PERFORMANCE ANALYSIS OF FREE SPACE OPTICS WITH ATTENUATION CONSEQUENCE IN TROPICAL ENVIRONMENT

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

Faculty of Electronics and Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka

2024

DECLARATION

I declare that this report entitled "Performance Analysis of Free Space Optics with Attenuation Consequence in Tropical Environment" is the result of my own work except for quotes as cited in the references.

Signature : ....

Author : Muyassarah Ilyana Mustafa

Date : 24 January 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.

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Date	:	24 JANUARY 2024

DEDICATION

I dedicate this project to my family, who have been the inspiration behind my academic path with their everlasting support, encouragement, and believe in me. My success has been based on their unwavering support and selfless gifts. My research and project have been greatly influenced by my dedicated supervisor, Dr. Siti Khadijah, whose advice, knowledge, and tolerance have been invaluable. Her guidance and insightful advice have expanded my perspectives and helped me develop as a scholar. For their companionship, thought-provoking conversations, and encouragement during my stay at Universiti Teknikal Malaysia Melaka, my friends, and peers. This journey will always be remembered because of your friendship and our shared experiences. In conclusion, I dedicate this project to myself as a memory of my willpower, tenacity, and the innumerable hours of labor required to see it through to completion. This success is evidence of my dedication to education and self-improvement. I want to thank everyone for joining me on this amazing adventure. I dedicate my endeavor to every one of you, as you have contributed greatly to both my academic and personal growth.

ABSTRACT

Optical fiber technologies have been feasible solutions for backhaul networks. However, in high-density urban areas or topologies surrounded by mountains, it is not cost-effective to deploy compared to Free Space Optics (FSO) technologies. FSO uses a Line of Sight (LOS) communication system which transmits data through atmospheric absorption where scattering is the main mechanisms of optical signal loss which cause power degradation. The main challenge of FSO systems is that light propagation is influenced by different weather conditions. This project aims to design and analyze single and multiple-beam FSO systems using different attenuation of rain, haze, and fog. Different rates of attenuation represent different weather conditions of rain, fog, and haze at a data rate of 10 Gbit/s and a distance range of 700-1000m. Optisystem software is used to simulate the system's performance. System performance was observed through the BER, eye diagrams, and Q factor obtained. The eye diagram for the multiple beam FSO system was opened big, clean, and clear compared to the single beam FSO system for all situations. For multiple beams, the Q factor was higher and the BER was lower, which indicates good data transmission and good signal quality compared to the single-beam FSO system.

ABSTRAK

Teknologi gentian optik telah menjadi penyelesaian untuk rangkaian backhaul. Walau bagaimanapun, dalam kawasan bandar berkepadatan tinggi atau topologi yang dikelilingi oleh pergunungan, ia tidak kos efektif untuk digunakan berbanding teknologi Free Space Optics (FSO). FSO menggunakan sistem komunikasi Line of Sight (LOS) yang menghantar data melalui penyerapan atmosfera di mana penyerakan adalah mekanisme utama kehilangan isyarat optik yang menyebabkan kemerosotan kuasa. Cabaran utama sistem FSO ialah perambatan cahaya dipengaruhi oleh keadaan cuaca yang berbeza. Projek ini bertujuan untuk mereka bentuk dan menganalisis sistem FSO rasuk tunggal dan berbilang menggunakan pengecilan hujan, jerebu dan kabus yang berbeza. Kadar pengecilan yang berbeza mewakili keadaan cuaca hujan, kabus dan jerebu yang berbeza pada kadar data 10 Gbit/s dan julat jarak 700-1000m. Perisian Optisystem digunakan untuk mensimulasikan prestasi sistem. Prestasi sistem diperhatikan melalui BER, gambar rajah mata, dan faktor Q yang diperolehi. Gambar rajah mata untuk sistem FSO rasuk berbilang dibuka besar, bersih dan jelas berbanding sistem FSO rasuk tunggal untuk semua situasi. Untuk pelbagai rasuk, faktor Q adalah lebih tinggi dan BER lebih rendah, yang menunjukkan penghantaran data yang baik dan kualiti isyarat yang baik berbanding sistem FSO rasuk tungga.

ACKNOWLEDGEMENTS

Without mentioning the people who made it possible and whose constant direction and support crown all the effort's accomplishment, the satisfaction that comes with the successful completion of any work would be lacking.

Firstly, I want to express my gratitude and genuine thanks to Dr. Siti Khadijah for the professionalism and knowledge she showed while overseeing this project. I declare that she provided excellent direction and support, which led to this fantastic work. I must not fail to express my gratitude to my friends and to everyone else who has assisted me, whether directly or indirectly. I appreciate your help.

Above all, I want to express my gratitude to my family for their constant support as I conducted this research. I could not have successfully finished this task on deadline without their help. I extend my gratitude and blessings to everyone who helped me in any way during the project's completion.

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LIST OF SYMBOLS AND ABBREVIATIONS

FSO	:	Free Space Optics
BER	:	Bit Error Rate
Gbps	:	Gigabits per second
dB	:	Decibel
LOS	:	Light of Sight
SNR	:	Signal-to-noise Ratio
IR	:	Infrared
THz	:	Terahertz
PRBS	:	Pseudo-Random Bit Sequence
CW	:	Continuous Wave
APD	:	Avalanche Photodiode
NRZ	:	Non-return to Zero
MZM	:	Mach-Zehnder Modulator
WDM	:	Wavelength-Division Multiplexing
QoS	:	Quality of Service
RF	:	Radio Frequency
LED	:	Light Emitting Diodes
ISI	:	Intersymbol Interference

CHAPTER 1

INTRODUCTION

1.1 Introduction

Particularly in data transmission technology, advancements in the technology sector are currently moving quickly. Technology that can transport data swiftly is needed because of the growing demand for fast data traffic in the telecommunications industry. While FSO can transmit and receive data at speeds of up to 100 Gbps, optical fiber can only do so at a speed of 2.5 Gbps. This difference is due to factors such as wavelength, the modulation method employed, and the distance of the telescope between the transmitter and receiver. The quality of the signal, which has a positive correlation with signal strength, affects both the speed at which data is received and sent. Using the atmosphere as a propagation medium, FSO is an optical communication technology. While optical fiber employs silica as its transmission medium, FSO is an optical communication technology that uses the atmosphere.

Due to their complicated installation requirements and very pricey fiber technology, wired optical networks can occasionally be challenging to implement. Despite having a large range and fast gearbox speeds, they are not always a good solution. For short or medium distance transmission, FSO technology is a good substitute, especially in locations where installing wired optical network infrastructure is challenging [3]. The application of the FSO system is simpler, easier, faster, and thus less expensive than wired optical networks.

In addition to the many benefits that the FSO communication system offers, there are several issues that cause the optical link to deteriorate and make it difficult to utilize. Systems using FSO are extremely susceptible to atmospheric conditions. Since the signal travels through free space, aiming mistakes and atmospheric turbulence have an impact on it, which reduces system performance. When opposed to air turbulence, fog and rain have a substantially smaller impact on the gearbox quality [4].

The wavelengths of the system and the signal being broadcast are both significantly impacted by atmospheric turbulence. Because of variations in temperature, pressure, and wind along the path of optical transmission via the channel, atmospheric turbulence is brought on by both spatial and temporal random fluctuations of the refractive index [3], [5]. Beam spreading, picture dance, beam wander, scintillation, intensity variation, and signal phase can all happen because of unfavorable air conditions [6]. This has an impact on the FSO system performance and results in high BER or low Q factor values [7]. Small changes in the positions of the transmitter and receiver have a significant impact on the FSO system's performance as well. The misalignment can result in pointing errors and signal fading at the receiver due to a variety of causes, including building motion, wind loads, and thermal expansion. All these elements must be considered when building an FSO system [8].

In this research, the work focuses on the performance analysis of free space optics with attenuation consequence in tropical environments. This project is to design and develop a single beam and multiple beam FSO system using different attenuation of rain, haze, and fog. Optisystem software is used to simulate the system's performance.

1.2 Objectives

The primary objective of this research is to use various attenuations of haze, fog, and rain to design and construct a FSO system with a single beam and multiple beams. To evaluate the FSO systems performance, the project intends to compare the data transmission between single beam and multiple beam FSO systems. Additionally, by analyzing important performance metrics including the eye diagram, Q factor, and BER, the study aims to analyses the performance of the single beam and multiple beam FSO system. These measures offer insightful information about signal quality, dependability and data transfer speeds, making it possible to determine which system is most effective and efficient at transmitting data with little attenuation in a tropical environment. In short, the objective listed for the project are to:

1. To design and develop a single beam and multiple beam FSO system using different attenuation of rain, haze and fog.

2. To analyze the performance of single beam and multiple beam FSO system based on BER, eye diagram and maximum Q factor.

1.3 Problem Statement

Optical fiber technologies have been considered as a feasible solution for backhaul networks. However, in high density urban areas or topologies surrounded by mountains, it is not cost-effective to deploy. In urban areas, installing fiber optic connections can be disruptive and time-consuming compared to FSO technologies. FSO is a wireless optical communication technique that eliminates the need for physical wires and allows for high-speed data transfer. For short to medium range point-to-point communication links, FSO technology is frequently employed because it has the advantages of high data rates, rapid deployment, and cost-effectiveness in some situations. Since FSO systems are wireless, they can be set up rapidly and do not require a lot of physical infrastructure. This can be especially helpful in circumstances requiring quick connectivity. It is frequently necessary to navigate through complex urban environments, handle different right-of-way concerns, and secure permits to carry out fiber optic installations. Since FSO systems are wireless, it avoids a lot of these difficulties, making implementation easier. Redundancy and diversity can be added to the network architecture with FSO. FSO can provide as a backup or alternative connection option in urban locations where fiber optic cables may be vulnerable to physical harm or outages. Scalability and flexibility are provided by FSO systems. They are easily expandable or movable to accommodate shifting needs for urban areas. This flexibility is especially useful in urban settings that are constantly changing. Nonetheless, since air attenuation, weather and other factors can all have an impact on FSO performance, it is imperative to take these constraints and environmental conditions into account.

1.4 Scope of the project

The project's scope has been specified, and it should be utilized as a guide for finishing it. This project is a fully software based, simulated using Optisystem software. The channels are employed with each of them having 10 Gbit/s data rate. The elements to test are the single beam and multiple beam FSO system that are correlated to the tropical environment such as rain, haze and fog. In this project, the attenuation used to test the system is 6.0 dB/km for rain, 10.94 dB/km for haze and 12 dB/km for fog. The distance range used in this project is between 700m to 1000m. The output signal received is observed by analyzing using minimum BER, maximum Q factor and eye diagram.

1.5 Thesis Outline

There are five primary chapters in the thesis. As a thorough introduction, Chapter 1 offers a detailed rundown of the project. The project objectives, problem statement, scope and an overview of the overall initiative are all included.

In-depth analysis of the background research pertinent to the application at hand is provided in Chapter 2, which dives into the literature review. This chapter includes an examination of previous studies and literature, highlighting important discoveries and possible knowledge gaps.

The methodology used is covered in full in Chapter 3, along with the technical architecture of the system that was used for the project. It provides an explanation of the selected techniques, strategies and instruments and argues that they are appropriate for the project's execution.

The purpose of Chapter 4 is to describe the findings and encourage discussion of them. The results are examined.

In summary, Chapter 5 brings the thesis to a close by offering suggestions for improving and extending the work that has been done as well as a reflection on the overall success. It might also suggest possible directions for additional study or investigation in the area.

CHAPTER 2

BACKGROUND STUDY

This chapter briefly describes the previous research related to the FSO performance with attenuation consequence. Literature review is about the study of FSO in tropical environments such as rain, fog and haze, single and multiple beam FSO and even the principle and product implemented.

2.1 Overview

FSO is an optical communication system that relies on light that travels across empty space to convey data for telecommunications or computer networking and is subject to atmospheric attenuation, such as absorption and scattering. When a single beam FSO system is employed, these kinds of attenuations significantly reduce the strength of the transmitted signal. A multiple beam FSO transceiver system has thus gained supremacy and is typically utilized to solve this issue.

FSO is a recently developed spectacular sort of communication system that is of significant interest to all engineers and researchers. FSO offers a variety of benefits and among them is to minimize system-related costs. There is no need to install fiber optic cables, pay for expensive rooftop installations, improve the security system, or obtain an RF license. Currently, this system can send a lot of data at a rate of 1.25 Gb/s. The absence of RF interference is yet another advantage of the FSO technology [9]. It is a communication system that achieves broadband communications by passing modulated visible or infrared (IR) beams through the environment. Like the optical fiber transmission system, it operates on the same fundamental theory. If the FSO faces a clear LOS of the channel between the transmitter and the receiver, it can broadcast data over distances of up to several kilometers [10]. As a result, atmospheric factors like absorption and scattering have a significant impact on the transmission of modulated light. Aerosols and large raindrops, respectively, cause the generation of these parameters [9].

Fog, rain, and haze are likely to have a significant impact on the availability of FSO links in Malaysia's tropical environment. Low link performance exists in FSO communication systems with a single beam transceiver. It is feasible to use several beams at the transmitter and receiver to improve link performance [11]. Based on BER and connection distance, using a four beam FSO system with sixteen FSO channels produced the best results that could be considered acceptable [11].

2.2 FSO Systems in Tropical Environment

The term FSO is sometimes known as "free-space photonics" (FSP). It describes the transmission of modulated visible or IR beams across the atmosphere to achieve broadband communications. Although non-lasing sources like light-emitting diodes (LEDs) or IR-emitting diodes (IREDs) will work, laser beams are employed the most frequently [12].

