APPLICATION OF DEEP LEARNING IN FREE SPACE OPTICAL COMMUNICATION SYSTEM

Submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

by

Masood Asim (2000970310099)

Manoranjan Kumar Singh (2000970310097)

Kunwar Nitesh Singh (2000970310094)

Under the Guidance of

Dr. Lakshmanan M.

Head of the Department

Department of Electronics and Communication Engineering

(B. Tech ECE – Accredited by NBA),

Galgotias College of Engineering and Technology,

Greater Noida

(Affiliated to Dr.A.P.J Abdul Kalam Technical University, Lucknow)

DECLARATION

We hereby declare that the report entitled **"APPLICATION OF DEEP LEARNING IN FREE SPACE OPTICAL COMMUNICATION SYSTEM"** submitted by us, for the award of the degree of Bachelor of Technology in Electronics and Communication Engineering to Galgotias College of Engineering and Technology, Greater Noida affiliated to Dr. A.P.J. Abdul Kalam Technical University, Lucknow is a record of bonafide work carried out by us under the supervision of Dr. Lakshmanan M..

We further declare that the work reported in this report has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place: Greater Noida

Date: 03/01/2022 **Signature of the Candidates**

CERTIFICATE

This is to certify that the report entitled **"APPLICATION OF DEEP LEARNING IN FREE SPACE OPTICAL COMMUNICATION SYSTEM"** submitted by Masood Asim, Manoranjan Kumar Singh and Kunwar Nitesh Singh from the Department of Electronics and Communication Engineering, Galgotias College of Engineering and Technology, Greater Noida affiliated to DR. A.P.J. Abdul Kalam Technical University (AKTU), Lucknow, for the award of the degree of Bachelor of Technology in Electronics and Communication Engineering, is a record of bonafide work carried out by them under my supervision, as per AKTU code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfils the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place: Greater Noida

Date: 03/01/23 **Signature of the Guide**

The report is satisfactory / unsatisfactory

Approved by

Head of the Department

ABSTRACT

The use of Free Space Optical (FSO) communication systems is growing as a result of their ability to deliver high data speeds through unlicensed spectrum with large bandwidth, higher power efficiency, and more security. These systems are also suitable candidates for backhaul lines for the next-generation communication networks, as well as for bottleneck and last-mile applications. However, the performance of FSO systems is harmed by atmospheric turbulence, which is caused by variations in the temperature and pressure of the atmosphere along the propagation path. We have used Malaga distribution which can model a wide range of turbulence conditions it also precisely aligns with the experimental data and incorporates a number of previously existing statistical models for atmospheric turbulence effects, such as the gamma-gamma, lognormal, exponential, and K distributions. As a result, researchers and communication system designers can benefit while investigating and enhancing the performance of FSO links with Malaga distribution. At the receiver end the received signal is fed into an ML detector with CSI, theoretically the Maximum Likelihood (ML) detector is the ideal detector and channel State Information (CSI) that can be provided either in perfect or blind forms. From the simulation results, we observe that Bit error rate decreases with increase in average electrical SNR for Malaga turbulence channel.

ACKNOWLEDGEMENT

First of all, we would like to express our gratitude to our Project Supervisor and Head of Department, Prof. Lakshmanan M. for providing us encouragement and support in completion of this project. It is just unthinkable that we could have achieved anything without him. Those patient hearings, confidence boosting discussions, expert opinion on the subject and a very prompt evaluation of the work at every stage have lent an unparalleled support all along.

We are thankful to Prof. Rekha Rani, from the core of our heart and will be ever indebted to her for not only guiding but also helping us in learning the MATLAB. There were difficult times during our project which could have easily become a mire of frustration but for her expert guidance and encouragement it looked all too easy.

We wish to sincerely thank Prof. Mohd. Asim Qadri, Director, Galgotias College of Engineering and Technology, for providing an environment of learning which have been of great assistance in pursuit of this work

We wish to take this opportunity to thank our faculty members who provided us with necessary inputs and feedback which was very helpful in compilation of this project.

Our sincere thanks also go to the management of Galgotias college of Engineering and Technology, Greater Noida for providing the necessary infrastructure and conducive environment to carry out this project.

It would not have been possible to complete this arduous task without extraordinary support extended by our family and friends, who endured the neglect by us and kept on praying for our success, all through.

Place: Greater Noida

Date: 03/01/23

Masood Asim

Manoranjan Kumar Singh

Kunwar Nitesh Singh

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

FSO	Free Space Optics
RF	Radio Frequency
BER	Bit Error Rate
SNR	Signal to Noise Ratio
ML	Maximum Likelihood
CSI	Channel State Information
DNN	Deep Neural Network
LOS	Line Of Sight
BPSK	Binary Phase Shift Keying
OOK	On-Off Keying
PDF	Probability Density Function
CDF	Cumulative Density Function

CHAPTER 1

INTRODUCTION

Free-space optical communication is method of transferring information through modulated optical signal from one end to the other, where the medium for transmitting this information is free space. This medium is often called as channel which is either free space or vacuum, and it is the characteristics of this channel that provides us in improving the performance and reliability of FSO communication. FSO has gained interest of researchers through many aspects, some of which include its advantages like high speed data transmission, low cost installation, low power consumption, more security, and wide bandwidth with an unlicensed spectrum in comparison. When FSO is compared with RF systems , the major drawbacks in RF systems is less security of data and licensed spectrum and because of this licensed spectrum RF communication is more costly than FSO . It is also seen as the best alternative for future development in communication systems especially in the field where high-speed data communication is required. In comparison with fiber optics communication systems, FSO are more flexible and for maximum exchange of information, the transmitter and receiver need to be aligned i.e. there should be Line of Sight (LOS) communication. The performance of FSO system highly depends on atmospheric conditions like wind, fog, rain, earthquake, as well as phenomenon like scattering, absorption and pointing errors but the major problem is caused due to atmospheric turbulence. Scattering, absorption, and turbulence impact the transmitted light signal when the atmospheric channel conditions are poor. The non-uniformity in temperature, pressure, and wind speed over the channel change the atmosphere's refractive index, which alters the optical signal strength. The pointing errors are a result of misalignment between the transmitter and receiver. When the signal is received it has to be demodulated, this process of demodulation can be done by using various modulation-demodulation schemes like BPSK, MSK , OOK etc. , but the ML detector is a generalized method for demodulation and detection of the received signal . The ML detection is done with CSI (channel state information). The CSI allows transmissions to be tailored to current channel conditions, which is critical for achieving reliable communication at high data rates in multi antenna systems.

