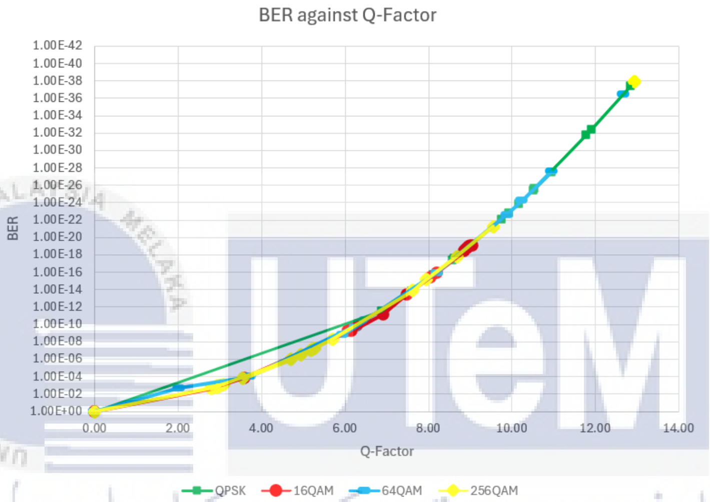
(b)

Figure 4.5 BER over distance at (a) 1550 nm, (b) 1330nm

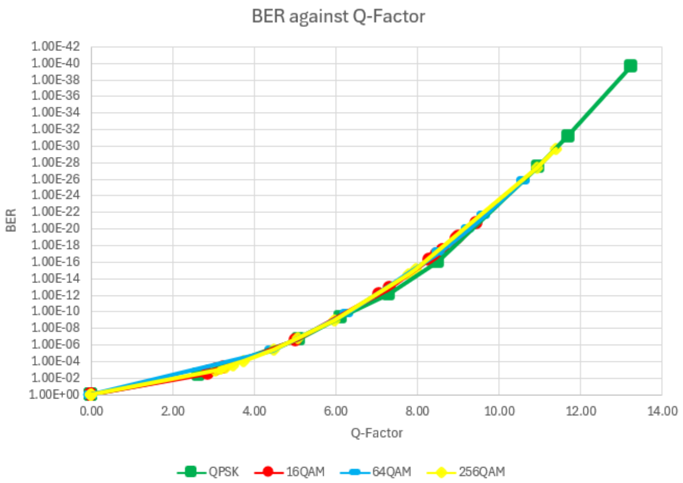
From Figure 4-5, the pattern of the graph for all modulation techniques can be seen as the BER is increased along with the distance of the optical fiber. These happened because the attenuation and signal degradation is higher when the length of the optical fiber cable is increased.

4.2.4 BER over Q-factor

The relationship between BER and Q-factor is plotted into a graph. Figure below shows the BER over Q-factor at 1550nm and 1310nm.



(a)



(b)

Figure 4.6 BER Over Q-factor at (a) 1550 nm, (b) 1310nm

To determine the relationship between BER and Q-Factor, the data that has been collected from the simulation test from the distance 5km to 100km is recorded and plotted into a graph. Figure 4-6 shows the graph plotted as BER against Q-Factor on 10Gbps at 1550nm, From the observation, when the value of Q-factor is decreased, the value of BER is increased.

4.3 Digital Modulator Performance for 5G System at 40Gbps

There are two different wavelengths tested with four different modulation techniques at bit rate of 40Gbps. The obtained data such as eye diagram, BER value and Q-factor were monitored and observed to justify the digital modulator performance. Each data was tabulated and classified as follows.

4.3.1 Eye diagram at 1550nm

Figure below shows the eye diagram for 40Gbps at 5km for QPSK, 16QAM, 64QAM and 256QAM.

