ANALYSIS OF MIMO FSO SYSTEMS USING DIFFERENT CHANNEL MODELLING AND MODULATION TECHNIQUES

DISSERTATION-II

Submitted in partial fulfillment of the Requirement for the award of the Degree of

MASTER OF TECHNOLOGY
IN

Electronics and Communication Engineering

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TOPIC APPROVAL PERFORMA

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CERTIFICATE

This is to certify that Kulvir Kaur bearing Registration no. 11507209 has completed her objectives of the thesis titled, **"Analysis of MIMO FSO systems using different channel modeling and modulation techniques"** under my guidance and supervision. To the best of my knowledge, the present work is the result of her original investigation and study. No part of thesis has ever been submitted for any other degree at any university.

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DECLARATION

I, Kulvir Kaur**,** student of MASTER OF TECHNOLOGY under Department of ELECTRONICS & COMMUNICATION ENGINEERING of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive research and is genuine.

This Dissertation-II titled "**Analysis of MIMO FSO systems using different channel modeling and modulation techniques"** to the best of my knowledge, does not contain any part of my work which has been submitted for the award of my degree without proper citation.

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I wish to express my sincere gratitude to my supervisor MR. RAJAN MIGLANI (Assistant professor) at LPU, Punjab from electronics and communication department for his cooperation and guidance for preparing the Dissertation-II report on “Analysis of MIMO FSO systems using different channel modeling and modulation techniques”

I wish to avail myself of this opportunity to express a sense of gratitude and love to my friends for their support and strength.

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ABSTRACT

The Radio frequency links have reached to a saturation level in order to provide high data rates. The demand for higher data rates opens up the era free space optical communication which transmits the optically modulated data through free space. The transmitters are used here are Laser and Light emitting diodes where at the receiver side the optical data is detected by photo detectors. Free space optical communication has various admirable properties which attract the researchers from past few decades. The capability to provide the high data rate, license free band, security and less cost makes it superior than RF communication.

As the channel is free space, various atmospheric factors are affecting the performance of optical links. The performance degrading atmospheric factors are like: rain, fog, snow etc., misalignment losses and atmospheric turbulence induced fading. The turbulence induced fading being the most dominating amongst them. To model the extent of turbulence there are various models have been proposed in literature like: Lognormal, K-distribution, Rician, I-K model, Gamma-Gamma and Double Generalized Gamma model. The probability density function based analysis is proposed in our work to define the turbulence regime for particular channel as the turbulence has direct impact on PDF of received intensity.

To enhance the performance of FSO links and to reduce the turbulence effect various mitigation techniques are applied to FSO links like: modulation techniques, coding techniques, spatial diversity and hybrid RF/FSO system etc. In our work we have implement modulation and spatial diversity (MIMO) to increase the performance of FSO links and comparative analysis of these techniques is proposed. From our probability density function based analysis it is concluded that to model all types of turbulence regimes the Gamma-Gamma channel model was appropriate model but later when we analyze the bit error rate performance of Double Generalized Gamma and Gamma-Gamma model it is found that under strong turbulence regime Double Generalized Gamma performs better than Gamma-Gamma model. The spatial diversity techniques are further employed to enhance the performance and it is concluded that multiple input single output (MISO) performs better than single input multiple output (SIMO). The binary phase shift keying (BPSK) outperforms other modulation techniques like: on-off keying (OOK) and differential phase shift keying (DPSK).

The relay assisted FSO system is employed enhance the performance of FSO system with respect to link distance.

LIST OF ABBREVIATIONS

RF	Radio frequency
FSO	Free space optics
SI	Scintillation index
LED	Light emitting diode
OOK	On-off keying
PPM	Pulse position modulation
PWM	Pulse width modulation
PSK	Phase shift keying
SISO	Single input single output
SIMO	Single input multiple output
MISO	Multiple input single output
MIMO	Multiple input multiple output
BER	Bit error rate
PDF	Probability density function
EGC	Equal gain combining
MRC	Maximum ratio combining