The theory underlying FSO is quite like fiber optic transmission. The distinction is that instead of being directed by an optical fiber, the energy beam is collimated and transported from the source to the destination over open space or clear air. Collimation can be done with lenses if the energy source does not provide a parallel beam that is long enough to travel the needed distance. The data to be communicated is modulated into the visible or IR radiation at the source. The data is retrieved from the visible or IR beam and transferred to the hardware once the beam is intercepted by a photodetector at the destination. FSO systems can operate over several kilometers. Theoretically, communication is conceivable if there is a direct LOS between the source and the destination. Even if there is not a direct LOS, the energy can be reflected using carefully placed mirrors [12].

FSO has many benefits, which are readily available. However, since air serves as the FSO transmission medium and the light must travel through it, some environmental difficulties cannot be avoided. Most atmospheric occurrences happened in the regions of the troposphere. There are various limitations for FSO and one of the limitations is physical obstruction such as when they come in the LOS of transmission of the FSO system, flying objects like birds, trees, and towering structures can momentarily block a single beam. Other than that, the water molecules hanging in the terrestrial atmosphere are what cause absorption. These particles would take in the photons' energy. Absorption has a direct impact on the availability of the gearbox and the power density of the optical beam in an FSO system. Signals can also be absorbed by carbon dioxide [12].

The weather and environment's physical makeup cause atmospheric disturbance. Convection and wind combine the air parcels at various temperatures, which is what causes the problem. This results in variations in air density and changes in the refractive index of the atmosphere. Depending on the scale size of the turbulence cells, various effects can be produced. Beam wander would be the main effect if the turbulence cell had a bigger diameter than the optical beam. The fast displacement of the optical beam point is used to explain beam wander. When turbulence cells are smaller in diameter than optical beams, the optical beam's intensity variation or scintillation becomes more prominent. The optical transmission beam may degrade because of turbulent conditions. Refraction of the beam occurs at a different angle due to a change in the refractive index, and the optical beam spreads [12].

In most cases, fog, and haze result in air attenuation. Additionally, dust and rain play a role. Contrary to popular belief, air attenuation is not wavelength dependent. Wavelength affects haze. In hazy weather, attenuation at 1550 nm is lower than at other wavelengths. Wavelength does not affect attenuation in a foggy environment. When the optical beam and scattered particles collide, scattering phenomena occur. It is a wavelength-dependent phenomena in which the optical beam's energy is unaltered. However, only directional redistribution of optical energy occurs, which causes the intensity of the beam to decrease across a greater distance [12].

There are three types of atmospheric attenuation which are Rayleigh scattering which is known as molecule scattering, Mie scattering which is known as aerosol scattering and Nonselective scattering which is known as geometric scattering. The type of scattering depends upon the physical size of the scattered. Rayleigh scattering is what happens when something is smaller than the wavelength. It is referred to as Mie scattering when the size of the dispersed object is equivalent to the wavelength. Nonselective scattering occurs when it is substantially larger than the wavelength's diameter. Weather conditions in the atmosphere. FSO link uses the atmosphere as its transmission medium. Its ability to attenuate depends on several factors. Attenuation is primarily caused by weather. To get the prior knowledge of attenuation, the place in which a link is being constructed must have certain specified weather conditions, for instance, the two main weather conditions in temperate climates are fog and heavy snowfall. The availability of FSO lines in tropical areas is greatly impacted by two main weather conditions, heavy rain, and haze [12].

Typical tropical environment that most likely occurs in Malaysia would be rain, fog, and haze. Visible radiation is significantly reduced by fog. The obstruction brought on by fog absorbs, scatters, and reflects an optical beam of light. Mie scattering, often known as fog scattering, is primarily a function of increasing transmitted power. Rain attenuation, a nonselective scattering, occurs because of rainfall. Attenuation of this kind is wavelength-independent. Rain can cause variations in the delivery of lasers. The amount of rain affects how visible the FSO system is. Heavy downpours cause water droplets to solidify, which can change the characteristics of optical beams or obstruct their passage. During these conditions, light is absorbed, scattered, and reflected. Haze particles can linger in the atmosphere for a longer period, weakening the atmosphere. As a result, attenuation values depend on the current visibility level. There are two ways to collect data on attenuation for evaluating the effectiveness of the FSO system which is first, by temporarily placing the system at the site and evaluating its efficacy; and second, by applying the Kim and Kruse model [12].

The ability of rain, dust, snow, or fog to impede the transmission line and bring the network to a halt is the most crucial factor. In paper [2], the researcher has stated that an appealing alternative method has been demonstrated by FSO communication, which uses gigabit data rates to replace radio and microwave connection. FSO offers unlicensed spectrum for local area networks, easy implementation, little electromagnetic signal interference, and very high data rates [2]. These substantial FSO benefits are, however, constrained by the FSO's considerable vulnerability to attenuation due to weather and turbulence conditions [2]. Because of the absorption brought on by molecular diffusion and scattering brought on by fog, rain, snow, and haze, light beams are lost [2]. Fog, haze, mist, snow, and rain create scattering, absorption, and dispersion that results in air turbulence. To optimize the received power, an adaptive beam that adjusts its divergence angle based on the receiver aperture diameter and communication distance was recently presented in 2018 [16]. However, neither the improved visibility distance nor the decreased BER was significant enough. The digital modulations, comprising amplitude shift keying and pulse position modulation approaches [17], are assessed for various atmospheric turbulences.

In research [18], it is stated that wireless optical communication is much superior than radio frequency (RF) communication because it operates at a higher frequency and provides a faster data rate. However, the challenges associated with atmospheric conditions present a challenge. A desirable data rate of 10 Gbps was obtained at various optical bands in 2017 [19], however the visibility range was only 500 m.

The performance of three optical transmission windows in adverse weather was assesses, but it makes no recommendations for minimizing atmospheric turbulence [20]. Phase shift keying outperformed amplitude shift keying when various types of digital modulations specifically, amplitude shift keying and phase shift keying which were evaluated in 2018 [21]. However, it has little growth potential and is insufficient for the generation's and beyond breaking multimedia needs.

Based on research in [2], the author declared that to create an adaptive communication system employing iterative optimization, the appealing FSO properties were the driving force. The suggested method responds to changing atmospheric conditions, such as haze, fog, snow, mist, and rain. More particularly, the amplifier operates in a way that covers the distance when the visibility of the transmission distance changes because of meteorological circumstances. On the other hand, the suggested iterative optimization technique ensures communication dependability. By limiting the BER to the lowest achievable value, Quality of Service (QoS) is ensured. Iterative optimization, which maximizes transmission range without boosting transmit power while maintaining QoS by reducing BER to a manageable level, maintains BER constancy.

In research [9], the author used simulation in the software Optisystem 7.4, the FSO system operating at wavelengths of 850 nm, 1315 nm and 1550 nm was observed. The influence of different levels of atmospheric turbulence and link distance on the signal transmission quality was investigated. The Q factor and BER were used as a measure of quality. The changes of the Q factor depending on the observed system parameters are graphically shown. Eye diagrams and signal spectrum are also given. The analysis of the results shows how the quality of the received signal changes due to different atmospheric phenomena at certain distances from the transmitter.

2.3 Single and Multiple Beam FSO System

FSO has the potential to take the role of optical fiber as a last mile option. FSO is preferred over other communication systems like fiber optics because of its low maintenance costs and short implementation times. For FSO using traditional single beam systems, atmospheric attenuation is an issue, particularly when it rains hard, especially in tropical regions like Malaysia. A multibeam FSO transceiver system has therefore gained popularity as a solution to this issue.

It is feasible to use several beams at the transmitter and receiver to improve link performance [11]. Based on BER and connection distance, using a four beam FSO system with sixteen FSO channels produced the best results that could be considered acceptable [11]. Additionally, it has been demonstrated that multibeam FSO systems, particularly 4-beam ones, operate significantly better in clear weather than 1-beam, 2-beam, and 3-beam FSO systems, regardless of air attenuation.

The performance benefit of using more beams than four beams is minimal [11]. The work in research [9] focuses on simulating the performance of traditional 1-beam and 4-beam FSO systems during severe rain events from the perspectives of BER against link distance and SNR, regardless of additional atmospheric losses.

In research [9], the author has proved that the performance of single and four beam FSO system has been analyzed for average of maximum rain rate intensities for the period of five months in typical Malaysian weather based on conception of simulation models, and the study concludes that four beam FSO system can successfully operate for a link distance of 1130 m under heavy rain with specific attenuation of 19.6 dB/km and BER of 10^{-9} with acceptable SNR as compared to single beam FSO system.

The concept of the multibeam FSO system is the replacement of the single beam transceiver by multiple beam transceivers. By this replacement, multiple channels with different attenuation levels in the atmosphere are obtained in [23]. Other than that, Hybrid wavelength division multiplexing (WDM)-multi-beam FSO is a promising technique to overcome atmospheric attenuation due to tropical rain and to fulfill the growing demand for increased communication bandwidth and scalability. WDM is a multiplexing technique in which multiple optical signals are multiplexed on a single medium using different wavelengths [23].

Several single beam FSO WDM transmission systems have been successfully demonstrated [4], [24] where the different wavelengths are carried by one beam. Even though more than one wavelength is used to increase the data rate, after all, this system lies under a single beam attenuation effect. The study performed by [4], [24] concerning the rain rate is carried out in a temperate climate region, where the rain rate does not exceed 80 mm/hr. Moreover, the geometrical loss was not considered even though this type of loss is essential in evaluating the performance of FSO communications. Both researchers have used a single beam FSO system which is vulnerable to high attenuation. The transmitted power used by [24] is too high which is not practical in case of FSO system.

Despite all the system's noted shortcomings, created by [4], it nevertheless managed to reach a good link range of 2400 m. It is important to develop and analyze a hybrid WDM-multi-beam FSO system to function in tropical weather to minimize the transmitted power of the FSO system to a specified value, lessen the attenuation of the FSO link caused by heavy rain, and raise the data rate per end-user.

2.4 Related and Previous Work

Table 2.1 shows the summarize research related to single beam and multiple beam FSO system with attenuation consequence to tropical weather. The tropical weather that are mainly used in the research is rain, haze and fog.

Table 2-1 Summarize Research Related with Current Project

No	Title of Project	Summary	References
1.	Multibeam WDM-FSO System: An Optimum Solution for Clear and Hazy Weather Conditions	The technique used in this paper is the combination of multibeam technology and the WDM-FSO system. This system has been compared with the conventional single beam system by simulating both the systems under clear and hazy weather conditions. The results are compared in terms of link distance achieved by both systems. In conclusion, the multibeam system performs well under these two weather conditions. The comparison of	[22]

		results is done by simulating the multibeam system using MATLAB codes with Optisystem.	
2.	Optimization of FSO System in Tropical Weather using Multiple Beams	This paper analyzes and designs single beam and multiple beam FSO systems to compare the best system for combating the effects of tropical weather by using WDM multiplexing. The performance of a multibeam FSO system in tropical conditions is investigated. Simulation and accuracy are checked using measurements of local attenuation and rainfall intensity. The received power, geometrical losses, and atmospheric losses from severe rain have all been considered.	[23]
3.	Single and Multiple Transceiver Simulation Modules for Free-Space Optical channel in Tropical Malaysian Weather	This paper concludes a four beam FSO system can operate for a link distance of 1130 m under heavy rain with specific attenuation of 19.6 dB/km and BER of 10^{-9} with acceptable SNR as compared to single beam FSO system. The performance of single and four beam FSO system has been analyzed for average of maximum rain rate intensities for the period of five months in typical Malaysian weather under the interim, research is being done to develop a real-time system that operates under heavy rain as opposed to the simulation.	[9]
4.	Free space optics communication	This paper performs iterative optimization on FSO communication to reduce the	[2]

	system design using iterative optimization	effects of geography and weather. By reducing the BER, the optimization maximizes visible distance while ensuring reliability. The 10 Gbps data rate is the most that the wireless optical communication system is capable of. In terms of visible distance, Q factor, BER, and eye diagram in various atmospheric circumstances, the suggested wireless optical communication's performance is contrasted with that of the literature. The simulation results show that the suggested work had more successful performance.	

CHAPTER 3

METHODOLOGY

The project design is discussed in this chapter. The details on the proposed system including the circuit that will be designed and simulated is explained here. The conceptual features of the software component and the project execution aspects are also covered in this chapter.

3.1 Project Flowchart

Figure 3.1 shows the flowchart methodology of this project. It started with the background study and research related to performance analysis of FSO system with attenuation consequence in tropical environment. Since this is a fully simulated project, the software for simulation should be familiarized from an early stage. Next the design and modelling single beam and multiple beam FSO system. This involves creating a design for the single beam and multiple beam FSO including the attenuation for the tropical environment.