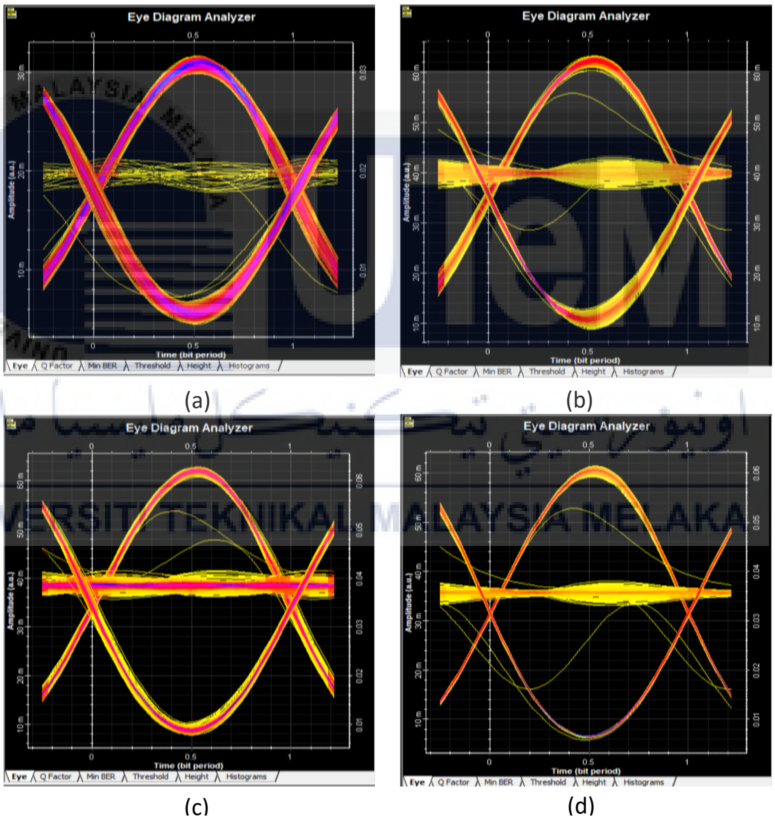


Figure 4.7 Eye diagram for 40Gbps 1550 nm at distance 5 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

At 5km, the good eye pattern can be seen in Figure 4-7 for (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM. The value of BER and Q-factor for all modulators passed the optimum value.

Figure below shows the eye diagram for 40Gbps at 100km for (a) QPSK, (b) 16QAM, (c) 64QAM and (d) 256QAM.