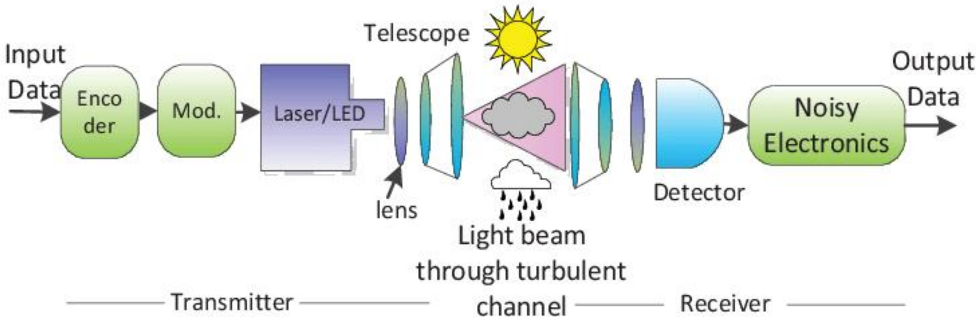

Fig.1.1 FSO Communication system model

1.1HISTORY OF FSO

The fundamental idea originates from the ancient times,, when light (or smoke) signals have been used to transmit data. Modern FSO techniques may have originated with Graham Bell's invention of the photophone that transmitted audio signals by modulating sunlight. The accessibility of lasers, light sources with elevated output power and coherence, enabled accurate beam direction over long distances, eventually reviving FSO systems. The primary proposed application of FSO systems during the 1970s and 1980s was for secure and long-distance communication, primarily for ground-satellite or satellite-satellite communication.

1.2WORKING OF FSO

The operation of an FSO communication system is similar to that of a wireless communication system in that an optical signal is modulated and transmitted from an optical source and travels through a medium that can be free space, vacuum, or atmosphere. The signal is then demodulated and detected by a detector after passing through the channel. The operating principle is similar to that of optical fibre cable, but in FSO, instead of using glass fiber, optical beams are sent through free space. It operates on the principle of line of sight technology and can be used over distances of several Kilometers until and unless there is a clear line of sight between the transmitter and the receiver. For selecting FSO systems which is efficient and reliable the features can be listed as below:

(a) It must be able to operate at higher levels of power over longer distances, and high speed modulation is essential for fast FSO systems.

(b) An as a whole system layout should have a compact size and low consumption of electricity for maintenance.

(b) For outdoor systems, FSO systems should be able to operate over a wide range of temperature with less performance degradation.

(d) The mean time among failures (MTBF) of the system should be larger than ten years.

1.3ADVANTAGES OF FSO

FSO communication has various advantages like high speed data transmission, license free bandwidth, wide bandwidth, low cost for installation and less power consumption. To achieve high data rate transmission, the carrier frequency can be increased. When particularly in comparison to radio frequency communication, optical communication has a higher carrier frequency, resulting in a higher data transmission rate. When compared to RF systems, FSO communication requires less power to operate. The primary difference between RF and FSO is spectrum licensing. Because FSO does not require spectrum licensing, the information is simple and economically feasible. In contrast, licensed bandwidth is accessible in RF communication. Because FSO uses unlicensed bandwidth, it is both cost efficient and simple to implement.

1.4 CHALLENGES IN FSO

However, despite the high potential of FSO communication, its performance is limited by the adverse effects of the atmospheric channel namely (absorption, scattering, and turbulence). The most severe of these three effects is atmospheric turbulence, which can critically degrade the system's bit error rate (BER) quality and render the communication link inoperable. The atmosphere distorts and bends the light wave in addition to attenuating it. The transmitted power of the emitted signal is strongly influenced by scattering and turbulence occurrences. Various disorders affect the optical wave that is transferred via air in free space optical communication, causing overall transmission deterioration.

Some of the issues are discussed in greater detail below:

1.4.1 Aerosol

Aerosols are particles with varying concentrations floating in the atmosphere. They differ in nature, shape, and size. The distribution, components, and concentration of aerosols can all vary. As a result, the interaction between aerosol particles and light can have a vast interplay in terms of wavelength spectrum of interest and atmospheric scattering magnitude. The primary interaction between aerosols and a propagating beam is scattering.

1.4.2 Atmospheric attenuation

Atmospheric attenuation is the process by which some or all of the electromagnetic wave energy is lost while travelling through the atmosphere. Thus, the atmosphere degrades and attenuates signal in an FSO system link in a variety of ways, including absorption, scattering, and scintillation. All of these effects change over time and are affected by local weather and conditions.

1.4.3 Atmospheric turbulence

Atmospheric turbulence occurs as a result of weather and environmental structure. It is triggered by wind and convection, which incorporate air parcels of varying temperatures. The above causes volatility in air density and a change in the refractive index of the air. If the turbulence cell is larger in diameter than the optical beam, beam wander will be the dominant consequence. Beam wander is defined as the rapid displacement of the optical beam spot.

1.4.4 Absorption

Absorption: Water molecules suspended in the terrestrial atmosphere cause absorption. These particles would absorb the power of photons. Absorption reduces the power density of the optical beam and directly affects transmission availability in an FSO system. Carbon dioxide can also cause signal absorption.