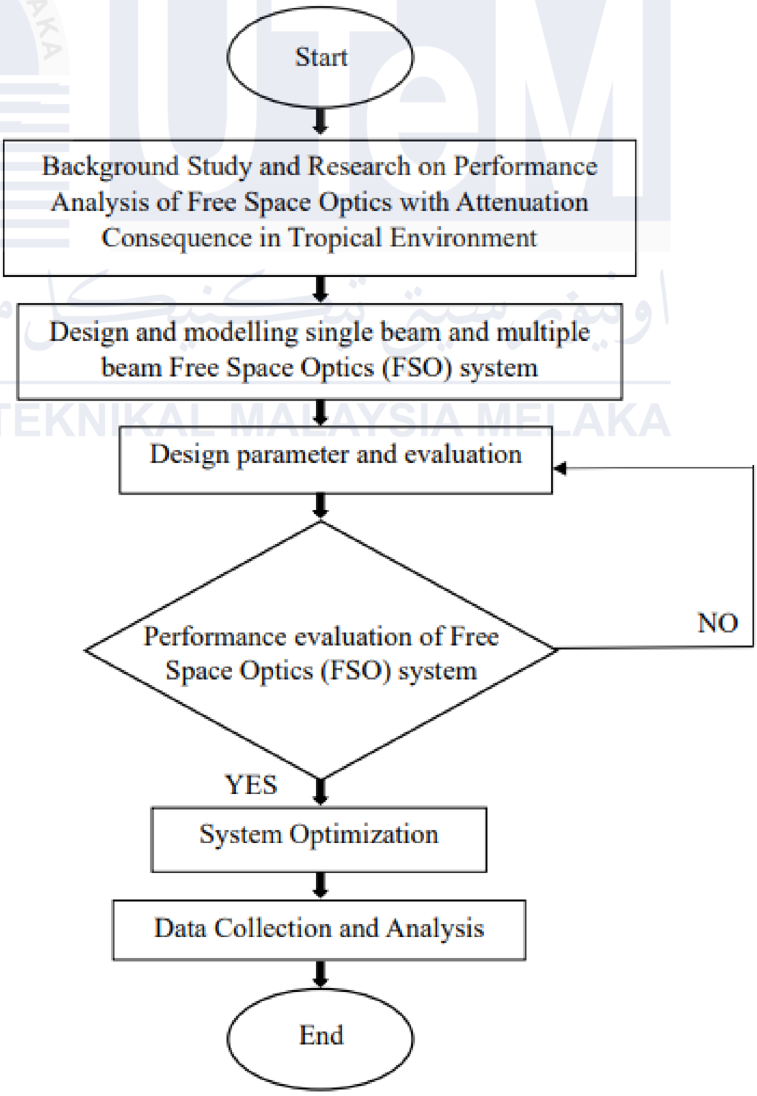

Figure 3-1 The Flowchart of the Project

The flowchart proceeds to the design parameter and evaluation step upon completion of the first design. Here, the system's precise characteristics such as the modulation scheme, transmitter power, receiver sensitivity, and error correction coding are defined. After that, an assessment is conducted to ascertain whether these metrics satisfy the intended standards and performance goals.

FSO system performance is then assessed. The system is simulated and performance parameters like the BER, eye diagram, and Q factor are evaluated using OptiSystem. The flowchart repeats the process of the design parameter and evaluation step if the evaluation shows that the system does not fulfil the intended criteria which is the clear eye diagram with minimum BER. The great value needed for Q factor for FSO systems is at BER 10^{124} with wavelength of 1550 nm. It is possible to increase the system performance by adjusting the transmitter power or receiver sensitivity, or by changing other system design factors.

Finally, the flowchart proceeds to the system optimization stage whether the evaluation demonstrates that the system satisfies the required criteria. To enhance the system's performance even more, the settings and parameters are adjusted here. The most suitable values for the transmitter power, receiver threshold, modulation format, and other parameters can be found using methods like numerical optimization techniques or simulation-based studies.

The procedure is successfully completed when the flowchart reaches the end, signifying the end of system optimization and the achievement of the targeted performance targets. With the help of this iterative flowchart, the single beam and multiple beam FSO systems continue to experience constant improvement, facilitating the design and optimization of a dependable and effective system.

3.2 Software for Simulation

A software called OptiSystem is used to develop and simulate optical communication networks. In this project, it is not possible to run the project with highly cost transmission testing, that is why the simulation is done. When discussing tropical weather which affected the transmission system performance, it can be represent by attenuation in system simulation. Attenuation is the term used to describe how weak an optical signal becomes as it travels through the atmosphere. Users can recreate a wide range of atmospheric conditions, particularly those that occur in tropical weather, with OptiSystem. This involves simulating variables that may affect the attenuation of optical signals, such as temperature, humidity, and atmospheric turbulence.

The typical characteristics of tropical weather are high humidity and a lot of rainfall. Optic signals may be attenuated by atmospheric water vapor and raindrops. Users may simulate these effects with OptiSystem, which makes it easier to evaluate how well optical communication links function in tropical environments. Depending on the duplicated air conditions, OptiSystem offers parts and techniques for formulating the attenuation properties of optical signals. This helps users to explore the possible effects of tropical weather on transmission performance and quality.

Other than that, under tropical conditions of weather, users may apply OptiSystem to optimize optical communication networks. To minimize the impact of attenuation and retain sustainable communication, this involves determining optimum modulation formats, programming schemes, and other characteristics.

Furthermore, users may use OptiSystem to examine their FSO system's performance using metrics such as Q factor, BER, and signal quality. A variety of analytical tools, such as eye diagrams for visualizing and assessing system behavior, are offered by the software. Moreover, OptiSystem provides optimization features that let users adjust system configurations and parameters for better performance. To optimize system efficiency and dependability, engineers can determine the best settings for transmitter power, receiver threshold, and other parameters by utilizing optimization algorithms and parameter sweeps.

With the help of Optisystem, engineers and researchers can analyze and improve the systems' efficiency due to its wide list of features. The complete FSO system, includes the transmitter, receiver, and optical link, may be developed, and modelled using OptiSystem. It offers several parts that are easily incorporated into the FSO system, including modulators, photodetectors, lasers, and optical fibers. Users can specify system parameters including data rate, modulation method, transmitter power, and receiver sensitivity. Figure 3.2 shows the Optisystem Software logo.

Figure 3-2 Optisystem Software

In conclusion, OptiSystem software offers a complete platform for the design, simulation, and optimization of FSO systems with single beam and multiple beams that have different attenuation consequences due to tropical weather. Through its broad component library, analytical tools, and optimization capabilities, users may reliably transmit data in FSO systems, evaluate the effectiveness of their systems, and make well-informed design decisions.

3.3 FSO System

FSO system is a communication system that transfers data between a transmitter and a receiver by using free space which is usually air or a vacuum as the transmission medium. One of the most important parts of the FSO system is the transmitter. Usually, a light source like a laser is included. Electrical data signals must be converted into optical signals via the transmitter. The data that needs to be communicated is encoded by the optical signals' modulation or intensity. The optical signals created by the transmitter move at the receiver across the free space medium.

The open air is the free space medium in a FSO system through optical signals that travel between the transmitter to the receiver. The propagation of light across the atmosphere or free space is used to facilitate communication in the absence of physical connections.

At the other end of the communication link is where the receiver is situated. Its main job is to recognize and decipher the optical signals that it receives from the transmitter. The sent data is recovered by the receiver by converting the optical signals into electrical data signals. The transmitter and the receiver must have a direct LOS for the FSO system to operate at its best. Any obstacles or atmospheric circumstances that restrict the LOS may affect the communication's dependability and efficiency.

3.3.1 Single Beam FSO System

The single beam FSO system consists of 1 input channel with 10 Gbit/s bit rate and then the signal is multiplexed before transmitting through FSO. The signal received from FSO will be demultiplexed before it is monitored.

Two terms can be added together to express the specific atmospheric attenuation which is haze and fog by using γ_{atmo} (dB/km):

$$\gamma_{atmo} = \gamma_{clear\_air} + y_{excess}$$

where:

γ_{clear_air}: specific attenuation under clear air (due to the presence of gaseous molecules)

y_{excess}: specific attenuation due to the occasional presence of fog, mist, haze, drizzle, rain, snow, hail, etc.

Atmospheric is a stochastic process since it is a time-varying transmission medium. On the other hand, limiting system availability and its consequences are typically handled statistically. The link margin, or M_{link} is the maximum attenuation that a system can withstand within a specific range.

To determine the specific attenuation caused by fog, γ (λ) fog (dB/km), under attenuation consequence fog conditions, the FSO community has utilized an empirically reduced formula which is:

$$\gamma_{fog^{(\lambda)}} = \frac{3.91}{V} \frac{\lambda}{550nm}^{-q}$$

where:

V: visibility (km)

λ: wavelength (nm)

q: a coefficient dependent on the size distribution of the scattering particles. It has been determined from experimental data and given by:

q = 1.6 V > 50 km

=1.3 6 km < V < 6 km

= $0.585V^{1/3}$ V < 6 km

To determine the attenuation value exceeded for a specific percentage of time p, the value of the visibility that was not exceeded for this percentage p is necessary for equation.

For attenuation consequence rainy condition, specific rain attenuation rain γ (dB/km) is given by the relation:

$$\gamma_{rain} = \mathrm{k}.R^{\boldsymbol{\alpha}}$$

Suggestion for each given percentage of the average year, p, and for any location, ITU-R P.837 gives the rainfall rate (R(p) (mm/h) surpassed, the equation above gives the specific attenuation exceeded for the time proportion. The parameters k and α depend on the rain characteristics. Hence, the attenuation of the atmospheric conditions for this project such as rain, haze and fog will be set at 6.0 dB/km for rain, 10.94 dB/km for haze and 12 dB/km for fog.

In a single beam FSO system, a transmitter carries out the transfer of the message signal into an appropriate form. Between the output of the transmitter and the receiver input, the channel serves as a conduit for the message to be transmitted. The transmitted signal is received on the receiver side, which then transforms it back into its original form. Pseudo-Random Bit Sequence (PRBS) generator, NRZ Pulse Generator, Continuous Wave (CW) laser and Mach-Zehnder Modulator (MZM) were all components of the transmitter section. Figure 3.3 shows the transmitter section for the single beam FSO system.

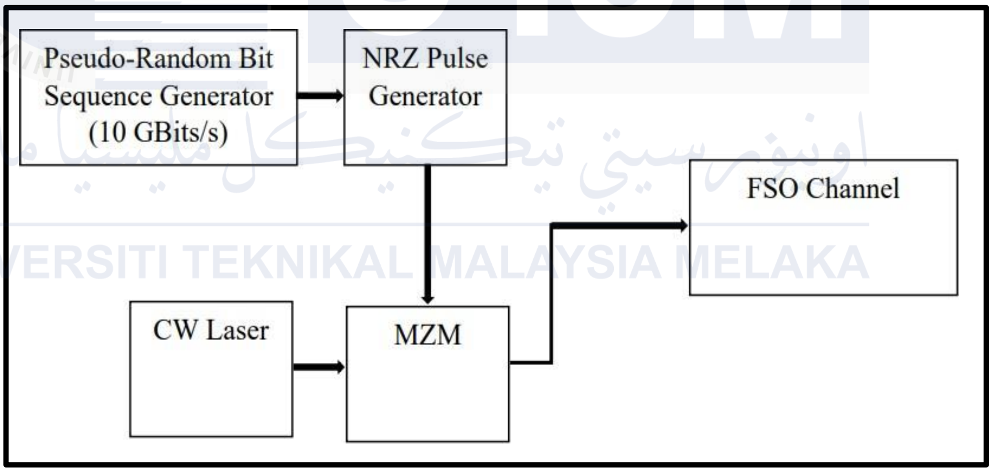

Figure 3-3 Transmitter section for single beam FSO system

The MZM device is one of the electro-optic modulators that use electro-optic effects for light modulation. By using this modulator, it can provide less chirp, tolerant to chromatic dispersion and low drive voltage. Indeed, it is high performance, thus suitable for developing next generation transmission systems [25]. The MZM modulator modulated the incoming optical carrier signal from the CW laser with the electrical signal from the NRZ pulse generator. A CW laser is used with 5 dBm of input power.

At the receiver end, an APD photodetector and low pass Gaussian filter are utilized. Visualizing the simulation value requires the use of an optical power meter and BER analyzer. Figure 3.4 shows the receiver section for the single beam FSO system.

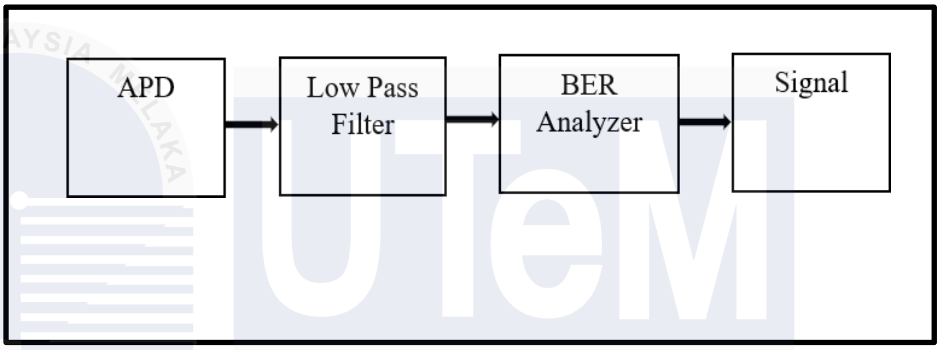

Figure 3-4 Receiver section for single beam FSO system

Before passing the optical signal to the filter at the receiver, a PIN photodetector with a high quantum efficiency was utilized to detect and demodulate the signal [26]. The higher frequency components and noise in the signal were removed using a low pass Bessel filter with cutoff frequency. The performance of the minimum BER was analyzed using a BER analyzer. The number of bits in a data stream that have been altered because of interference, distortion, and orbit synchronization issues is known as the BER [22].

The attenuation of the FSO channel has been set according to attenuation of the atmospheric conditions. The rain, haze and fog were set at 6.0 dB/km, 10.94 dB/km and 12 dB/km respectively [2]. The distance was set to 800 m. A CW laser that resonates at 193.1 THz and 193.2 THz emitted an optical light and generated the optical signal was modulated by the MZM modulator. A PRBS generator that generates random binary sequences at a bit rate of 10 Gbit/s modulates the data signal with another generator, which is an NRZ generator. The NRZ pulse generator was used to convert the binary sequence into an electrical signal. The NRZ pulse generator was chosen because it performs better for long haul communication based on the Q factor and eye diagram.