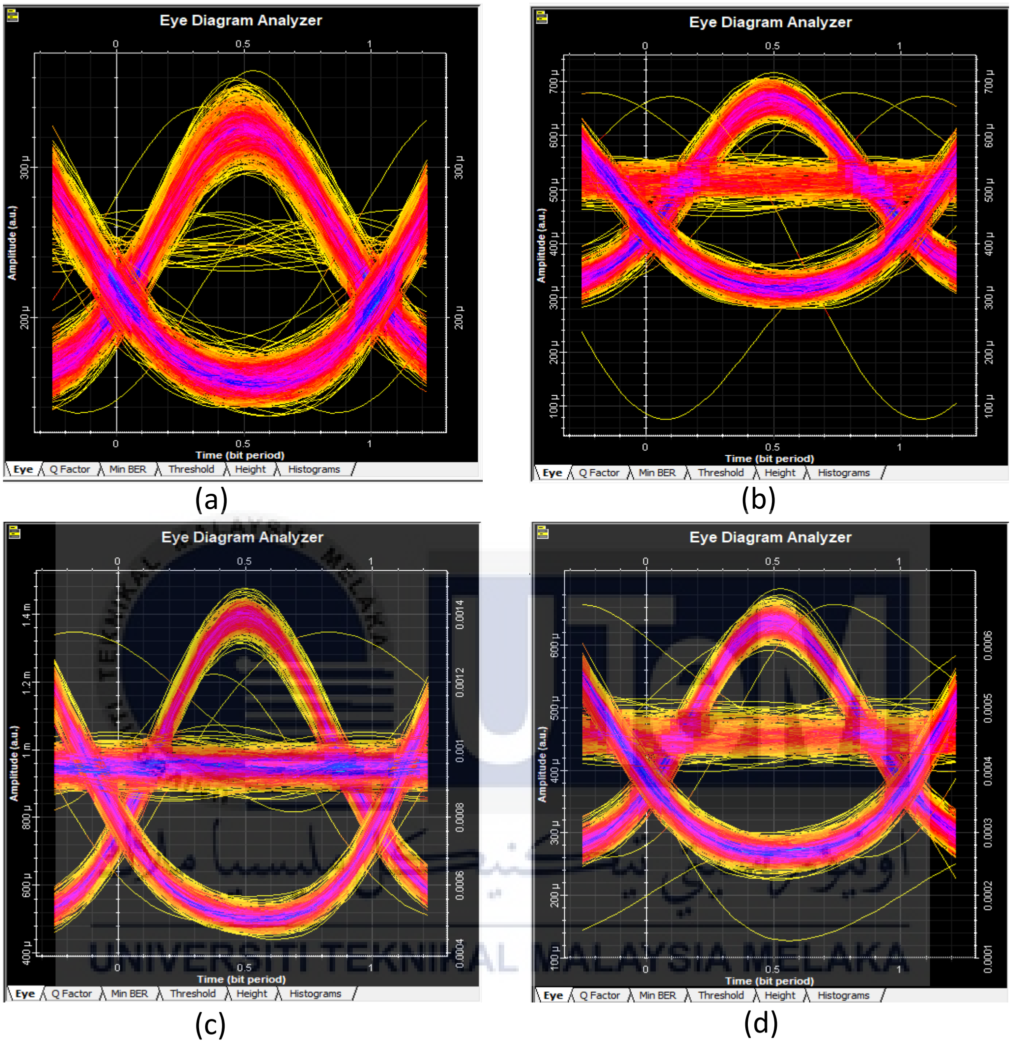


Figure 4.8 Eye diagram for 40Gbps 1550 nm at distance 100 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

After the distance is set to 100km, even though the eye opening can be observed but all the eye diagrams are in poor quality. These happened because the signal received has low value of Q-factor and high value of BER.

Referring Figure 4-8, after the distance is increased to 100km, even though the eye opening can be seen at (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM but the quality of the eye diagram is poor as the BER value is too high and Q-factor value is low.

4.3.2 Eye diagram at 1310nm

Figure below shows the eye diagram for 40Gbps at 100km for (a)QPSK, (b)16QAM, (c) 64QAM and (d) 256QAM.