1.4CHANNEL MODEL USED:

In FSO communication system, the channel models are categorized according to the turbulence level of channels. In this study, we have used Malaga Distribution without pointing error. The Malaga channel is valid for a wide range of turbulence conditions also it unifies a number of previously existing statistical models such as log-normal, gamma-gamma, K-distribution etc. For this distribution we have found the expression for channel also referred as observed Irradiance as ‘h’. Thus analysis and improvements in the FSO system done by using Malaga distribution would be beneficial for researchers and communication system designers. In table 1.1 an overview of various channels conditions and their corresponding statistical distributions.

Table 1.1 Channel for different turbulence conditions

WEAK TURBULENCE	MODERATE TURBULENCE	STRONG TURBULENCE
Log Normal Distribution	Log Normal Distribution	G-G Distribution
G-G Distribution	Negative Exponential	K-Distribution
Exponentiated Weibull	Exponentiated Weibull	Exponentiated Weibull
Double Generalized Distribution	Double Generalized Distribution	Double Generalized Distribution

1.5MOTIVATION

High data rates and wider bandwidth are now essential requisites for any communication system model. The FSO system is a wireless communication technique that offers high-speed data transmission, a wide bandwidth, and a license-free spectrum. We used an ML detector to detect our received signal, and the transmission channel was analysed using the Malaga distribution, and the results were verified. When the Malaga distribution is considered, which can be applied to a broad range of atmospheric turbulence conditions and also incorporates other statistical models such as log-normal, gamma-gamma, and K-distribution eic, the results obtained from the ML detector are optimised.

1.6LITERATURE REVIEW

A lot of work is done on FSO communication by researchers as it is one the latest technologies in wireless communication and there is massive scope for advancements and optimization in it. The log-normal and gamma-gamma distributions are used to characterise the channel; first, the author examined the various benefits and challenges of FSO communication in [1]. The OOK methodology is used at the transmitter end for modulation, and a non-coherent optical detector is used at the receiver end for demodulation. A main implication in [2 & 3] is that the atmospheric turbulence channel is assumed to be flat, and that AWGN, or additive white Gaussian noise, is always taken into account when writing the expression for the transmitted signal 'y'. This AWGN noise has a mean of zero and a variance of σ^2. The ML detector is also explained in detail, and a general analysis is provided that includes challenges with blind and perfect CSI-based ML detectors, followed by the presentation of a novel Deep learning-based model to analyse BER effectiveness in the channel using log-normal as well as gamma-gamma distributions. Various modulation schemes, such as QAM, BPSK, and OOK, are also discussed, along with their complexities and advantages. A thorough analysis of various Deep Learning-based detectors is performed, and a comparison is made between conventional ML detectors and the suggested one. The closed form expression for BER for Malaga turbulence channel is derived in [3], the authors have used power series expansion for Malaga turbulence channel in order to find PDF expression. Probability density function (PDF) is calculated for M-distribution.

According to [4] the observed field at the receiver is expected to consist of three terms: the first term, U_L, is the line-of-sight (LOS) contribution; the second term, U_S^C, is the component that is quasi-forward scattered by the eddies on the propagation axis and coupled to the LOS contribution; and the third term, U_S^G, is due to energy that is scattered to the receiver by off-axis eddies and is statistically independent. The addition of this LOS scattering component, U_S^C, justifies the model's primary innovation, which is justifiable by the strong directivity and small beamwidths of laser beams used in air optical communications.

Analysis of BER and outage probability for Malaga distribution using SIM-BPSK modulation technique,is done in [5] the BER analysis is similar to that done in [3], and the ultimate expression of BER for Malaga turbulence channel is deduced with pointing error. They have also demonstrated Asymptotic BER analysis and asymptotic BER performance analysis are used to investigate behaviour of the system in high SNR regimes. Monte-Carlo simulation is used in [6] and [3] for simulation purposes. [7 & 8] discussed Gamma-Gamma atmospheric turbulence and the use of spatial variety techniques, while [2 & 3] discussed the impact of pointing errors. [2 & 7] investigated the M-distribution model of the FSO system affected by atmospheric turbulence using variety of strategies.

The blind detection of OOK in an FSO system is proposed in [3]. The receiver can calculate a blind detection threshold by assuming that the channel state is consistent and that the count of transmitted 1s and 0s is nearly equivalent over a specified observation window. According to simulation outcomes, for a satisfactorily large observation window, the suggested receiver can achieve performance comparable to the lower performance bound provided by detection with CSI. The received signal model describes that electrical signal obtained from photo detector is proportional to the intensity of the incoming field, thus this signal is integrated for each bit interval to generate a collection of statistics compatible with detection. Mean ambient light bias from background radiation along with AWGN is also considered in [2].

Malaga distribution to account for irradiance variability is implemented in [4]. The Malaga model is based on an actual model of the scattering method, and it can be viewed as an evolution of the previous model developed by Churnside and Clifford. PDFs of various distributions, such as Rice-Nakagami, gamma, exponential, or gamma-rician, are also discovered to be a special case of Malaga Distribution.

The pdf for gamma-gamma fading is derived in [9], and it is used directly to find the BER expression in [2].

The detection of OOK using channel state information (CSI) is a common assumption in theoretical FSO research involving OOK [8], [9]. CSI assumes that the receiver has full understanding of the instantaneous fading strength. Despite the possibility for using pilot-aided modulation or training symbols to enhance estimation of immediate atmospheric turbulence [7], detection without CSI is preferred because it is superior in terms of infrastructure transparency (i.e. avoiding data framing and packetization) [2], [3].

The use of MRT on the consistency of FSO systems over Malaga turbulence channels is investigated. A power series is used to convey the PDF of distribution. The instantaneous SNR's PDF and CDF are then calculated to yield the BER and outage probability expressions in [10]. Furthermore, asymptotic BER and outage probability analyses were provided to gain a better understanding of the attainable variety gains and reliability. It has been illustrated that using MRT can significantly enhance the efficiency of FSO links, which is highly desirable, especially when low complexity receivers are feasible to have low power, small size, and low cost units.