In this work, a single beam with each channel transmitting at 10 Gbit/s rate has been designed using Optisystem simulation software. Figure 3.5 shows the block diagram of a single beam FSO system and Figure 3.6 shows the Optisystem design layout for single beam FSO system with attenuation 6.0 dB/km for rain.

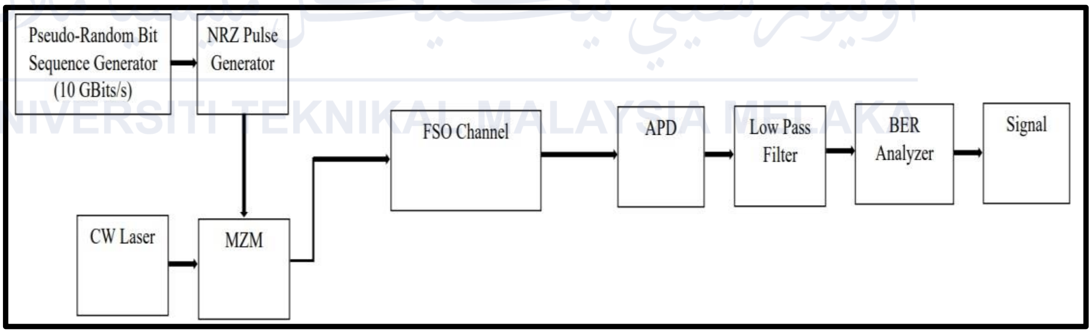

Figure 3-5 Block diagram of single beam FSO system

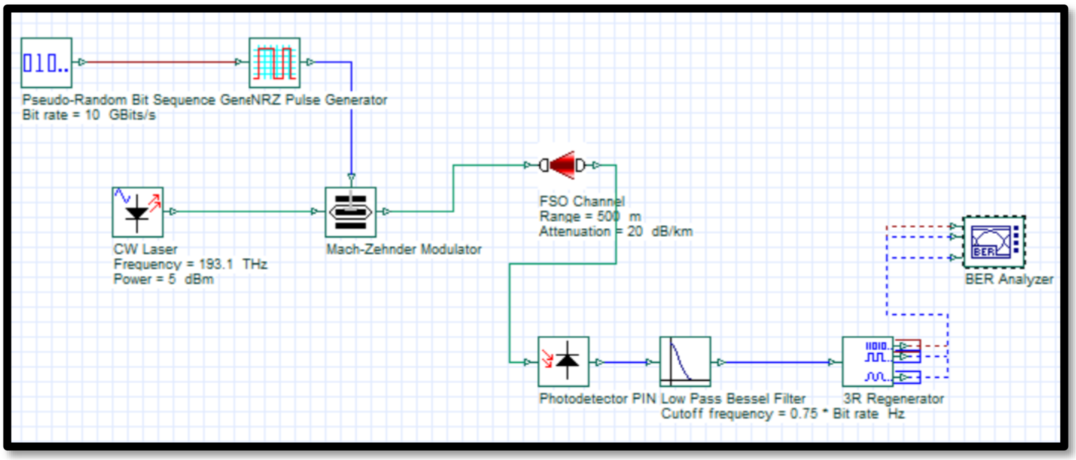

Figure 3-6 Optisystem design layout for single beam FSO system for rain

3.3.2 Multiple Beam FSO System

The multiple beam FSO system consists of 4 input channels with 10 Gbit/s bit rate and then the signal will be multiplexed before transmitting through FSO. Then, a multiple beam FSO system was designed the same way as the single beam FSO but with additional FSO channel and WDM. The goal of developing a multiple beam FSO system is to increase the transmission capacity and the data rate transfer compared to a single beam FSO system. This is to increase the capacity and achieved by using the WDM in an optical communication system. Figure 3.7 below shows the transmitter section of the multiple beam FSO system.

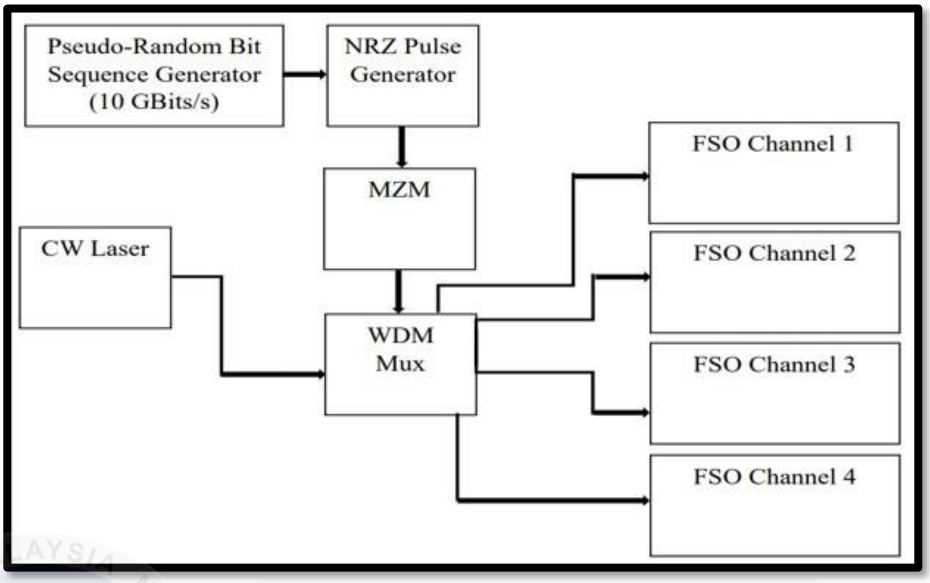

Figure 3-7 Transmitter section for multiple beams FSO system

Multiple beams are an efficient technique used with long-distance transmission [21]. On the receiving side, the received optical signal is returned to the original carrier's wavelengths by a demultiplexer. 4 channel WDM Mux and Demux are used in transmitter and receiver end respectively. WDM multiplexes the optical signal together and an optical amplifier is used to amplify the optical signal. Figure 3.8 below shows the receiver section of the multiple beam FSO system while Figure 3.9 below shows the block diagram of a multiple beam FSO system.

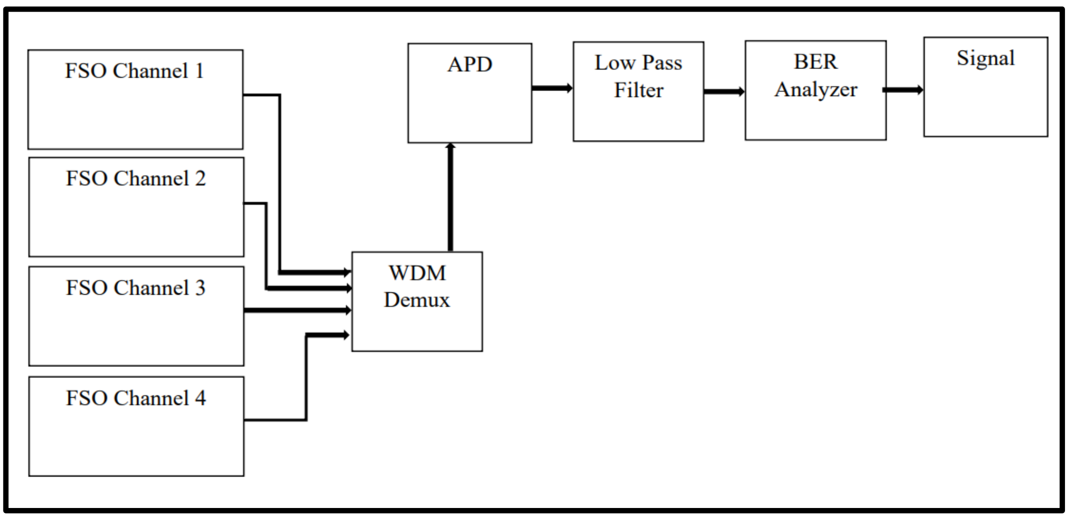

Figure 3-8 Receiver section for multiple beams FSO system

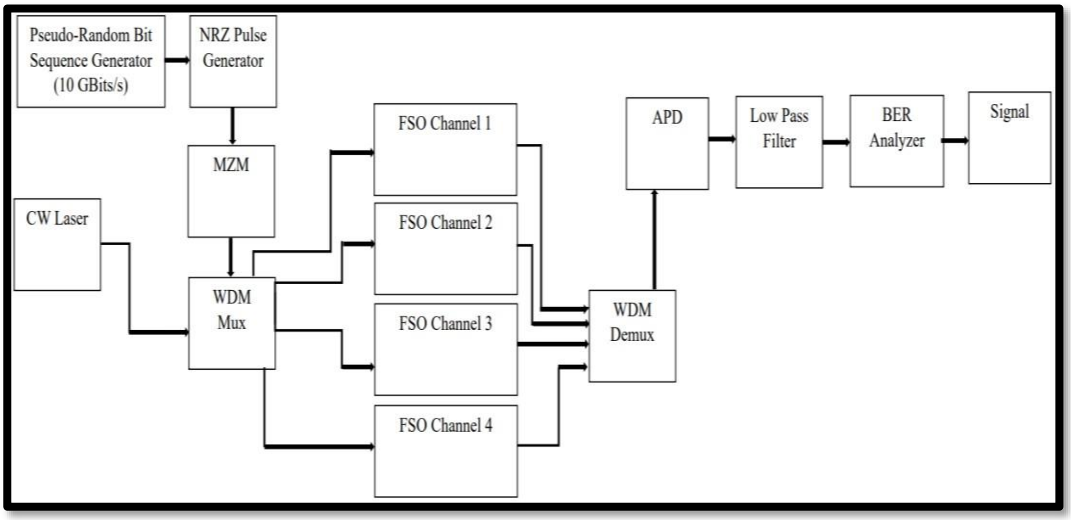

Figure 3-9 Block diagram of multiple beams FSO system

The attenuation of the FSO channel has been determined according to attenuation of the atmospheric circumstances [2] such as rain, haze and fog will be set at 6.0 dB/km for rain, 10.94 dB/km for haze and 12 dB/km for fog. The range, input power and frequency were set to be the same as a single beam FSO system. Figure 3.10 shows the Optisystem design layout for multiple beam FSO system with attenuation 6.0 dB/km for rain.

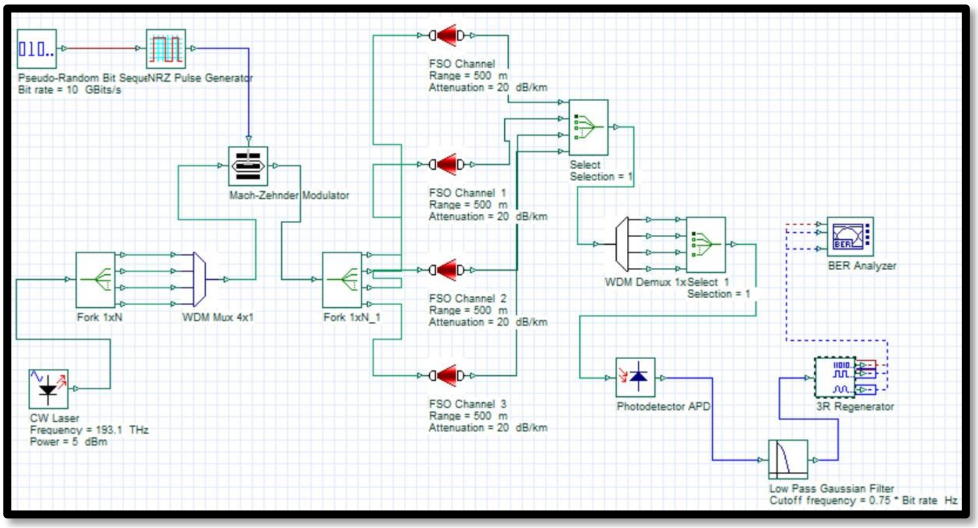

Figure 3-10 Optisystem design layout for multiple beam FSO system for rain

A system is simulated to examine the performance of both single beam and multiple beam FSO systems. Table 3.1 is a list of the crucial system parameters. To examine the system performance, key metrics such the eye diagrams, BER, and Q factor were measured.

Table 3-1 Simulation Parameters for Single Beam FSO system and Multiple Beam FSO System

No	Parameters	Values
1.	Data rates	10 Gbps
2.	Lase input power	5 dBm
3.	Attenuation for rain	6.0 dB/km
4.	Attenuation for haze	10.94 dB/km
5.	Attenuation for fog	12 dB/km
6.	Frequency	193.1THz
7.	Distance range	800m

3.4 Performance Parameter

In Optisystem, performance indicators such as the eye diagram, BER, and Q factor can be used to monitor and evaluate the single beam and multiple beam FSO system performance.

3.4.1 Eye Diagram

In single beam and multiple beam FSO systems, the eye diagram is a fundamental visual tool for understanding the quality of the received signal. It is a visual representation of the timing and amplitude properties of the signal that aids in BER calculation and system performance assessment. The signal that is transmitted and its quality over time is graphically represented by the eye diagram. A distorting or blocked eye diagram signifies signal degradation, whereas a well-defined and clean, wide open eye diagram shows strong signal quality.

The eye diagram is created by charting several signal waveforms that are overlaid where these waveforms are usually acquired by taking periodic samples of the incoming data. The resulting plot has the shape of an eye, with two distinct lobes encircling an open area in its center.

The optimal measurement window, where the signal that is received is least prone to noise and distortion, is represented by the open area in the center of the eye diagram. It displays the voltage and timing thresholds that are acceptable for accurate bit detection.