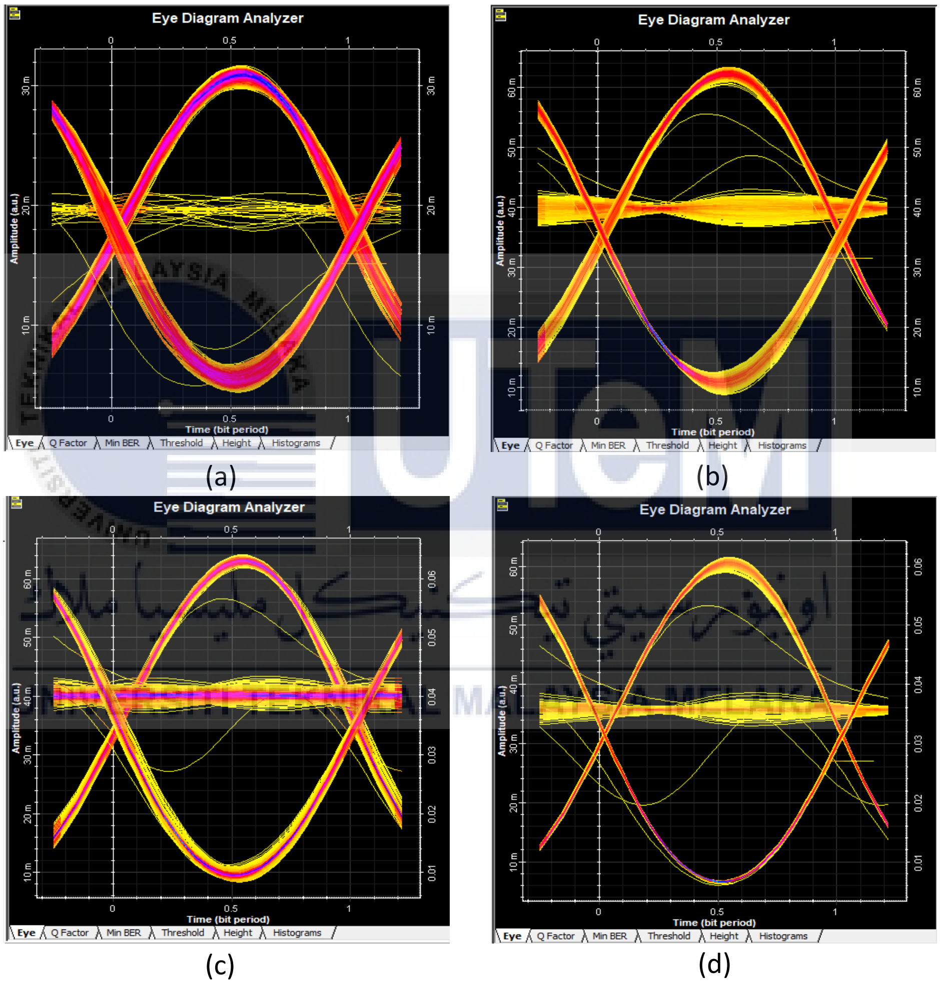


Figure 4.9 Eye diagram for 40Gbps 1310nm at distance 5 km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

Figure 4-9, the eye diagram for 40Gbps 1310nm at distance 5km for (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM are in excellent condition when the BER and Q-factor is at optimum value.

Figure below shows the eye diagram for (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM on which length at BER begins to drop below ITU standard.

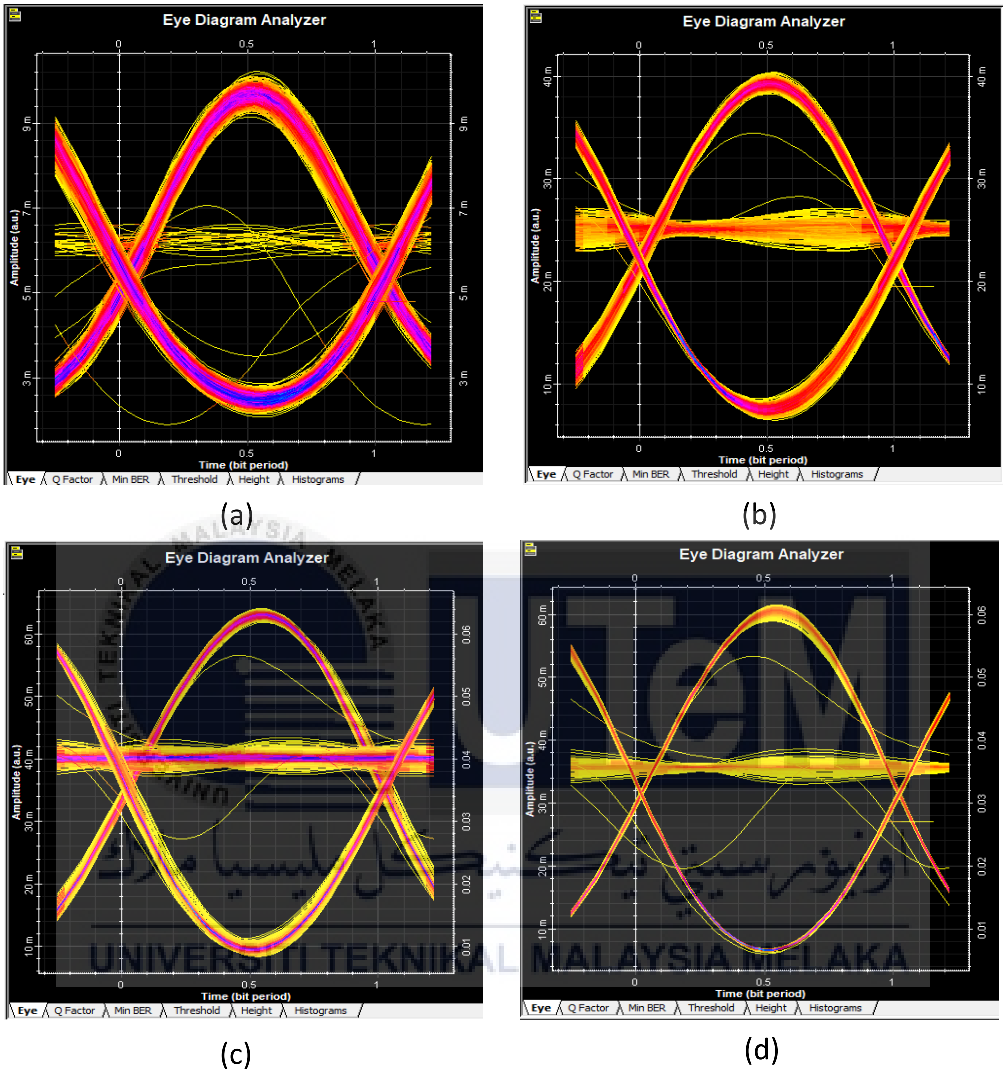
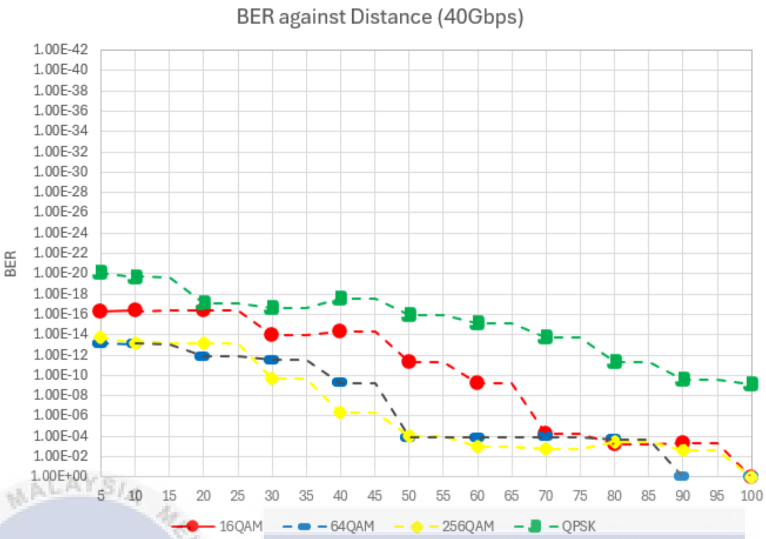