The author portrayed an accelerated GLRT detection method for an optical communication system that uses OOK modulation via an atmospheric turbulence-induced slow fading channel in [13]. To address the error floor issues, a decryption algorithm for a simple and spectrum-efficient block coding scheme is proposed. To evaluate its error performance and compare it to a one-bit training scheme, comprehensive computer simulations for log-normal and Rayleigh fading channels with various sizes of data transmitted blocks are used.

Three novel Machine Learning-based FSO-MIMO structures as solutions for combating the effects of atmospheric turbulence on FSO system performance in [12] . Transceiver learning, transmitter learning, and DL were applied in Machine Learning for the first time for FSO investigations in structures. Furthermore, the paper considered a MIMO framework in Machine Learning for FSO studies for the first time. A wide range of atmospheric turbulences, from weak to strong, and various MIMO combining scenarios were considered for a thorough investigation. The efficiency of the proposed structures was evidenced by comparing the results with the well-known MQAM-based FSO-MIMO system with ML detection.

Wireless technology has existed for quite some time. In [14] the author describes how humans used to favour sunlight and polished metal plates to function as mirrors and reflect light for long-distance communication. Alexander Graham Bell and his friend Sumner Tainter invented the "photo phone" in 1880 [12]. A photo phone allowed for voice transmission over hundreds of meters. The photo phone provides a crude method of transmitting data through the environment, and it is unprepared to deal with atmospheric turbulence such as fog and clouds. Ever since advancement of light strengthening by stimulated release of radiation (LASER) in 1960, researchers have attempted to put it to use in a wide range of situations [12].Various distribution were anlysed during our study and Malaga distribution is selected for its various advantages and to get much more optimised results as compared to other distributions , BPSK modulation is considered for modulating and demodulating our signal .A comprehensive study is made for deriving the PDF of Malaga distribution without pointing error , and the final BER expression is calculated . Finally a ML detector with perfect CSI is applied on the simulation results curve for the same is plotted using MATLAB.

CHAPTER 2

SYSTEM MODEL AND ML DETECTION

The system model of an FSO communication system is similar to any wireless communication. First, the Sender sends a message in any form, then this signal is encoded into binary data by an Encoder, this encoded form of signal is fed into a Modulator, the modulator operates by increasing the frequency of the input signal for further transmission. Various modulation techniques are used, in this study, we have worked on the BPSK modulation scheme which transmits the binary data in form of 1 and -1 i.e $0 \rightarrow -1$ and $1 \rightarrow 1$. After the modulation the signal is transmitted to a LED or LASER which are optical sources, these sources convert the electrical signal into optical form for further transmission. Then the information-bearing signal is passed through free space (channel) where atmospheric turbulences cause degradation of the signal and effects the performance of the system. Some noise is also added to this signal when traveling through free space. Every channel has its characteristics that vary according to time, geographic location and atmospheric conditions, etc., in this work we have modeled the channel gain 'h' of the Malaga turbulence channel. At the receiver end, the signal has to be demodulated, this process of demodulating the signal is known as demodulation where the frequency of the signal is reduced or converted back to the original value so that the receiver can recognize the signal. ML detector is used for detecting and demodulating the received signal, various other detectors are available, but since at the receiver end the detector does not know about the modulation scheme used while transmitting the information, therefore, ML detection is a generalized way of detecting the received signal that can be compared to the original signal transmitted and when the difference between the two is known it can be reduced for better performance of the FSO system. In the following sections, we have shown how BER expression is calculated for analysis and the implementation of ML detectors with and without CSI.

2.1 **CHANNEL MODEL**

The received signal is expressed as 'Y' and the transmitted signal as 'X' , AWGN noise is also considered and represented as 'W' , the channel gain is described by 'h' . The equation for describing the System can be expressed as:

$Y = h \times X + W$

The gain 'h' varies according to the distribution selected. In this study we are using Malaga Distribution and the channel characteristics are obtained from [3] and [5] .

The PDF of h for Malaga distribution is derived in [4, Eqn(24)] as :

$$f_{h_i}(x) = A \sum_{j=1}^{\beta} a_j x^{\frac{\alpha+j}{2}-1} K_{\alpha-j}\left(2\sqrt{\frac{\alpha\beta x}{g\beta + \Omega'}}\right) \quad \text{(i)}$$

Where, α and β are the fading parameters that denote the large-scale and small-scale fluctuations, respectively.

In (i), $K_v(.)$ stands for the modified Bessel function of the second kind and order v (.) mentioned in [19, sec. (8.432)]

Parameter Ω represents the average power of the optical signal for the line-of-sight (LOS) component, it is the average power of the total scatter component, and defines the amount of scattering power coupled to the LOS component when $g = 2b_o\ (1 - \rho)$. Furthermore, Φ_A and Φ_B denote deterministic angles for the LOS and coupled-to-LOS scatter components.

$$\Omega' = \Omega + \rho 2b_0 + 2\sqrt{2b_0 \Omega \rho}\cos(\phi_A - \phi_B) \quad \text{(iv)}$$

The modified Bessel function in (i) rewritten in terms of the Meijer-G function from [20] is as follows:

$$f_{h_i}(x) = \frac{A}{2}\sum_{j=1}^{\beta} b_j x^{-1} G_{0,2}^{2,0}\left(\frac{\alpha\beta x}{g\beta + \Omega'} \mid \alpha, j\right) \quad \text{(v)}$$

Where, $$b_j = a_j \left(\frac{\alpha\beta x}{g\beta + \Omega'}\right)^{-\frac{\alpha+j}{2}} \quad \text{(vi)}$$