The eye diagram structure and precision, which represent system performance, provide important details on the strength of signal and quality integrity. A durable and clean signal with distinct separation between voltage levels and low intersymbol interference (ISI) is shown by a well-defined, wide-open eye diagram. This results in a decreased BER and a greater chance of precise bit detection.

On the other hand, a distorted or deteriorated eye diagram that shows a closed or narrower eye opening suggests that the received signal is hampered by interference or other issues. This may result in overlapped voltage levels, an increase in ISI, and a larger chance of bit detection mistakes, all of which raise the BER.

Identifying and diagnosing different signal deficiencies in single beam and multiple beam FSO systems is made easier by analyzing the eye diagram. To improve the quality of the received signal and reduce the BER, it helps optimize system parameters like transmitter power, receiver sensitivity, equalization strategies, and signal conditioning.

In conclusion, the eye diagram offers an optical representation of the timing and signal amplitude properties in single beam and multiple beam FSO systems. The form and quality of the eye diagram can be used to evaluate system performance, identify limitations, and adjust parameters for low BER, dependable data transfer.

3.4.2 Bit Error Rate (BER)

BER is a crucial performance metric in OptiSystem that is utilized to evaluate the caliber of digital communication networks. The probability of mistakes in the received bits relative to the transmission bits is measured by BER.

It can offer redundancy and diversity in the communication system for multiple beam FSO systems. There is a chance that one beam will deteriorate or become blocked by atmospheric circumstances, whereas another beam might remain operational. In challenging circumstances, this may lead to better BER performance than a single beam system.

Optical communication link performance can be affected by atmospheric circumstances such absorption, scintillation, and turbulence. These atmospheric factors may have different effects on different beams, and the diversity provided by numerous beams may improve the overall system BER.

Spatial variation can be achieved by directing multiple beams along distinct spatial directions. In some cases, spatial diversity can result in lower BER because it reduces fading and boosts overall connection reliability. Other than that, the BER can be affected by the entire system architecture, which includes receiver configurations, coding methods, and modulation formats. In OptiSystem, system optimization entails modifying these settings to attain the intended BER performance for single beam and multiple beam setups.

3.4.3 Quality Factor (Q factor)

The Q factor is an essential metric in both single beam and multiple beam FSO systems that is used to evaluate the optical link performance and quality. It offers a numerical representation of the SNR and the overall accuracy of data transmission and reception inside the system.

The eye diagram, a graphic depiction of the timing and amplitude properties of the received signal, is where the Q factor is obtained. The ratio of the variance between the two signal levels amplitudes to the noise level can be used to compute the Q factor by examining the eye diagram. When comparing multiple beam FSO systems to single beam FSO systems, a greater Q factor denotes a higher quality and dependability of the received signal. It suggests a wider eye opening, which denotes a wider range of signal intensities and a lower probability of bit detection errors. Thus, a lower BER is correlated with a larger Q factor.

On the other hand, a lower Q factor denotes a narrower or partially closed eye opening and worse quality of the received signal. This suggests a closer spacing between signal levels and a greater sensitivity to noise and distortions, which raises the likelihood of errors and the BER.

The Q factor can be used to optimize different system parameters and is a useful statistic for assessing the performance of single beam and multiple beam FSO systems. The Q factor and total system performance can be raised by modifying variables like transmitter power, receiver sensitivity, modulation schemes, equalization methods and signal conditioning.

The Q factor can also be used to guide the design and optimization of the single beam and multiple beam FSO system, detect potential bottlenecks or performance constraints and compare various optical links.

In conclusion, a quantitative indicator of the performance and quality of the received signal is provided by the Q factor in single beam and multiple beam FSO systems. It is feasible to evaluate the system capacity for accurate data transmission and reception, optimize system settings and eventually provide dependable, high-caliber data transmission with a low BER by examining the eye diagram and figuring out the Q factor.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter focuses on exploring the different applications of the developed system and analyzing the results. To fully grasp the consequences, the gathered information and findings are meticulously documented and talked over in detail. This chapter offers a thorough study of the data, emphasizing important findings and coming to insightful conclusions. The system's applications are also examined, considering the ways in which the created system might be used and applied in real-world situations. This chapter adds to the general understanding of the project outcomes by presenting the results and addressing their significance. It also creates opportunities for future developments and applications.

4.1 Single Beam and Multiple Beam FSO System for Rainy Condition

Laser beams are used in FSO communication systems to send data over the atmosphere. When a signal is attenuated in a single beam FSO system, it means that its strength decreases as it travels through the atmosphere. In FSO systems, there are multiple factors that lead to signal attenuation. The environmental circumstances also play a role, therefore there is no standard attenuation value.

Hence, to determine if the project is feasible, a single beam FSO system with 1 channel and multiple beam FSO system with 4 channels was simulated. This part simulates the FSO at 800m distances with an attenuation of 6.0dB/km for the atmospheric state of rain. The power is set to 5dBm. BER and the Q Factor are examined. One of the main measures for assessing the optical performance that is applied to describe the BER is the Q factor. The eye diagram openness is used to measure the system performance.

The results of the simulation shows that the single beam FSO system could have successfully transmitted in a rainy environment but the multiple beam FSO system have an excellent data transmission compared to the single beam FSO system. The received signal quality is visually represented by the eye diagrams. Figure 4.1 through 4.2 shows the eye diagram obtained for single beam FSO system and multiple beam FSO system respectively.

At 800m, the eye diagram in Figure 4.1 displays a BER of 10^{-12}suggesting a good signal quality. The fact that the eye diagram is not so clear and open indicates that the data transmission is still successful and that the received signal can be distinguished.

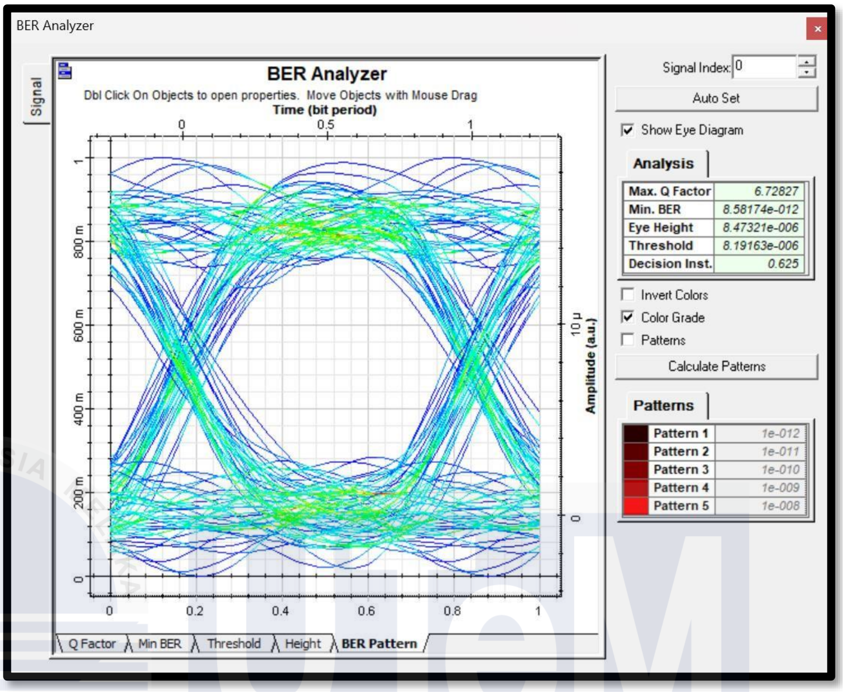

Figure 4-1 Eye diagram for single beam FSO system at 6.0db/km

Furthermore, in Figure 4.2, the eye diagram is clearer and wider compared to the eye diagram in Figure 4.1. The eye diagram shows a very low BER of 10^{-17} excellent signal quality which means data transfer is successful since the received signal is clearly discernible. The eye height for single beam FSO system is shorter compared to multiple beam FSO system.

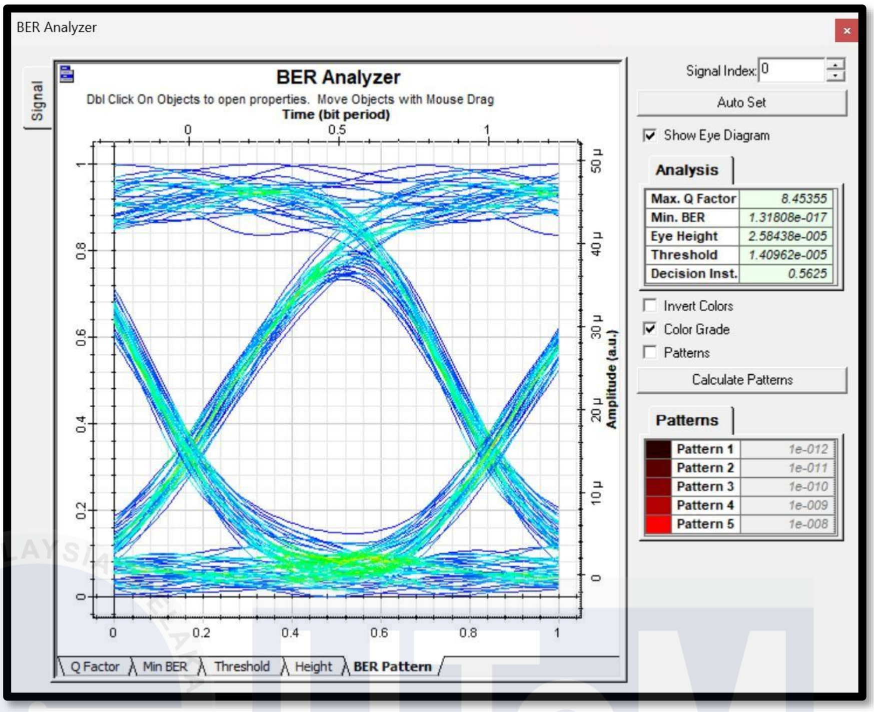

Figure 4-2 Eye diagram for multiple beam FSO system at 6.0dB/km

4.2 Single Beam and Multiple Beam FSO System for Haze Condition

In this part, for the atmospheric state of haze, a single beam FSO system with one channel and a multiple beam FSO system with four channels were simulated at 800m distances, with an attenuation of 10.94dB/km. Q Factor and BER are examined. The Q factor is one of the primary metrics used to evaluate the optical performance used to characterize the BER. The system performance is gauged using the eye diagram openness.

Results from the simulation indicate that while data in a single beam FSO system may have transmitted in a hazy environment, multiple beam FSO systems offer better data transmission capabilities. The eye diagrams provide a visual representation of the received signal quality. The eye diagrams for the single beam and multiple beam FSO systems, respectively, are displayed in Figures 4.3 through 4.4.

The eye diagram in Figure 4.3 shows a BER of 0.00358658 at 800m, indicating a greater frequency of errors. The fact that the eye diagram is not as clear and narrower shows a decrease in signal quality. The losses that occur along the FSO channel when attenuation rises are responsible for this performance decrease.

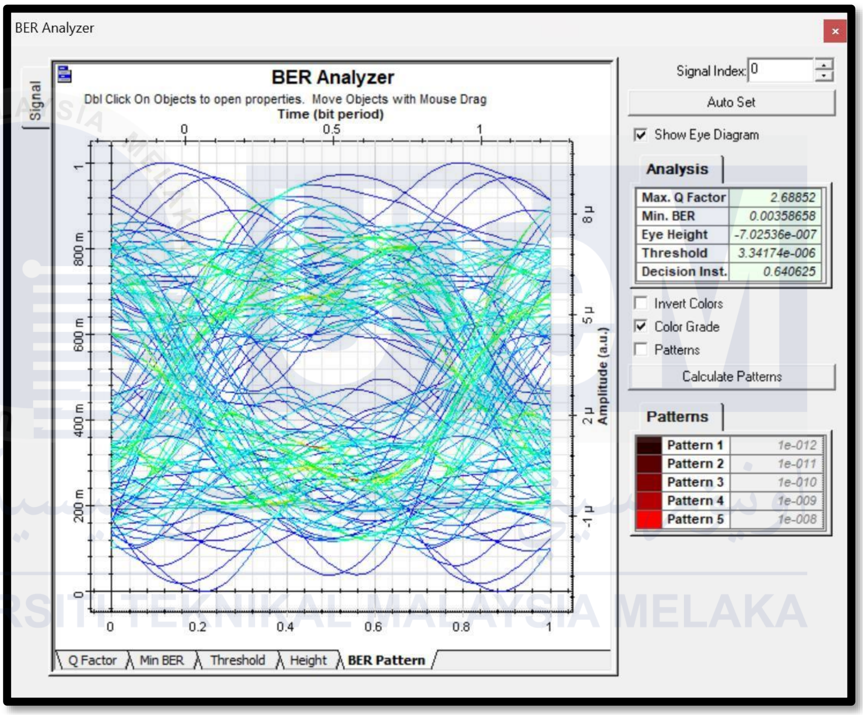

Figure 4-3 Eye diagram for single beam FSO system at 10.94dB/km

On top of that, the eye diagram in Figure 4.4 is bigger and clearer than the one in Figure 4.3. Since the received signal is plainly visible, the eye diagram low BER of 10^{-007} indicates great signal quality and indicates that data transfer was achieved.