Figure 4.10 Eye diagram for 40Gbps 1310 nm at distance 5 to 15km (a) QPSK (b) 16QAM (c) 64QAM and (d) 256QAM

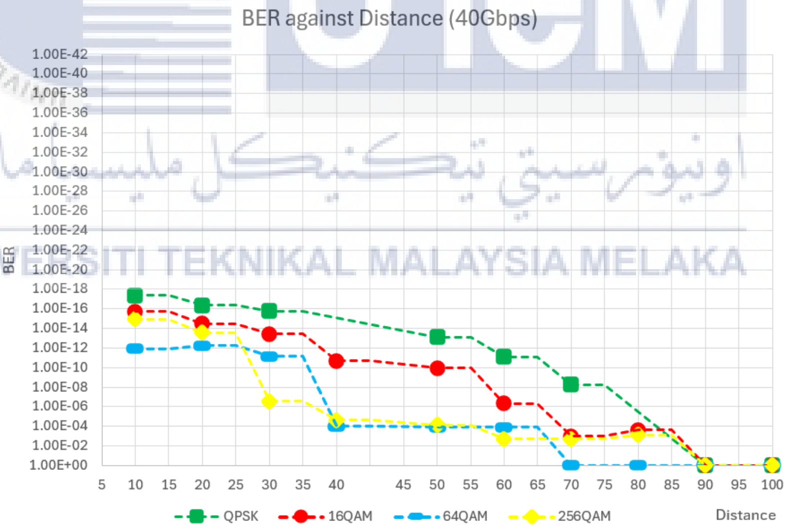
Based on Figure 4-10, the signal at (a) QPSK and (b) 16QAM can fully being transmitted at its maximum length of optical fiber cable is at 35km and 15km while (c) 64QAM and (d) 256QAM only can reached at below than 5km before the signal starts to distort.

4.3.3 BER over distance at 1550nm

Figure below show the graph for BER over distance at 40Gbps (a) 1550 nm, (b) 1330nm.