Here $G^{m,n}_{p.q}$ represents the Meijer-G function.
With the help of [20], the Meijer-G function in (v) can be described as

$$G^{2,0}_{0,2}\left(\frac{a\beta x}{g\beta+\Omega'}\mid a,j\right)=\Gamma[j-a]\left(\frac{a\beta x}{g\beta+\Omega'}\right)^{a}{}_0F_1\left[(1+a-j);\frac{a\beta x}{g\beta+\Omega'}\right]+\Gamma[a-j]\left(\frac{a\beta x}{g\beta+\Omega'}\right)^{j}{}_0F_1\left[(1+j-a);\frac{a\beta x}{g\beta+\Omega'}\right]$$

…..(vii)

Using [3] we get the final expression for PDF of Malaga distributions, 'h' parameter as:

$$f_{h_i}(x)=\sum_{j=1}^{\beta}\sum_{k=0}^{\infty}c_{k1}(a,j)x^{k+a-1}+\sum_{j=1}^{\beta}\sum_{k=0}^{\infty}c_{k2}(a,j)x^{k+a-1} \quad \text{(viii)}$$

Where,

$$c_{k1}(a,j)=\frac{Ab_j\Gamma[j-a]}{2(1+a-j)_k k!}\left(\frac{a\beta x}{g\beta+\Omega'}\right)^{a+k}; \quad \text{(ix)}$$

$$c_{k2}(a,j)=\frac{Ab_j\Gamma[a-j]}{2(1+j-a)_k k!}\left(\frac{a\beta x}{g\beta+\Omega'}\right)^{j+k} \quad \text{(x)}$$

2.1.1 **PERFORMANCE ANALYSIS OF BER:**

Bit error rate is he number of bit errors per unit time. The average Bit error rate can be calculated using:

$$P(e)=\int_0^{\infty}P(e\mid\gamma)f_{\gamma}(\gamma)d\gamma \quad \text{(x)}$$

Where $P(e)$ is the conditional error probability given as: $\frac{1}{2}erfc\left(\sqrt{\gamma}\right)$

For BPSK modulation [20], where erfc is the complementary error function.
Finally, the $p(e)$ is expressed in [11] as:

$$p(e)=\int_0^{\infty}\frac{1}{2\sqrt{\pi}}G^{2,0}_{1,2}\left(\gamma\,\Big|^{1}_{0,\frac{1}{2}}\right)f_{\gamma}(\gamma)d\gamma \quad \text{(xii)}$$

After applying Integration property of Meijer-G function [21]. The average BER for FSO system is expressed as:

$$P(e) = \frac{A}{\pi^{\frac{3}{2}}} \sum_{j=1}^{\beta} 2^{\alpha+j-4} b_j G_{2,5}^{4,2}\left(\frac{(\alpha\beta)^2}{2^4 \mu(g\beta + \Omega')} \Big|_{\frac{\alpha}{2},\frac{\alpha+1}{2},\frac{j}{2},\frac{j+1}{2},0}^{1,\frac{1}{2}} \right)$$

2.2 **SIMULATION**

The simulation is done using Monte-Carlo simulation and the results are shown in fig. 2.2.1.

For simulation, the observed irradiance (I) in [4 , Eqn 2] (i.e. h of our channel) for the Malaga turbulence channel is expressed as :

$I = |U_L + U_S^C + U_S^G|^2 \exp(2\chi) = YX,$

Where

$Y = |U_L + U_S^C + U_S^G|$ and $X = \exp(2\chi)$

Where U_L is the line-of-sight (LOS) contribution, U_S^C is quasi-forward scattered by the eddies on the propagation axis which is coupled to LOS component, energy which is scattered to the receiver is expressed as U_S^G .

2.3 **IMPLEMENTING ML DETECTOR WITH CSI**

Further we have applied ML detector with perfect CSI on our simulation results and the outcome is shown in fig 2.3.1. For blind CSI conditions the results are displayed in figure 2.3.2.

If the receiver has perfect CSI, data can be approximated from the obtained statistical data by comparing each 'y' to a pre-calculated decision threshold. In fact, due to the symmetric distribution of AWGN noise, the threshold is a simple function of instantaneous atmospheric turbulence and background radiation mean.

2.4 **IMPLEMENTING ML DETECTOR WITHOUT CSI (BLIND DETECTION)**

As discussed in [2], in the absence of CSI at the receiver end, an ML conclusion can still be made but for that statistical channel information should be available. For instance, symbol-by-symbol (mainstream) recognition without CSI can be conducted, where the binary decision on h is made by comparing y to a cutoff point (threshold).

CHAPTER 3
RESULT AND DISCUSSION

In this work we studied the performance of FSO system in terms of Bit error rate. The Performance of FSO system is degraded by various atmospheric turbulences, Malaga distribution is used to describe closed form expression for bit error rate and probability distribution function for the channel gain 'h'. Further ML detector is applied on the received signal, for perfect and imperfect CSI conditions and the outcome is verified with that in [2]. Various parameter values are adjusted for obtaining the desired outcomes, Table 3.1 shows an overview of all the parameters used and their values for Malaga turbulence channel.

S.No	**Distribution Parameters**	**MALAGA TURBULENCE CHANNEL**
1	α	2.1
2	β	4
3	Ω	0.75
4	ρ	0.85
5	N	2,4,8,16
6	Φ_A	90
7	Φ_B	0
8	b_o	0.5