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CHAPTER 1

INTRODUCTION

1.1 Introduction to free space optical communication

The exponential rise in demand of higher bandwidth has led to situation where the world has started looking for something beyond Radio Frequency (RF) links which have reached to almost saturation level in providing data rates to serve the bandwidth starved smart device era. The Free space optical (FSO) communication is technology which has been experimentally tested to provide data rates as high as 10 Gbps [1] can serve as reliable solution to problem described above. It transmits optically modulated data using visible or IR part of frequencies which do not require any license fee from government. However the earliest citation of light as information carrier relates to photo-phone experiment also known as world's first wireless telephone demonstrated by Alexander G. Bell. FSO Transmission being line of sight offers tremendous security and privacy. Being optically modulated using very narrow wavelengths [2] FSO links are not only immune co-channel interference and but also immune to RF interferences [3]. However, the link atmosphere, i.e. the link itself can play major dampener in degrading the performance of free space optical communication links. This is because the atmospheric and metrological conditions like wind, rain, fog, temperature variations etc. may impair the link owing to scatter absorption of light. In comparison to atmospheric conditions, the turbulence effect of atmosphere causes serious damage to link uptime. The Free space can be characterized to be composed of three main obstructions which are absorption, turbulence induced fading and scattering [4].Due to absorption and scattering the incident light does not able to reach at destination with full intensity because it gets scattered by water molecules. As mentioned above the most dominating effect which weakens the link is turbulence induced fading [5] which occurs in clear atmosphere due to temperature variations the air's refractive index changes which leads to atmospheric turbulence. The turbulence effect causes fluctuations in modulated signal phase and amplitude which may make it either difficult or impossible for the receiver to extract information, and this effect is known as fading. The Kolmogorov theory provides fundamental explanation to the concept of turbulence induced fading [6] using parameters which characterized the turbulence: the inner and outer scale turbulence is given by l_0 and L_0, respectively, the index of refraction is C^2_n. It is important to mention that for the given link atmospheric turbulence is never constant; its strength may vary from weak to strong depending upon dynamic link and atmospheric conditions. To describe the extent of turbulence, the scintillation index (SI) is used as standard which is defined in Eq. 1 as

$$\sigma^2_I=E\{I^2\}/E\{I\}^2-1 \qquad (1)$$

Where *I* is intensity of optical wave and *E{.}* defines the expected value of *I*.

To define the quantum of loss of signal intensity due these channel fluctuations, various models have been proposed over the years.

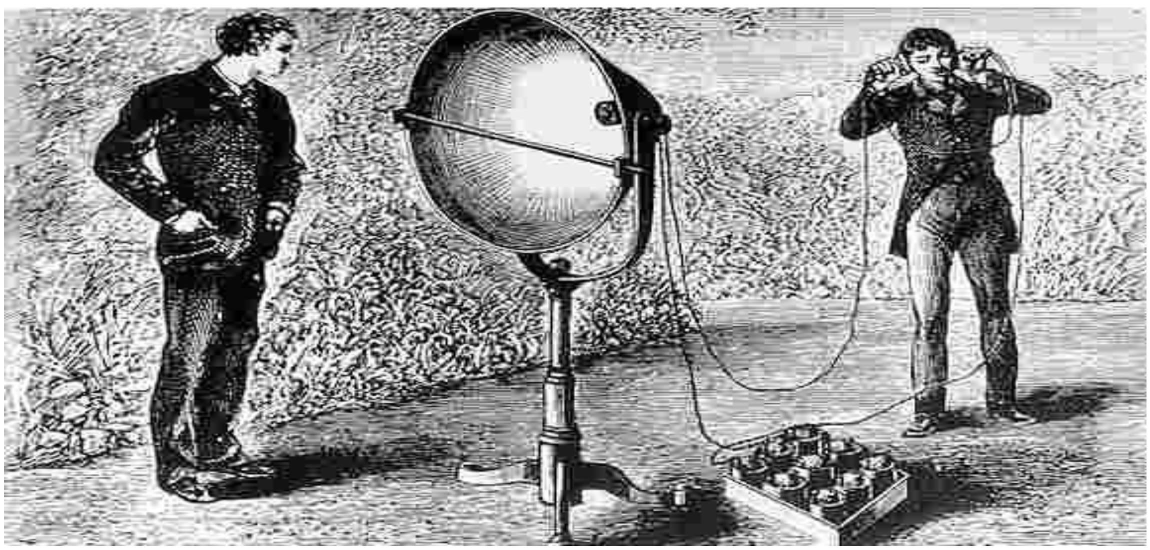


Figure1.1 Photo-phone experiment [7]