(a)



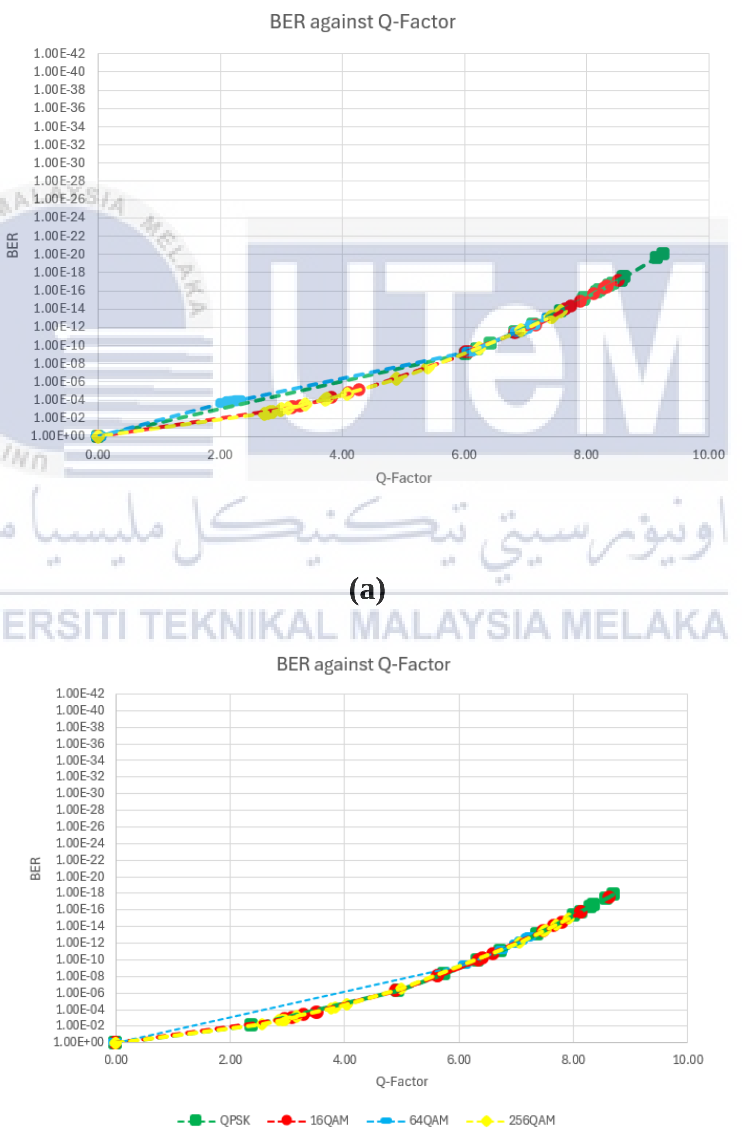
(b)

Figure 4.11 BER over distance at 40Gbps (a) 1550 nm, (b) 1330nm

Theoretically, when the distance of the optical fiber is increased, the BER value will increase too. It is because the longer the optical fiber cable, the more attenuation is produced, and the signal degradation also will increase too. In this project simulation, at Figure 4-11, (a) 1550 nm and (b) 1330nm, the graph shown the relation between BER against distance. From the observation, the BER will increase when the distance is increased too.

4.3.4 BER Over Q-factor at 1550nm

The relationship between BER and Q-Factor is plotted as in Figure below. Figure below shows the BER over Q-factor at 40Gbps (a) 1550 nm, (b) 1330nm.



(b)

Figure 4.12 BER over Q-factor at 40Gbps (a) 1550 nm, (b) 1330nm

Referring to Figure 4-12 (a) 1550 nm, (b) 1330nm, the BER value is increased when the Q-factor is decreased. Therefore, the length of the optical fiber cable can affect the value of the BER and Q-factor.

4.4 Comparison of Performance at 10Gbps versus 40Gbps

Based on the result that has been achieved from Figure 4.17 to Figure 4.20, 10Gbps of bit rate has shown that it has higher Q-Factor and lower BER than 40Gbps when the distance is increased from 5km to 100km. It is because at higher bit rates which at 40Gbps, it experienced more chromatic dispersion and attenuation compared to 10Gbps that lead the value of BER become higher and Q-Factor become lower than the 10Gbps. When the bit rates are higher, the bandwidth also becomes wider therefore it will cause more susceptible to chromatic dispersion and attenuation [38]. In summary, 10Gbps has lower BER and higher Q-Factor values compared to 40Gbps after being tested with different types of digital modulation and different wavelengths