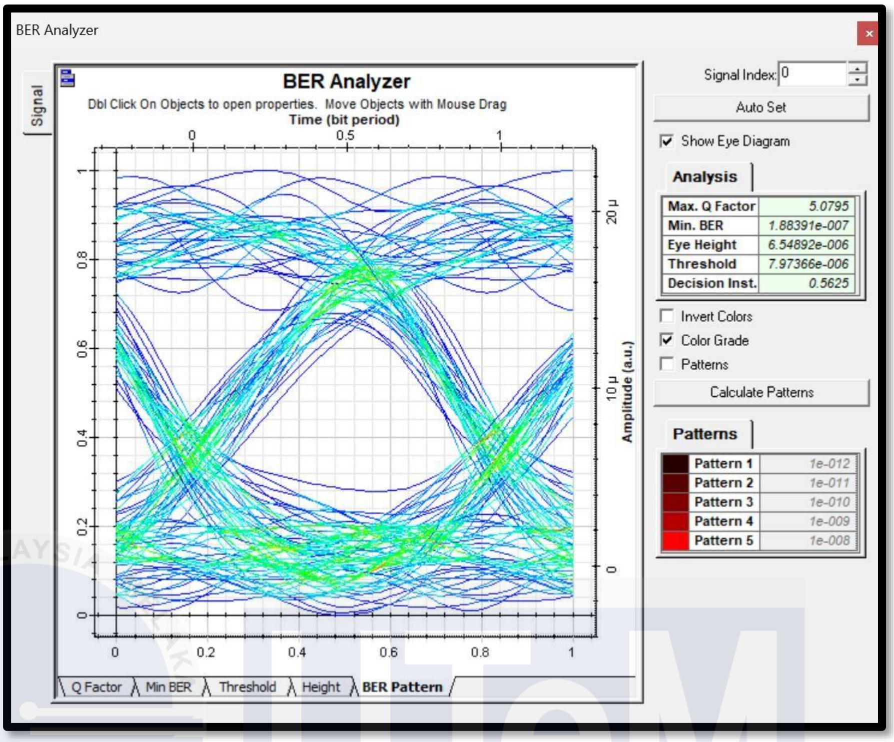

Figure 4-4 Eye diagram for multiple beam FSO system at 10.94dB/km

4.3 Single Beam and Multiple Beam FSO System for Fog Condition

This section simulated a multiple beam FSO system with four channels at 800m distances and a 12dB/km attenuation for the atmospheric state of fog, as well as a single beam FSO system with one channel. We look at BER and Q Factor. The Q factor is one of the primary metrics used to evaluate the optical performance that defines the bit error rate. The system performance is gauged using the eye diagram openness.

From the simulations the results show that multiple beam FSO systems have greater data transmission capabilities, although data in a single beam FSO system may have worked in a foggy environment. The received signal quality is shown graphically via the eye diagrams. Figures 4.5 through 4.6 show the eye diagrams for the single beam and multiple beam FSO systems, respectively.

The eye diagram in Figure 4.5 shows a BER of 0.0138326 at 800m, indicating an acceptable signal quality but with high frequency of errors. The fact that the eye diagram is not as open and clear suggests that the received signal can still be differentiated. This decline in performance is caused by the losses that arise along the FSO channel when attenuation increases.

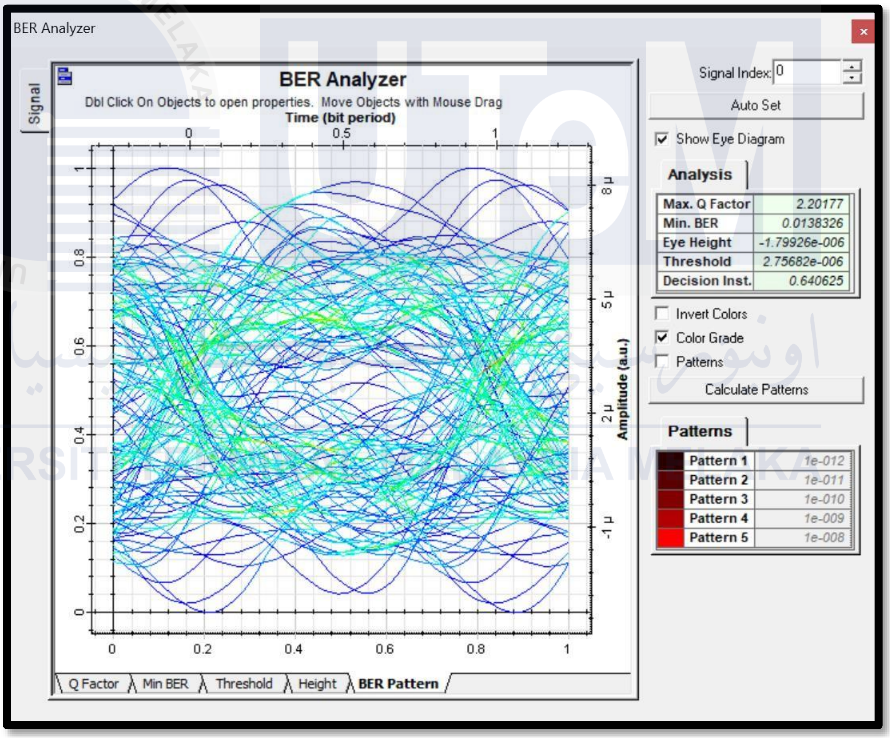

Figure 4-5 Eye diagram for single beam FSO system at 12dB/km

Additionally, the eye diagram in Figure 4.6 is bigger and wider than the one in Figure 4.5. Given that the received signal is clearly visible and the BER of 10^{-006} indicates high signal quality, the eye diagram indicates that data transfer is successful.

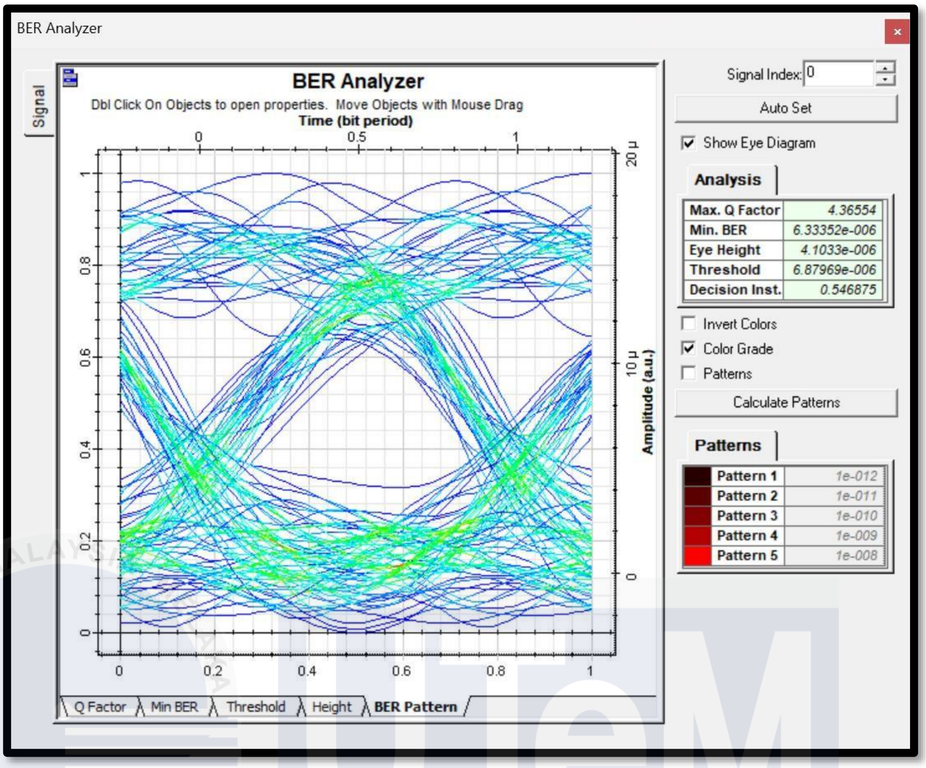

Figure 4-6 Eye diagram for multiple beam FSO system at 12db/km

Overall, all things considered, the simulations show that FSO technology can successfully transmit data at attenuations of 6.0dB/km for rain, 10.94dB/km for haze and 12dB/km for fog at distance of 800m. In comparison with multiple beam FSO systems, the single beam FSO system performance begins to deteriorate, leading to a smaller eye diagram and a greater BER.

The graph in Figure 4.7 displaying the difference between the value of maximum Q factor of single beam FSO system and multiple beam FSO system through different attenuation for different weather conditions.

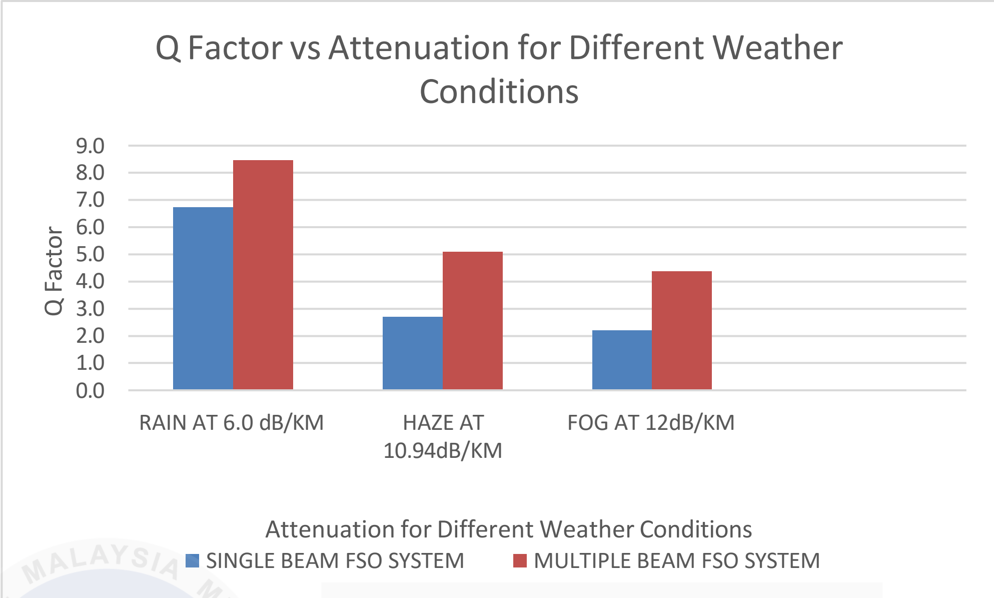

Figure 4-7 Q factor vs Attenuation for Different Weather Conditions

Based on the graph in Figure 4.7, it is shown that the Q factor for multiple beam FSO system is slightly higher than single beam FSO system. Q factor measures the degree of signal quality, that is, the distance between signal levels and noise. Higher Q factor generally indicates better signal quality and consequently, better system performance. In digital communication systems, the Q factor is frequently utilized.

In a single beam FSO system, the Q factor may be low due to several interrelated issues that might affect signal quality and introduce errors. Signal quality in FSO communication systems can be measured by the Q factor. System design, modulation format, and SNR are a few of the variables that affect it. There are a few reasons why comparing a multiple beam FSO system to a single beam FSO system may reveal that the multiple beam FSO system has a greater Q factor.

Many parallel beams with varying frequencies and paths are frequently used in multiple beam FSO systems. Because of the redundancy, there is diversity and the possibility that a beam with a high Q factor will continue to function even if another beam degrades because of atmospheric conditions. This makes the system more resilient to environmental shocks overall. Scintillation can be produced by atmospheric circumstances like turbulence, which can alter the air refractive index. By mixing or choosing the highest-performing beams from a variety of beams, the system can reduce the impacts of scintillation.

Other than that, geographical diversity is achieved through multiple beams covering various spatial routes. This can help in overcoming atmospheric disturbances that are focused and could impact a single beam. The FSO link dependability is increased by the redundancy multiple beams provide. The potential of a full connection failure is decreased if the system can dynamically switch to another beam in the event the previous one becomes obstructed or weakened which is why multiple beam FSO system has higher Q factor value compared to single beam FSO system. Other than that, multiple beams can improve link reliability by offering different routes for transmission. This is especially crucial in situations when physical barriers or atmospheric factors could impede a single beam.

In summary, the graph clearly shows that the Q factor for 4 channel FSO system which is multiple beam FSO system is higher than the single beam FSO system. This result shows how essential it is to take signal quality needs and distance restrictions into account while developing and putting into practice such a system. Table 4.1 shows the difference between the value of BER for single beam and multiple beam FSO system through different attenuation for different weather conditions.

Table 4-1 BER for single beam and multiple beams FSO system for different weather condition

	Single Beam FSO System	Multiple Beam FSO System
Rain	8.58174 e-012	1.31808 e-017
Haze	0.00358658	1.88391 e-007
Fog	0.0138326	6.33352 e-006

Based on the table shown in Table 4.1, it is shown that all the value of BER for multiple beam FSO system is lower than single beam FSO system. When evaluating a communication system quality, the BER is an essential indicator. It is frequently used to assess the effectiveness of optical communication systems and represents the dependability of the data conveyed. The lowest BER attained during simulations under specific configurations and parameters is known as the minimum BER. Frequently, the objective is to improve system parameters to reduce the BER and enable stable and errors-free transmission of data.

When opposed to a single beam system, a multiple beam FSO system typically has benefits in the form of variety, redundancy, as well as a lower BER. By using multiple beams, surrounding effects are reduced, which might contribute to a lower BER. As conclusion, especially during difficult atmospheric conditions, a multiple beam FSO system typically could produce a better BER than a single beam FSO system. Multiple beams provide redundancies and a variety, which enhance performance and dependability.

4.4 FSO System Under Various Weather Conditions over Distances

For additional result, different value of distances has been added to evaluate the performance of single beam FSO system and multiple beam FSO system under different weather condition. The value of attenuation for rain, haze, and fog are still the same where 6.0 dB/km for rain, 10.94 dB/km for haze and 12 dB/km for fog but the distance was changed with different value which is started with 700m, 800m, 900m and 1000m.