In recent past channel modeling techniques like Log Normal distribution, Rayleigh distribution, Rician distribution, Negative exponential distribution etc, have been formulated but are more or less general models which only defines the turbulence effect either as weak or strong [8]. Additionally some other models which like Gamma- Gamma, Weibull etc. are based on doubly stochastic theory [9] and these models are capable of describing fading effects of turbulence in all regimes ranging from weak to strong turbulences.

1.2 Advantages of FSO

In comparison to conventional RF based systems, an FSO system has certain unbeatable attributes like:

(1) For FSO channels there is no license is required from government agencies as in this the data is modulated optically.

(2) FSO channels provide high data rates in comparison to RF links and provide very high speed internet. The range of frequency on which it operates is up to 3Thz.The Experimental demonstrations recently claims to provide data rate up to 160Gbps.

(3) The data security is more in FSO because this is a line of sight based communication. An optical ray is hard to intercept.

(a)

(b)

Figure 1.2 (a) & (b) Cable digging problem in fiber optics [10]

1.3 Applications of FSO

(A) Metro Area Network (MAN): The problem of the last mile customers is solved by FSO system, thereby Metro Network extension comes into picture by providing the high speed MAN's access to customers.

(B) Last Mile Access: The FSO is utilized to give the scaffold between fast connections and End clients. It can likewise be utilized to sidestep nearby circle frameworks to furnish business with rapid associations.

(C) Enterprise availability: As we probably am aware FSO connections can be introduced effectively, so these connections give a straightforward strategy for interconnecting LAN fragments that are housed in structures isolated by open roads.

(D) Fiber backup: To reinforcement fiber, FSO can likewise be sent in repetitive connections set up of a moment fiber interface.

(E) Backhaul: FSO can be utilized to convey cell phone activity from radio wire towers back to offices wired into people in general exchanged phone organize.

1.4 Working

In order to provide the full duplex communication in Free space optics there are two transceivers at both the ends. The data is first converted into binary form of 0's and 1's and then transmitting through free space. The LED and laser diodes are used at transmitter side to generate infrared which works as carrier to send data.

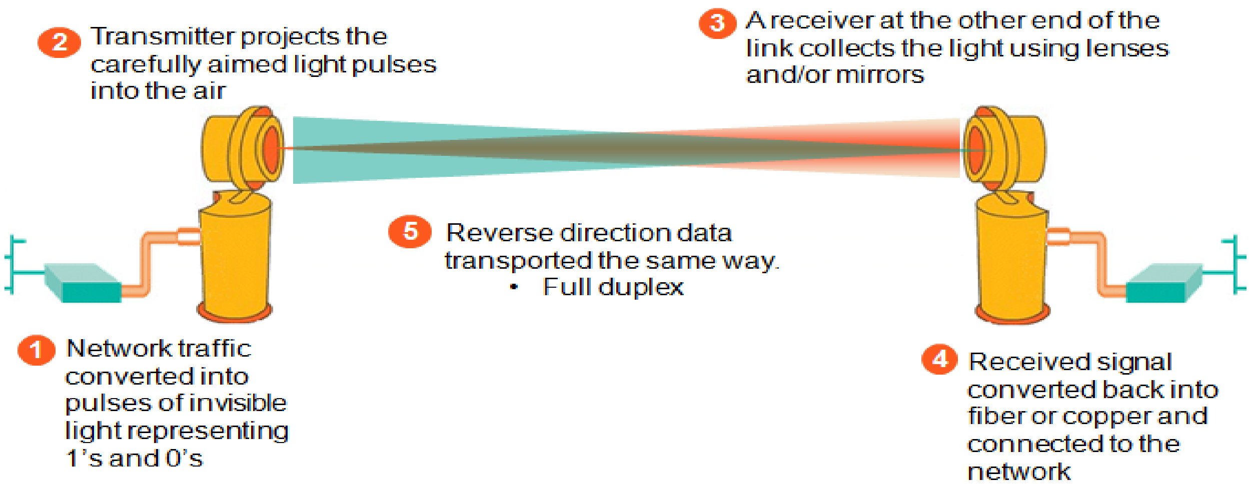


Figure 1.3 FSO Overview [10]

1.5 Losses in FSO links

There are various losses which affects the performance of FSO. These losses are named as misalignment losses, atmospheric losses, atmospheric turbulence induced fading and background noise.