Table 4.2 shows the recorded distance for the receiver to receive the data at optimum value of BER and Q-Factor according to ITU standard. At 10Gbps and 1550nm, QPSK, 16QAM, 64QAM and 256QAM performs well up to 80km, 40km, 30km and 15km while at 1310nm, QPSK, 16QAM, 64QAM and 256QAM performs well up to 50km, 35km, 30km, and 15km. At 40Gbps, the distance recorded is lower than 10Gbps which at 1550nm, QPSK and 16QAM performs well up to 55km and 25km while 64QAM and 256QAM can perform well only below to 5km. At 1310nm, QPSK, and 16QAM perform well up to 35km and 15km while 64QAM and 256QAM perform well only below than 5km.

Table 4.2 Overview of the Fiber Path Length at which BER Starts to Drop Below ITU Standard

Bit Rates (Gbps)	Wavelength (nm)	Modulation	QPSK	16QAM	64QAM	256QAM
10	1550	Fiber Length (km) BER is < 10^{-12} and Q-Factor > 8	80km	40km	30km	15km
	1310	Fiber Length (km) BER < 10^{-12} and Q-Factor > 8	50km	35km	30km	15km
40	1550	Fiber Length (km) BER is < 10^{-12} and Q-Factor > 8	55km	25km	Below 5km	Below 5km
	1310	Fiber Length (km) BER < 10^{-12} and Q-Factor > 8	35km	15km	Below 5km	Below 5km

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

In conclusion, all the objectives are achieved. The optical systems with different type of modulation technique on 5G system implementation has been constructed. The bit rate is set to 10Gbps and 40Gbps while the modulators used are QPSK and QAM. The length of optical fiber cable is varied between 5km to 100km, and the wavelength used is 1550nm and 1310nm.

QPSK has shown that it can transmit signal information over long distances which is 5km to 80km for 1550nm of wavelength and 5km to 50km for 1310nm of wavelength while using 10Gbps. QPSK is more robust to noise and has its lower susceptibility to signal degradation compared to 16QAM, 64QAM and 256QAM. Different wavelengths also can affect the quality of data signal when the distance is increased. 1550nm has lower attenuation compared to 1310nm which is 0.2db/km while 1310nm has 0.35db/km. Therefore, 1550nm is suitable for long haul communication while 1310nm is suitable for short distance only. So, based on the result that has been recorded, the data transmitted along fiber cable with 1550nm can maintain good BER and Q-Factor value compared to 1310nm.

In terms of bits per symbol at QAM, 16QAM has higher BER and Q-Factor compared to 64QAM and 256QAM. It is because 16QAM is more robust to noise due to wider spacing between constellation point but it can maintain the good BER and Q-Factor for a long distance compared to 64QAM and 256QAM. For 64QAM and 256QAM, it has higher Q-Factor and BER compared to 16QAM but only for a shorter distance than 16QAM. Therefore, QAM can be applied for short distance of optical fiber and to maintain the good signal, the repeaters need to be applied to boost the signal quality.

Lastly, in this project, 10Gbps has better results compared to 40Gbps because 10Gbps has lower susceptibility to dispersion and attenuation while 40Gbps faced more significant signal degradation that can affect the BER and Q-Factor performance.

In summary, with 10Gbps of bit rates, QPSK can transmit quality data signal over longer distances of optical fiber while QAM only can transmit the quality data signal over shorter distance of optical fiber cable.

5.2 Future Work

Future work of this project, other higher bits per symbol of the modulation such as 1024QAM investigate to analyse and compare the signal quality with modulation techniques that has been analysed in this project and investigate other advance modulation techniques such Orthogonal Frequency Division Multiplexing (OFDM).

Besides that, in future work also will be implementing optical amplifiers such as Erbium-Doped Fiber Amplifiers and any other repeaters within the links. When the number of amplifiers and repeaters are being placed more on the links, the signal quality can be improved, and attenuation effects can be reduced even if the distance of optical fiber is increased.

Lastly, by exploring various dispersion compensation techniques such as Fiber Bragg Gratings and Dispersion Compensation to reduce the impact of chromatic dispersion especially when using higher bit rates such as 40Gbps and above.

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