Table: 3.1 Parameter value

3.1SIMULATION RESULTS

3.1.1Bit Error Rate performance for Malaga distribution without ML detector

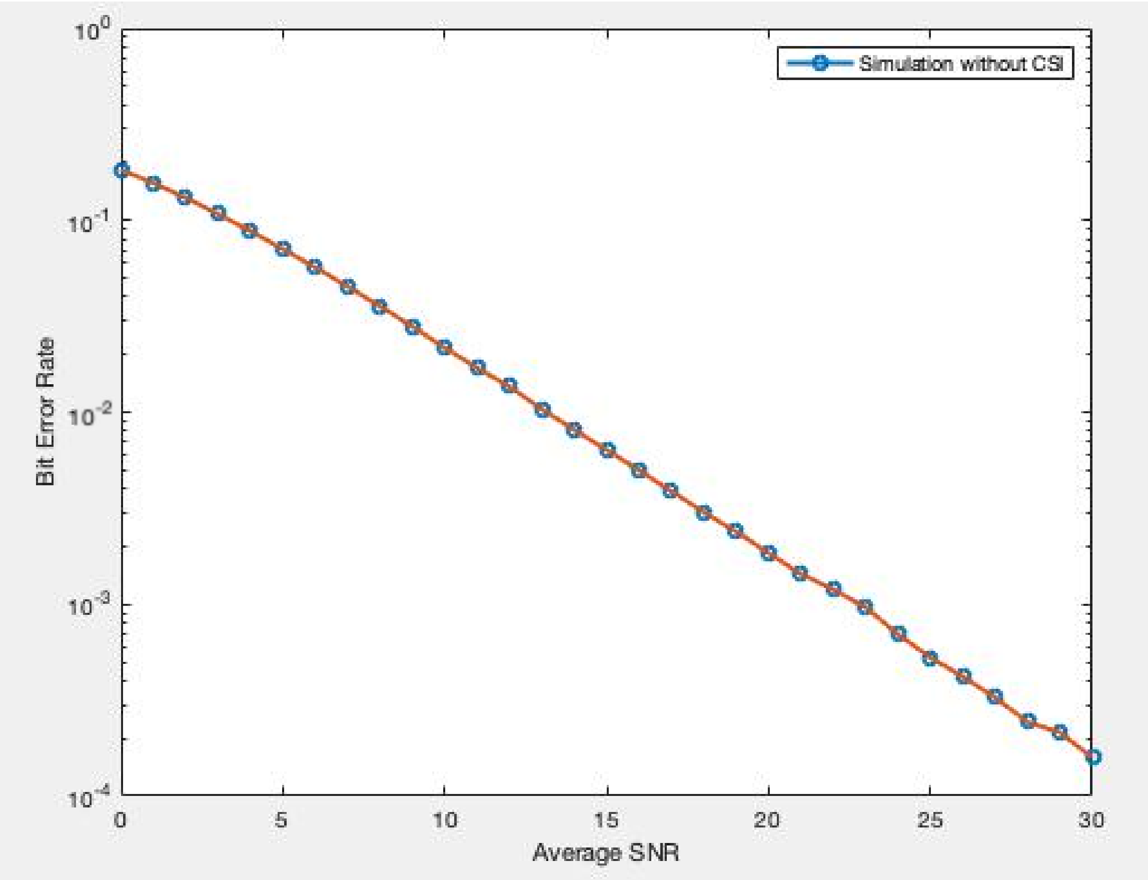

Fig. 3.1 Bit Error rate for Malaga fading (Condition: $\alpha = 2.1$, $\beta = 3$, $\Omega = 0.75$, $\rho = 0.85$, $\Phi_A=90$, $\Phi_B=0$, $b_o=0.5$) for FSO system

Fig 3.1 represents the Bit Error Rate and Average Electrical SNR over Malaga channel ($\rho=$ 0.85) for FSO system under Malaga Turbulence channel. This shows that for a particular threshold as the average electrical SNR increases the Bit error rate decreases.