(a) Misalignment loss: The causes for misalignment losses are beam wander and building sway. In beam wander the beam deviates from its real path due to deflection in optical beam and building sway originates from earthquakes, wind loads and vibrations.

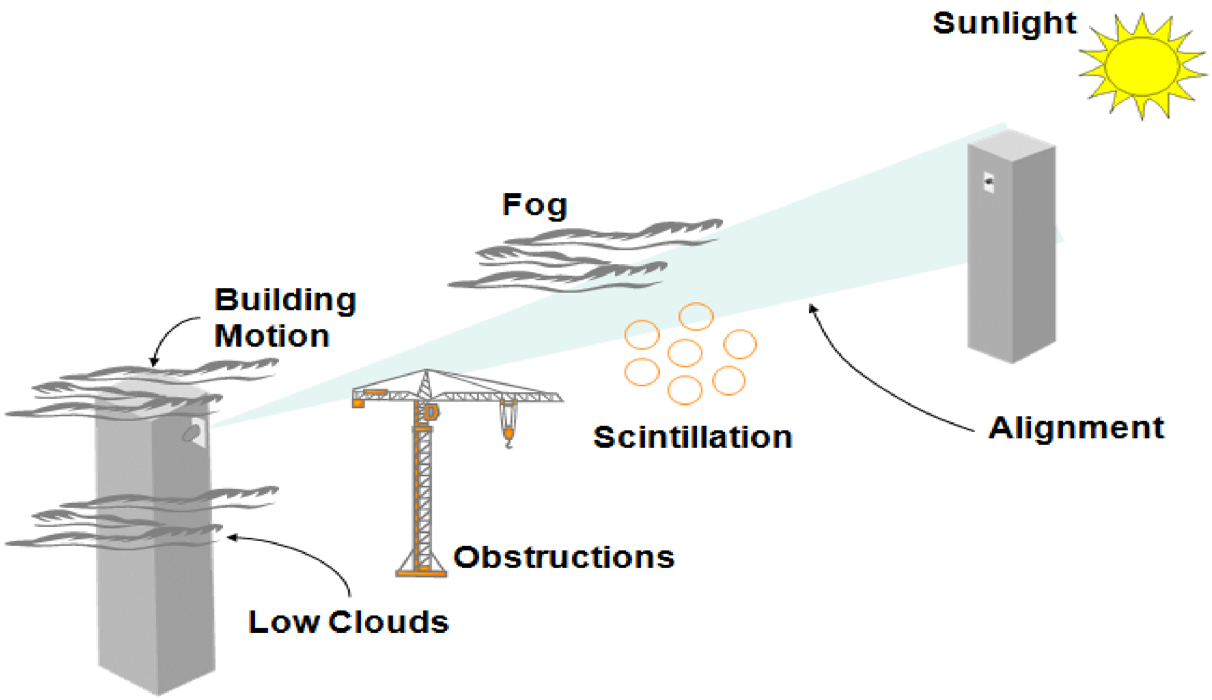


Figure 1.4 Losses in FSO [10]

(b)Atmospheric Losses: In atmospheric loss the causes are rain, pollution, fog, snow etc. Because of water particles absorption occurs which leads to scattering in which incident light changes its path. These atmospheric losses has negligible affects in clear atmosphere but there is another effect known as fading caused by variations in temperature results in atmospheric turbulence.

(c)Turbulence induced fading: This atmospheric turbulence leads to the fluctuations in phase and amplitude of a signal which results channel fading. Some parameters are characterized the atmospheric turbulence: the inner scale of turbulence is l_0 and outer scale is L_0 and index of refraction C^2_{n}.Kolmogorov theory explains these parameters. The atmospheric turbulence strength is varies from weak to strong fading in FSO.