4.4.1 Performance of FSO System with Rain Attenuation over Distances

In this section, a single beam FSO system with a single channel and a multiple beam FSO system with a total of four channels have been generated at distances of 700m, 800m, 900m, and 1000m with an attenuation of 6.0 dB/km for the atmospheric state of rain under the same amount for power which is 5dBm. BER and Q factor are analyzed. One of the primary factors to determine the optical performance which is used to define the BER is the Q factor. The graph below shows the value of Q factor for single beam FSO system and multiple beam FSO system with attenuation of 6.0 dB/km for rain over distances.

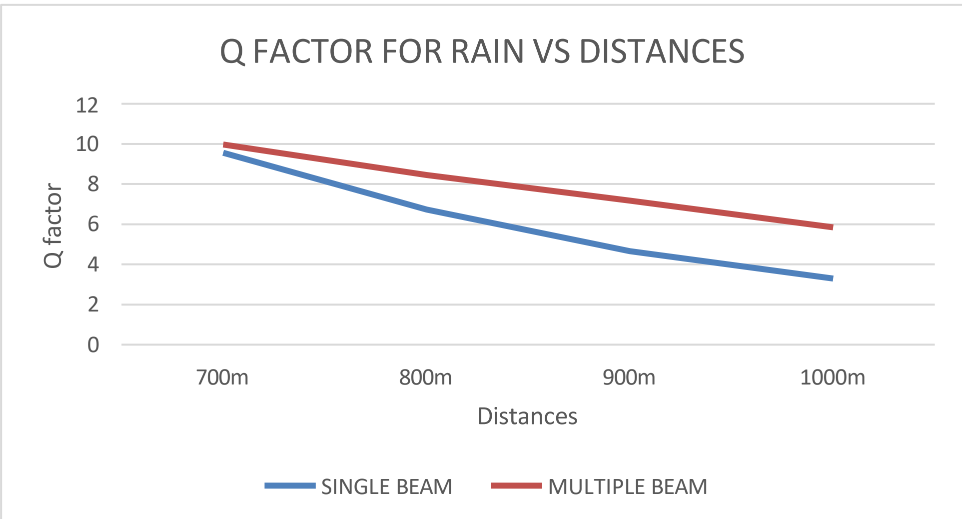

Figure 4-8 Q factor for rain attenuation over distances

Based on Figure 4.8 shown above, it is shown that the Q factor for multiple beam FSO system is slightly higher compared to single beam FSO system in all different value of distances under raining condition. This shows that the performance for multiple beam FSO system is better compared to single beam FSO system up to 1000m for distance.

At the distance of 700m, the Q factor for single beam FSO system is 9.56046 while for multiple beam FSO system is 9.97209. Next, at distance of 800m, the Q factor for single beam FSO system is 6.72827 and multiple beam FSO system is 8.45355. For distance of 900m, the value of Q factor produced by single beam FSO system is 4.6593 while for multiple beam FSO system is 7.16964. Lastly, for 1000m Q factor is 3.29349 and 5.84623 for single beam and multiple beam FSO system respectively.

As we can see from the comparison of Q factor for single beam and multiple beam FSO system under raining, the multiple beam FSO has higher value of Q factor compared to single beam. When faced with challenges such as the environment and atmospheric turbulence, a multiple beam FSO system may exhibit a greater Q factor than a single beam FSO system. It is possible for additional beams to continue to function reliably even if one beam is impacted by turbulent atmospheric conditions or other problems. FSO system with a larger Q factor will likely have better transmission distances, lower error rates, stronger signal quality and improved system durability.

However, the larger the distances taken for the FSO system, the lower the Q factor will be because the division enables the optical signal to lose strength with increasing distance. Over distance, the strength of the signal decreases due to the laser beam dispersion. The received signal intensity decreases with increasing distance. As the distance grows, atmospheric factors like rain might affect the quality of the signal. This could cause distortions in the signal and have an impact on the Q factor, where determines how well a signal is received. Furthermore, the value of BER of single beam and multiple beam FSO system is observed. Table 4.2 below shows the difference between the value of BER for FSO system under raining condition.

Table 4-2 BER for FSO system under Rain over distances

Distance	Single Beam FSO System	Multiple Beam FSO System
700m	5.1707 e-022	1.0095 e-023
800m	8.58174 e-012	1.31808 e-017
900m	1.58581 e-006	3.64545 e-013
1000m	0.000494521	2.48835 e-009

Based on Table 2 shown above, the value of BER for multiple beam FSO system is lower than single beam FSO system through distance of 700m, 800m, 900m and 1000m. There are many of benefits related with using multiple beams FSO system that make it possible for a multiple beam FSO system to have a smaller BER than a single beam FSO system. Durability is provided in a communication link by multiple beams. Other beams may be able to sustain a dependable connection even in the event of interference or atmospheric impacts on one beam. A reduced total BER is the result of this redundancy ability to lessen the effects of diminishing, oscillation, and other channels impairments.

To summarize, the utilization of multiple beams in an FSO system provides redundancy, variety, and adaptability, all of which work together to reduce the BER. In comparison to a single beam FSO system, multiple beams shown better BER because of its enhanced robustness and reliability due of its capacity to exploit many pathways and adapt to changing situations.

4.4.2 Performance of FSO System with Haze Attenuation over Distances

In this section, the attenuation of 10.94 dB/km for the atmosphere state of haze under the exact same amount of power which is 5dBm has been created at the following distance which is 700m, 800m, 900m, and 1000m for a single beam FSO system and a multiple beam FSO system with an overall of four channels. Analysis is done on the Q factor and BER. The Q factor is one of the main determinants of the optical performance that defines the BER.

The Q factor values for single beam and multiple beam FSO systems with an attenuation of 6.0 dB/km for haze at various distances are displayed in the graph below.

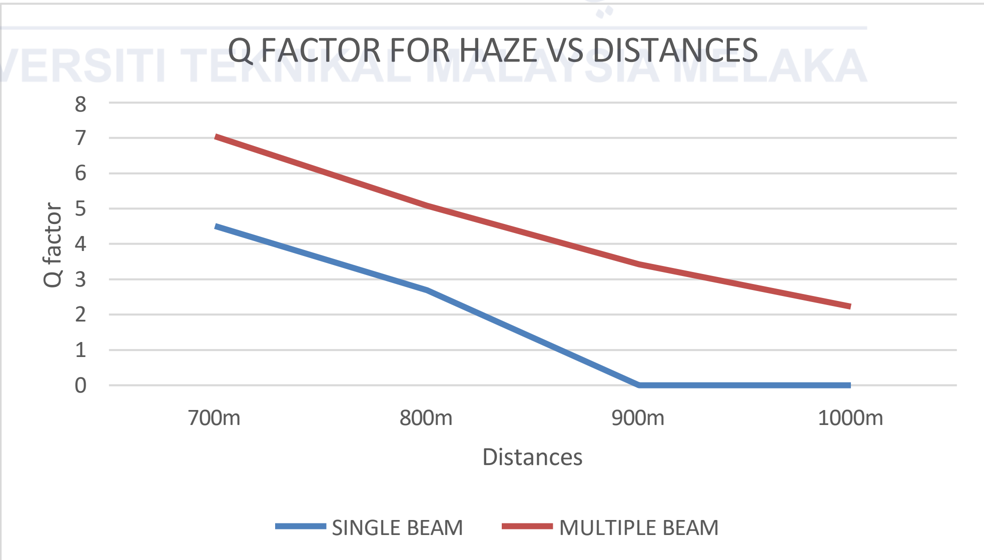

Figure 4-9 Q factor for haze attenuation over distances

The Q factor for haze for multiple beam FSO systems is marginally greater than for single beam FSO systems for all values of distance, as can be shown in Figure 4.9 above. This demonstrates that, at distances up to 1000m, the performance of a multiple beam FSO system outperforms a single beam FSO system. At distance of 900m, the Q factor for single beam FSO system has reached to 0 because the data cannot be transferred anymore.

The Q factor for a single beam FSO system at 700m is 4.50858 and for a multiple beam FSO system is 7.04666. Next, at 800m, the multiple beam FSO system Q factor is 5.0795 while the single beam FSO system's Q factor is 2.68852. The Q factor generated by a single beam FSO system is 0 at 900m, whereas it is 3.42324 with a multiple beam FSO system. Finally, at 1000m, a single beam FSO system produces a Q factor of 0, whereas a multiple beam FSO system produces 2.22647.

The Q factor values for the multiple beam FSO system with attenuation for rain and the single beam FSO system show that the multiple beam FSO system has a greater value than the single beam FSO system. Even if one beam is affected by turbulent weather conditions or other issues, other beams may still operate dependably. A bigger Q factor is expected to offer stronger signal quality, longer transmission lengths, lower error rates, and increased system endurance.

On the other hand, the Q factor decreases as the FSO system travels farther. The division allows the optical signal to weaken with increasing distance, which will result in a Q factor. The dispersion of the laser beam causes the signal power to diminish with distance. As the distance increases, the received signal intensity drops. Rain and other weather conditions may have an impact on the signal quality as the distance increases. This may result in signal distortions and affect the Q factor, which gauges how well a signal is received.

Nonetheless, because of the division that allows the optical signal to weaken with increasing distance, the Q factor will decrease the longer the FSO system takes. The laser beam dispersion causes the signal strength to diminish with distance. As one gets farther away, the received signal intensity drops. Haze and other weather variables could degrade the signal quality as the distance increases.

Additionally, the single beam and multiple beam FSO systems minimum error rate values are noted. The difference between the value of the BER for a single beam and a multiple beam FSO system with a hazy attenuation of 10.94 dB/km is displayed in Table 4.3.

Table 4-3 BER for FSO System with Haze over distances

Distance	Single Beam FSO System	Multiple Beam FSO System
700m	3.2618 e-006	8.90774 e-013
800m	0.00358658	1.88391 e-007
900m	1	0.000309397
1000m	1	0.0129801

According to Table 4.3 above, over 700m, 800m, 900m, and 1000m, the multiple beam FSO system BER is less than that of the single beam FSO system. A multiple beam FSO system can have a lower BER than a single beam FSO system due to several advantages that come with having multiple beams. Multiple beams in a communication channel improve durability. If one beam has interference or atmospheric effects, other beams might be able to maintain a stable connection. This redundancy capacity to mitigate the effects of decreasing, oscillation, and other channels impairments results in a reduced total BER.

In summary, an FSO system's use of numerous beams reduces the BER by offering redundancy, variety, and adaptability. The system outperforms a single beam FSO system in terms of overall performance due to its increased robustness and reliability, which derive from its ability to exploit multiple paths and adjust to changing circumstances.

4.4.3 Performance FSO System with Fog Attenuation over Distances

This section explains the creation of an attenuation of 12 dB/km for the atmosphere state of fog at the following distances: 700m, 800m, 900m, and 1000m for a single beam FSO system and a multiple beam FSO system with a total of four channels, all under the exact same power of 5dBm. The lowest BER and Q factor are analyzed. One of the key factors influencing the optical performance that establishes the BER is the Q factor.

The graph below shows the Q factor values for rain at different distances for single beam and multiple beam FSO systems with an attenuation of 12 dB/km.

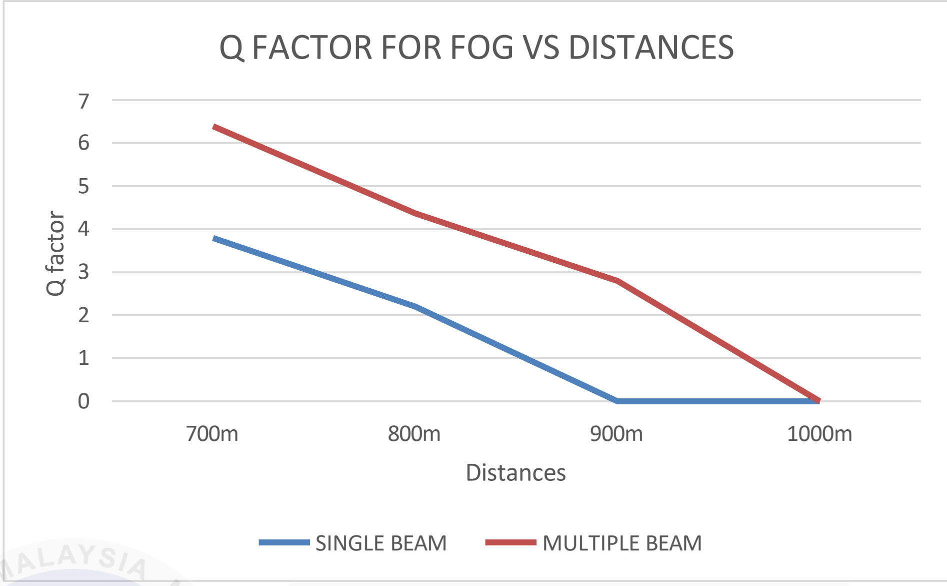

Figure 4-10 Q factor for fog attenuation over distances

As observed in Figure 4.10 above, the Q factor for fog for multiple beam FSO systems is slightly higher for all distance values than for single beam FSO systems. This indicates that a multiple beam FSO system performs better than a single beam FSO system at distances up to 1000m. The Q factor for a single beam FSO system has hit zero at 900m since data transfer is no longer possible. While for multiple beam FSO system, the data transfer has reached 0 at 1000m.