3.1.2 Bit Error Rate performance for Malaga distribution with ML detector for perfect CSI .

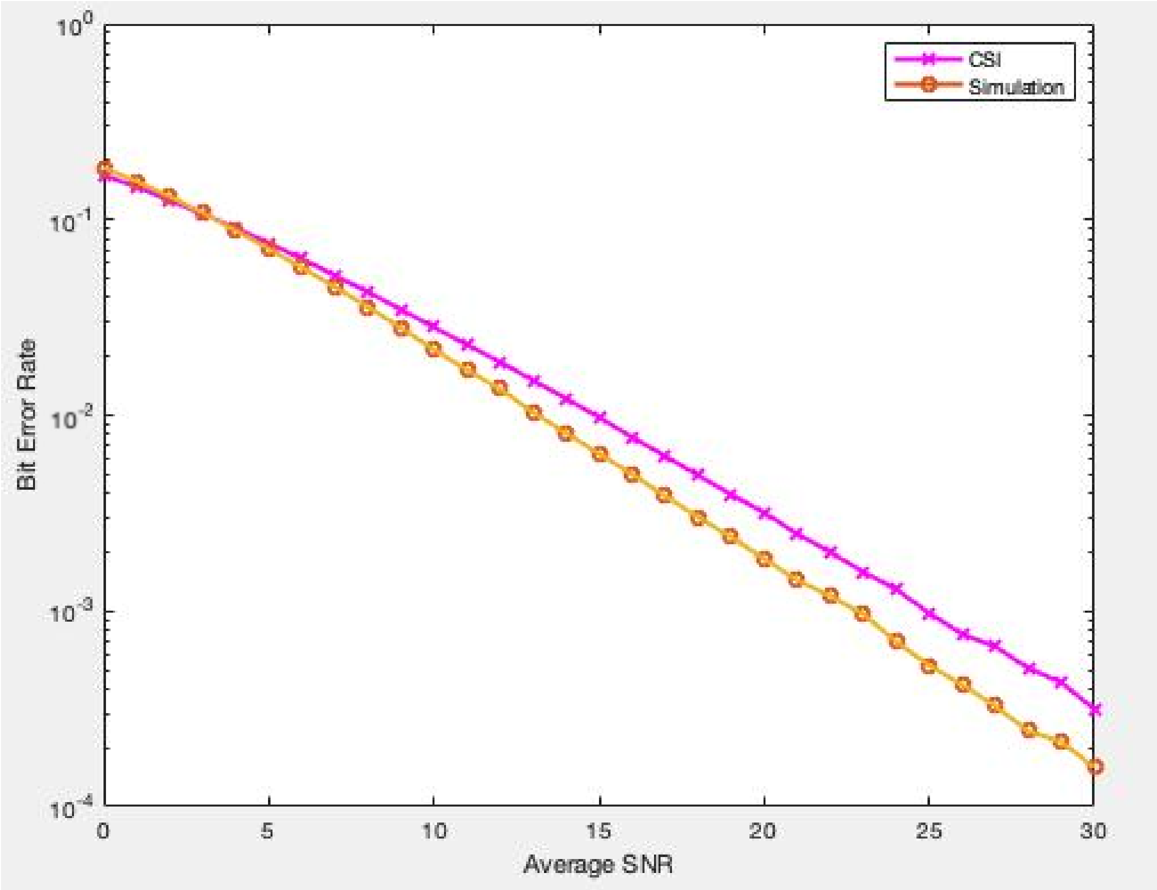

Fig 3.2 Bit Error rate for Malaga fading (Condition: $\alpha = 2.1$, $\beta = 3$, $\Omega = 0.75$, $\rho= 0.85$, $\Phi_A=90$, $\Phi_B=0$, $b_o=0.5$) for FSO system

Fid 3.2 Represents Bit error performance with ML detector under perfect CSI conditions for Malaga turbulence channel (Condition: $\alpha = 2.1$, $\beta = 3$, $\Omega = 0.75$, $\rho= 0.85$, $\Phi_A=90$, $\Phi_B=0$, $b_o=0.5$). It can be observed that with ML detector for perfect CSI conditions the graph obtained is closer to that of simulation done without ML detector.

CHAPTER 4
CONCLUSION

In this study, we investigated the BER performance of BPSK modulation in the Malaga Turbulence channel, using a Maximum Likelihood detector with both perfect and blind CSI conditions to recognise the received data and evaluate its BER performance over a given SNR range. There are numerous distributions available for different atmospheric turbulences, one of which is the Malaga distribution, which can be used for a wide range of atmospheric turbulences varying from weak to strong, and which also precisely matches theoretical results. We considered the observed irradiance, i.e. the channel gain 'h,' as the product of small-scale fluctuations (Y) and large-scale fluctuations (X) for simulation. The ML detector at the receiver end is ideally the optimum one, and is also applied here for detecting the signal. The simulation is done using monte-carlo simulation for BER vs SNR range. It is observed that ML detection with perfect CSI have better performance than that of blind CSI for the same simulation outcome.

REFRENCES

1. Amirabadi, M. A., Kahaei, M. H., & Nezamalhosseini, S. A. (2020). Deep learning based detection technique for FSO communication systems. Physical Communication, 43, 101229. https://doi.org/10.1016/j.phycom.2020.101229

2. I.S. Gradshteyn, I.M. Ryzhik, Table of Integrals, Series, and Products, Academic Press, 2014. Table of Integrals, Series, and Products. (2015). Elsevier. https://doi.org/10.1016/c2010-0-64839-5

3. Riediger, M. L. B., Schober, R., & Lampe, L. (2008). Blind detection of on-off keying for free-space optical communications. 2008 Canadian Conference on Electrical and Computer Engineering https://doi.org/10.1109/ccece.2008.456476

4. The Mathematical Functions Site. (n.d.). https://functions.wolfram.com/

5. Jurado-Navas, A., Maria, J., Francisco, J., & Puerta-Notario, A. (2011). A Unifying Statistical Model for Atmospheric Optical Scintillation. Numerical Simulations of Physical and Engineering Processes https://doi.org/10.5772/25097

6. Milosevic, N. D., Petkovic, M. I., & Djordjevic, G. T. (2017, August). Average BER of SIM-DPSK FSO System With Multiple Receivers over $ \mathcal {M}$-Distributed Atmospheric Channel With Pointing Errors. IEEE Photonics Journal, 9(4), 1–10. https://doi.org/10.1109/jphot.2017.2710320

7. Zixiong Wang, Wen-De Zhong, Songnian Fu, & Chinlon Lin. (2009). Performance comparison of different modulation formats over free-space optical (FSO) turbulence links with space diversity reception technique. IEEE Photonics Journal, 1(6), 277–285. https://doi.org/10.1109/jphot.2009.2039015

8. CableFree.(n.d.)https://www.cablefree.net/wirelesstechnology/free-space-optics/history-of-free-spaceoptics

9. Kumar, R., Singh, P., & Kumar, N. (2020). Alamouti Code Generator in Optical Domain Using Mach–Zehnder Interferometer. Lecture Notes in Electrical Engineering, 79–82. https://doi.org/10.1007/978-981-15-5546-6_7

10. Goldsmith, A. (2005). Wireless Communications. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511841224

11. Petkovic, M. I., Zdravkovic, N. M., & Dordevic, G. T. (2014, November). Outage performance of switch-and-examine combining receiver over FSO Gamma-Gamma atmospheric turbulence with pointing errors. 2014 22nd Telecommunications Forum https://doi.org/10.1109/telfor.2014.7034429

12. Amirabadi, M. A. (2019, November 22). Three novel efficient Deep Learning-based approaches arXiv.org. https://arxiv.org/abs/1912.12232

13. Zhu, Y. J., Sun, Z. G., Zhang, J. K., & Zhang, Y. Y. (2015, December). A Fast Blind Detection Algorithm for Outdoor Visible Light Communications. IEEE Photonics Journal, 7(6), 1–8. https://doi.org/10.1109/jphot.2015.2495104

14. Bhatnagar, M. R., & Ghassemlooy, Z. (2016, May 1). Performance Analysis of Gamma–Gamma Fading FSO MIMO Links With Pointing Errors. Journal of LightwaveTechnology, 2158–2169. https://doi.org/10.1109/jlt.2016.2526053

15. Uysal, M., Jing Li, & Meng Yu. (2006, June). Error rate performance analysis of coded free-space optical links over gamma-gamma atmospheric turbulence channels. IEEE Transactions on Wireless Communications, 5(6), 1229–1233. https://doi.org/10.1109/twc.2006.1638639