1.6 FSO channel modeling

A simplified schematic to design a free space optical communication link along with basic subsystems is illustrated in figure 1.5. The information source is suitably modulated onto optical modulator, using laser diode. This signal, also known as optically modulated signal is then transmitted atmospheric channel and guided to remote destination using line of sight communication model.

The received optical signal is given as equation 2:

$$y = \eta x I + n \qquad (2)$$

In equation 2 the x represents information bits it can be either 0 or 1.Where n is additive white Gaussian noise with mean = 0 and variance = No/2. I is the normalized irradiance. The optical to electrical conversion is denoted by η.

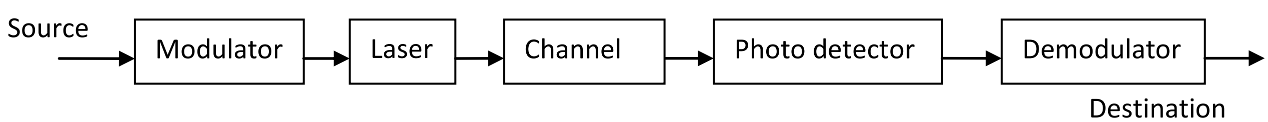


Figure 1.5 Basic block diagram of free space optical communication system

At receiver side the signal is optically collected using photo detectors. The free space optical communication provides large bandwidth to support more users than radio frequency (RF) communication and it generates more attention of the researchers from last few decades. For a good communication system it is necessary to design a high performance communication links or channels. In wireless communication to transmit the signal from transmitter to receiver a medium is required that is known as channel. The signal when travel from channel gets affected by various losses. Some basic channel models are Log-normal, Negative–exponential, K-distribution, Rician distribution and Gamma-Gamma model.

The turbulence comparison for different channel models is verified with probability density functions. The PDF formulas for different channel models are:

- **Log-normal model:** The log-normal models assumes the log intensity ***l*** of the laser light traversing the turbulent atmosphere to be normally distributed with a mean value of $=\sigma_I^2/2$.Thus the probability density function of the received irradiance is given by [11].

$$p(I) = \frac{1}{\left(\sqrt{2\pi\sigma_I^2}\right)I} \exp\left\{-\frac{(\ln\left(\frac{I}{Io}\right)+\frac{\sigma_I^2}{2})^2}{2\sigma_I^2}\right\}, I>0 \quad (3)$$

Where I represent irradiance and I_0 represents irradiance without scintillation

- **Negative-exponential:** The negative exponential is used for very strong turbulence condition and it concluded. The pdf for negative exponential model is given below [11].

$$p(I) = \frac{1}{Io} \exp\left[\frac{-I}{Io}\right], I > 0 \quad (4)$$

Where *E[I]* = Io is the mean received irradiance. The value of the scintillation index, S.I→1.

- **Rayleigh model:** The scintillation index for the Rayleigh situation is 1.The density function of Rayleigh is more concentrated at low (deeply faded) values and given below [11].

$$p(I)= \frac{I}{2\sigma^2} \exp\left\{-\frac{I}{2\sigma^2}\right\}, I>0 \quad (5)$$

Where, I=Irradiance, σ^2= Variance

- **Rician model:** In rician distribution model the line of sight path or direct path is also present along with reflected paths between the transmitter and receiver. The probability density function for rician channel is given as[11].

$$p(I)= \frac{1}{\sigma^2}\exp\left\{\frac{I^2+k^2}{2\sigma^2}\right\}Io\left[\frac{Ik}{\sigma^2}\right], I>0 \quad (6)$$

Where k is the rician factor which defines the ratio of power of LOS component to reflected.

- **K-distribution:** The K -distribution was proposed for strong turbulence and the probability density function (pdf) of this model is product of negative exponential and gamma distribution p(x) and p(y), given as below[12].

$$p(I)=\frac{2\alpha}{\Gamma(\alpha)}(\alpha I)^{\alpha-1/2}K_{\alpha-1}(2\sqrt{\alpha I}),I>0,\alpha>0 \qquad (7)$$

Where $K_m(.)$ is Bessel function of order m,
α used for calculation of scintillation index as: $\sigma^2_I=1+2/\alpha$.