The highest Q factor at 700m is 3.79484 for a single beam FSO system and 6.39075 for a multiple beam FSO system. Secondly, at 800m, the Q factor for the multiple beam FSO system is 4.36554, whereas the Q factor for the single beam FSO system is 2.20177. At 900m, the Q factor produced by a single beam FSO system is 0, whereas a multiple beam FSO system generates 2.79855. Ultimately, a multiple beam FSO system produces 0 at 1000m, while a single beam FSO system produces 0.

The multiple beam FSO system has a higher value than the single beam FSO system, according to the Q factor values for both systems with attenuation for rain and single beam FSO systems. Some beams may continue to function dependably even if one is impacted by bad weather or other problems. Longer transmission distances, reduced error rates, better signal quality, and longer system endurance are anticipated benefits of a larger Q factor FSO system.

Inversely, as the FSO system moves farther, the Q factor lowers. Q factor will arise from the division's ability to cause the optical signal to deteriorate with increasing distance. The power of the signal decreases with distance due to the laser beam's dispersion. The intensity of the received signal decreases with increasing distance. As the distance grows, the quality of the signal may be affected by rain and other meteorological factors. This could cause distortions in the signal and have an impact on the Q factor, which measures how effectively a signal arrives at its destination.

Still, as the FSO system takes longer, the Q factor will decline due to the division that causes the optical signal to deteriorate with increasing distance. The signal strength decreases with distance due to the dispersion of the laser beam. The strength of the received signal decreases with distance. As the distance grows, the signal quality could be deteriorated by fog and other meteorological factors.

The BER values for the single beam and multiple beam FSO systems are included as well. Table 4.4 below shows the variation in the BER value between a single beam FSO system and a multiple beam FSO system with a fog attenuation of 12 dB/km.

Table 4-4 BER of FSO System with Fog over Distances

Distance	Single Beam FSO System	Multiple Beam FSO System
700m	7.38353 e-005	8.11506 e-011
800m	0.0138326	6.33352 e-006
900m	1	0.00256597
1000m	1	1

Table 4.4 above indicates that the lowest BER of the multiple beam FSO system is lower than that of the single beam FSO system over distances of 700m, 800m, 900m, and 1000m. Because having many beams has several benefits over having one, a multiple beam FSO system may have a lower BER than a single beam FSO system. Durability is increased in a communication line with several beams. It may be possible for other beams to sustain a steady connection even if one beam experiences atmospheric effects or interference. A lower overall BER is the consequence of this redundancy's ability to lessen the effects of diminishing, oscillation, and other channel impairments.

In conclusion, many beams are used in an FSO system to provide redundancy, variety, and adaptability, hence lowering the BER. Overall performance is superior to a single beam FSO system because of the system's enhanced stability and dependability, which come from its capacity to take use of several pathways and adapt to changing conditions.

4.4.4 Results Comparison with Previous Research Study

In research paper [2], the goal of this research is to reduce the impact of weather and geography on FSO communication through iterative optimization. By reducing the BER, the optimization maximizes the visible distance while ensuring dependability. 10 Gbps is the data rate at which the wireless optical communication technology is intended. The suggested wireless optical communication's performance is evaluated against existing research in terms of visible distance, Q factor, BER, and eye diagram under various air conditions.

Throughout [22], this paper compares single beam and multiple beams technologies to analyze how well one of them handles the effects of hazy weather on the latter's FSO link. MATLAB coding have been used to validate the multibeam system's results for both clear and hazy weather conditions.

To create the best system possible for dealing with the effects of tropical weather, single beam, and multiple beam FSO systems are built and analyzed. [23] Using WDM, the performance assessment and suitability of the multi-beam beam FSO system in tropical conditions are researched and investigated. Rain intensity and attenuation data made on-site are used to verify the simulation-based analysis. The two types of FSO systems that were taken into consideration were single beam and multiple beam systems. The goal was to create the best system possible that could function in extreme tropical conditions while maintaining a high data rate and improved scalability. Using the average value, the single beam FSO system's performance was examined at intense rain rate intensities during a six-month period in typical Malaysian weather. The BER, geometrical losses, atmospheric losses, and received optical power are compared when utilizing varying numbers of optical beams at a data rate of 1 Gbit/s.

Through research paper [9], the performance of the single beam FSO system was investigated at high rain rate intensities during a six-month period in typical

Malaysian weather conditions, using the average value. The hybrid WDM/multi-beam FSO network is predicted to cause a large rise in scalability, geometrical loss, received optical power, and connection distance. We compare the BER, geometrical losses, atmospheric losses, and received optical power at a data rate of 1 Gbit/s with different numbers of optical beams.

Table 4.5 below shows the comparison of results between the performance of single beam FSO system for the proposed results and previous research study for attenuation consequence rainy conditions. From Table 4.5 below, it shown that when the attenuation is set according to rainy weather condition, the maximum Q Factor was high and the minimum BER was low which means the data was transferred successfully with minimal rate of error.

Table 4-5 Summary Results Under Rainy Condition for Single Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	6.0 dB/km	6.72827	8.58174 e-012	10 Gbps
[2], 2020 (Optimization)	30 dB/km	34.20	1.1544 e-256	10 Gbps
[23],2014 (Optimization)	19.2 dB/km	-	-	1 Gbps

Furthermore, based on Table 4.6 below, it is shown that when the attenuation is adjusted for rainy weather, the data is effectively conveyed with a low rate of error since the Q factor was high and the BER was low. Table 4.6 shows the comparison of results between the performance of multiple beam FSO system and previous research study. Due to the different value of attenuation for rainy condition, the value of maximum Q Factor and minimum BER obtained was also different.

Throughout research paper [2], the paper used optimization method to reduce the impact of weather and geography on FSO communication through iterative optimization. By reducing the BER, the optimization maximizes visibility distance while ensuring reliability. In this paper, it used only single beam FSO system.

Table 4-6 Summary Results Under Rainy Condition for Multiple Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	6.0 dB/km	8.453555	1.31808 e-017	10 Gbps
[2], 2020 (Optimization)	30 dB/km	34.20	1.1544 e-256	10 Gbps
[23],2014 (Optimization)	19.2 dB/km	-	-	1 Gbps

Next, Table 4.7 shows the analysis of differences in attenuation consequences during haze conditions between the performance of the single beam FSO system for the suggested results and earlier research studies. The value of attenuation, maximum Q factor, minimum BER and data rate were stated in Table 4.7 below.

Table 4-7 Summary Results Under Hazy Condition for Single Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	10.94 dB/km	2.68852	0.00358658	10 Gbps
[2], 2020 (Optimization)	20 dB/km	58.762	0	10 Gbps
[22],2014 (MATLAB)	2.33 dB/km	5.8320	2.67 e-09	10 Gbps

Table 4.7 above illustrates that when the attenuation is adjusted for haze conditions, the data was effectively transported with a low rate of error, as indicated by a high Q factor and a low BER. After that, Table 4.8 shows the result comparison between the proposed results and research paper results for multiple beam FSO system with attenuation for hazy conditions.

Table 4-8 Summary Results Under Hazy Condition for Multiple Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	10.94 dB/km	5.0795	1.88391 e-007	10 Gbps
[2], 2020 (Optimization)	20 dB/km	58.762	0	10 Gbps
[22],2014 (MATLAB)	2.33 dB/km	5.8089	3.08 e-09	10 Gbps

Based on Table 4.8 above, it is demonstrated that when the attenuation is modified for hazy weather, the data is successfully communicated with a low error rate since the BER is low and the Q factor is high. The obtained values of the Q factor and BER are differ because of the varied attenuation under haze conditions. Based on both Table 8 and Table 9, the data rate was set the same value which is 10Gbps.

As conclusion, under hazy condition for single beam and multiple beam FSO system, it is shown that the higher the Q factor and the lower the BER, good data transmission with less error can be achieved. From research paper [22], it is shown that the Q factor value of a single beam FSO system steeply declines beyond 6 km, and the signal quality is only suitable for 8.5 km. However, the Q factor for the multiple beam FSO system drops after 24 km and stays nearly constant up until then. In the case of the single beam FSO system, the Q factor drops to "0" at 12 km, but not in the case of system II, not even at 90 km. It follows that a multiple beam FSO system outperforms a single beam FSO system in terms of performance.

Furthermore, the examination of variations in attenuation consequences during fog conditions between the single beam FSO system's performance for the current findings and previous research investigations was presented in Table 4.9 below.

Table 4-9 Summary Results Under Foggy Condition for Single Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	12 dB/km	2.20177	0.0138326	10 Gbps
[2], 2020 (Optimization)	70 dB/km	19.8265	8.72786 e-88	10 Gbps

Table 4.9 above shows that the data was successfully transmitted with a low rate of error when the attenuation has been modified for fog conditions, as demonstrated by a high Q factor and a low BER.

Table 4-10 Summary Results Under Foggy Condition for Multiple Beam FSO System

References	Attenuation (dB/km)	Maximum Q Factor	Minimum BER	Data Rate (Gbps)
Proposed	12 dB/km	4.36554	6.33352 e-006	10 Gbps
[2], 2020 (Optimization)	70 dB/km	19.8265	8.72786 e-88	10 Gbps

Table 4.10 above illustrates how the data is effectively transferred with a low error rate when the attenuation is adjusted for foggy weather since the Q factor is high and the BER is low. Because of the variable attenuation in fog, the Q factor and BER values that are obtained will varied.

Research study [2] employed an iterative optimization technique to lessen the influence of geography and weather on FSO communication. The optimization increases visibility distance while maintaining reliability by lowering the BER. A single beam FSO system was used exclusively in this work.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

In conclusion, it has been shown that multiple beam FSO systems are more effective than single beam FSO systems in terms of increased data carrying capacity. In this work, FSO system were constructed and set with varying weather conditions of rain, haze, and fog for a single beam and multiple beam FSO system. In 700m to 1000m of free space channel, 10 Gbit/s of data and 5 dBm of power are transferred by both single beam and multiple beam FSO systems. The analysis of BER, Q factor, and eye diagrams was used to test the single beam and multiple beam FSO systems. Both channels were successfully transmitted, according to the simulation results.

When compared to a single beam FSO system, the performance of multiple beam FSO systems is excellent in terms of BER, eye diagram, and Q factor. When assessing the signal integrity and system reliability, these characteristics are very important.

A crucial indicator of a communication system's data transmission accuracy is BER. When compared to a single beam FSO system, the multiple beam FSO system exhibits better data transmission, and the performance study demonstrates that it maintains a low BER of 10^{-17} which denotes dependable data transfer. This is necessary to provide the error-free delivery of vital information in the FSO system, where fast data transfer is crucial.

A graphical visual representation of the signal intensity and quality is the eye diagram. When compared to a single beam FSO system, the multiple beam FSO system displays a clear and expansive eye diagram. The breadth and form of the eye diagram show how well the system can distinguish between various signal levels as well as the lack of distortion and noise. In the multiple beam FSO system, precise and dependable data reception is ensured by the robust and high-quality signal transmission represented by the clean and open eye diagram.

In a communication system, the Q factor serves as a signal quality indicator. When compared to a single beam FSO system, the multiple beam FSO system delivers a high Q factor of 8.45355 suggesting little signal deterioration and a good signal to noise ratio. A high Q factor minimizes the possibility of errors and maximizes system performance by guaranteeing effective data transmission and reception.

In summary, when compared to a single beam FSO system, the multiple beam FSO system exhibits excellent performance in terms of BER, eye diagram, and quality factor. It continues to transmit data reliably with a low BER. The system displays an eye diagram that is clear and uncluttered, signifying strong signal integrity and quality. Furthermore, the high Q factor guarantees effective signal reception and transmission. These performance traits make it a viable option for high-speed wireless communication in the FSO system by enhancing the system's accuracy, resilience, and reliability.

5.2 Future Works

Future research on FSO systems, both single beam and multiple beams, may concentrate on resolving issues, enhancing performance, and investigating new possibilities. For multiple beam FSO system, adaptive optics technologies could be further developed to lessen the effect of atmospheric disturbance on numerous beams. Better beam steering methods and actual time responsive systems of control are examples of this. For single beam FSO system, in terms of improving atmospheric resilience, creating innovative correction of errors and mitigation strategies especially for single beam FSO systems to improve their performance under demanding atmospheric circumstances is good for future works.

Furthermore, in future works, creating interference mitigation where studies may focus on methods for mitigating interference when multiple FSO systems are present in the same space. This incorporates sophisticated signal processing methods and beam forming procedures that are cognizant of interference. Examining techniques and technologies that offer stable, high-performance single beam FSO communication over long distances is part of the long-distance communication creation process for single beam FSO systems. This could entail improvements in modulation, coding, and amplification methods.

Next, by creating hybrid FSO and RF systems and examining how RF communication systems and multiple-beam FSO systems can be used to build hybrid networks. This strategy may increase dependability by utilizing the advantages of both RF and FSO technology. For single beam FSO system, future works can do cost-effective implementation where to increase the accessibility of single beam FSO systems for a wider range of applications, research endeavors should concentrate on creating affordable solutions for them. Investigating novel materials and production techniques is part of this.

Additionally, for common areas of research, security enhancement can be applied in future works by examining methods for strengthening the security of FSO systems, including single beam and multiple beams, considering potential weak points, and creating reliable encryption and authentication systems. Quantum technologies are also good for future works by examining how to improve the security and functionality of both single beam and multiple beams FSO systems by integrating quantum technologies, such as quantum key distribution.

Lastly, standardization and interoperability by providing guidelines and procedures to help disparate FSO systems work together, enabling smooth integration and communication between systems from various suppliers. Creating energy-efficient design are also can be considered by concentrating on developing FSO systems that are energy-efficient, taking sustainability and power consumption into account for both single beam and multiple beam designs.

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