16. Uysal, M., Jing Li, & Meng Yu. (2006, June). Error rate performance analysis of coded free-space optical links over gamma-gamma atmospheric turbulence channels.IEEE Transactions on Wireless Communications, 5(6), 1229-1233. https://doi.org/10.1109/twc.2006.1638639

17. Zhu, X., & Kahn, J. M. (2002, January 24). <title>Pilot-symbol assisted modulation for correlated turbulent free-space optical channels</title>. SPIE Proceedings. https://doi.org/10.1117/12.453222

18. "Xiaoming Zhu, & Kahn, J.(2002, August). Free-space optical communication through atmospheric turbulence channels. IEEE Transactions on Communication, 50(8), 1293–1300. https://doi.org/10.1109/tcomm.2002.800829

19. J. Li, J. Q. Liu and D. P. Taylor, "Optical Communication Using Subcarrier PSK Intensity Modulation Through Atmospheric Turbulence Channels," in IEEE Transactions on Communications, vol. 55, no. 8, pp. 1598-1606, Aug. 2007, doi: 10.1109/TCOMM.2007.902592.

20. S. Atapattu, C. Tellambura and H. Jiang, "A Mixture Gamma Distribution to Model the SNR of Wireless Channels," in IEEE Transactions on Wireless Communications, vol. 10, no. 12, pp. 4193-4203, December 2011, doi: 10.1109/TWC.2011.111210.102115.

21. Ibrahim, A. A., & Gucluoglu, T. (2019). Performance analysis of maximum ratio transmission based FSO link over Malaga turbulence channel. Optics Communications, 450, 341–346.

APPENDIX A1

MATLAB CODE FOR MONTE-CARLO SIMULATION OF BER PVS SNR RANGE , IN MALAGA TURBULENCE CHANNEL WITHOUT MAXIMUM LIKELIHOOD DETECTOR :

```
clear all;
close all;
Clc;
Mc = 1e6;
alpha=2.1;
beta=2;
m=2;
G = gamrnd(m,1/m,1,Mc);
phiA = 90;
phiB = 0;
b0 = 0.5;
rho = 0.75;
omega = 0.85;
y_avg_db= 0:10;
mu=10.^(y_avg_db/10)
L=length(y_avg_db)
y_avg = db2pow(y_avg_db);


UL = sqrt(G)*sqrt(omega)*exp(1i*phiA);
USC = sqrt(G)*sqrt(rho*2*b0)*exp(1i*phiB);
USp = sqrt(2*b0)/sqrt(2)*(randn(1,Mc) +
1i*randn(1,Mc));
USG = sqrt(1-rho)*USp;


ser_sim=zeros(1,L)
for k = 1:11
     snr=y_avg(k)
     ip = rand(1,Mc)>0.5; % generating 0,1 with equal
probability
s = 2*ip-1; % BPSK modulation 0 -> -1; 1 -> 0
noise_power=1/snr
     n = 1/sqrt(2)*[randn(1,Mc) + j*randn(1,Mc)]; %
white gaussian noise, 0dB variance
X = gamrnd(alpha,1/alpha,1,Mc);
```

```
Y = abs(UL + USC + USG).^2;
h = Y.*X;
     eta=1
% Channel and noise Noise addition
     y = h.*s +(noise_power)* n;

     y(real(y)<0)=-1;
     y(real(y)>=0)=1;
% receiver - hard decision decoding
err=nnz(y-s)

% counting the errors
ser_sim(k)=err/Mc
end

hold on

semilogy(y_avg_db,ser_sim,'mx-','LineWidth',2);
xlabel('SNR');
ylabel('Bit Error Rate');

title('BER for BPSK modulation in Malaga Channel')
```

APPENDIX A2

MATLAB CODE FOR MONTE-CARLO SIMULATION OF BER PVS SNR RANGE , IN MALAGA TURBULENCE CHANNEL WITH MAXIMUM LIKELIHOOD DETECTOR FOR PERFECT CSI CONDITIONS .

```
clear all;
close all;
clc

Mc = 1e6;
alpha=2.1;
beta=4;
m=4;
G = gamrnd(m,1/m,1,Mc);
phiA = 90;
phiB = 0;
b0 = 0.5;
rho = .75;
omega = 0.85;
y_avg_db= 0:30;
mu=10.^(y_avg_db/10)
L=length(y_avg_db)
y_avg = db2pow(y_avg_db);


UL = sqrt(G)*sqrt(omega)*exp(1i*phiA);
USC = sqrt(G)*sqrt(rho*2*b0)*exp(1i*phiB);
USp = 2*(sqrt(2*b0)/sqrt(2)*(randn(1,Mc) +
1i*randn(1,Mc)));
USG = sqrt(1-rho)*USp;

rho*2*b0+2*sqrt(2*b0*OMG*rho)*cos(phiA-phiB);


ser_sim=zeros(1,L)
for kk = 1:L
     snr=y_avg(kk)
     ip = rand(1,Mc)>0.5;
     s = 2*ip-1; % BPSK modulation 0 -> -1; 1 -> 0
```

```
     noise_power=1/snr
     n = 1/sqrt(2)*[randn(1,Mc) + j*randn(1,Mc)]; %
white gaussian noise, 0dB variance
X = gamrnd(alpha,1/alpha,1,Mc);
Y = abs(UL + USC + USG).^2;
h = Y.*X;
% Y=1/sqrt(beta)*[randn(1,Mc) + j*randn(1,Mc)]
% Z=1./Y

eta=1
% Channel and noise Noise addition
y = h.*s +(noise_power)* n;

csi=h/2;
y(real(y)<csi)=-1
y(real(y)>=csi)=1
% receiver - hard decision decoding
err=nnz(y-s);
% counting the errors
ser_sim(kk)=err/Mc
end

close all
figure


semilogy(y_avg_db,ser_sim,'o-','LineWidth',2);
xlabel('SNR');
ylabel('Bit Error Rate');

title('BER for BPSK modulation in Malaga Channel')
```