- **Gamma-gamma distribution**: The model based on doubly stochastic theory has been proposed which is widely known as Gamma-Gamma model. In this intensity I is product of two random variables. These random variables(X and Y) represent small and large scale turbulence .The probability density function (pdf) of I for this model is given below [12].

$$p(I)=\frac{2(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\,\Gamma(\beta)}I^{((\alpha+\beta)/2)-1}K_{\alpha-\beta}(2\sqrt{\alpha\beta I}),I>0 \qquad (8)$$

The Γ(.) is gamma function and α and β are number of small and large scale turbulence.
The scintillation index (SI) of this model is:$\sigma^2_I=(1/\alpha)+(1/\beta)+(1/\alpha\beta)$.

- **Double Generalized Gamma:** The received irradiance in Double generalized gamma is product of two random variables. These random variables Ix and Iy represent large and small scale turbulence .The probability density function (pdf) of this model is combination of two independent pdf's [13].

$$fIx(Ix)=\frac{\gamma 1\, Ix^{m1\gamma i-1}}{\left(\frac{\Omega 1}{m1}\right)^{m1}\Gamma(m1)}exp\left(-\frac{m1}{\Omega 1}Ix^{\gamma 1}\right) \qquad (9)$$

$$fIy(Iy)=\frac{\gamma 2\, Iy^{m2\gamma 2-1}}{\left(\frac{\Omega 2}{m2}\right)^{m2}\Gamma(m2)}exp\left(-\frac{m2}{\Omega 2}Iy^{\gamma 2}\right) \qquad (10)$$

$$fIx(I/Iy)=\frac{\gamma 1(I/Iy)^{m1\gamma 1-1}}{Iy\left(\frac{\Omega 1}{m1}\right)^{m1}\Gamma(m1)}exp\left(-\frac{m1}{\Omega 1}(\frac{I}{Iy})^{\gamma 1}\right) \qquad (11)$$

From above equations the final pdf for this model is given in equation 16:

$$p(I)=\int_0^{\infty} fIx(I/Iy)\ fIy(Iy)dIy \qquad (12)$$

1.7 Modulation

In order to transmit the signal over long distance we have to change the characteristics of carrier signal or to superimpose the message signal on carrier signal.

- **On-off keying (OOK):** The most common used technique for modulation is on-off keying (OOK). It is a binary modulation technique which directly use (on) for presence and (off) for absence of light pulse in modulated data.OOK requires dynamic thresholding and it has poor energy and spectral efficiency [14].The decision metric for OOK is given by

$$P(y|on, I_{mn})=P(y|off, I_{mn}) \qquad (13)$$

Where y is the received signal vector and represents as y = $(y_1, y_2, y_3, \ldots \ldots \ldots, y_N)$.The conditional bit error rates for SISO FSO systems are given below.In the absence of turbulence the BER for OOK modulated FSO links can be expressed as:

$$P_e = 0.5\text{erfc}\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right) \qquad (14)$$

The erfc(x) in above equation is in terms of Q-function is erfc(x) =2Q ($\sqrt{2}\,x$) where Q (.) is the Gaussian-Q function. By substituting the erfc(x) in equation 15 the conditional BER can be rewritten as:

$$P_e = Q\left(\frac{\sqrt{SNR}}{2}\right) \qquad (15)$$

The above expression in equation 15 represents OOK modulated single transmitter single receiver communication link. In OOK modulated FSO links the receiver performs intensity/direct detection of optically modulated signal to recover the original information. Correspondingly the bit error rate function for such channel can be obtained by modifying equation 15 to suit the single channel receiver with intensity/direct detection process as:

$$P_e = Q\left(\frac{\eta I}{2\sqrt{N_0}}\right) \qquad (16)$$

Where η is optical to electrical conversion coefficient and I is irradiance. The expression (16) represents generalized expression for FSO-OOK modulated links, however in presence of turbulence the average BER for SISO OOK links can be modeled as:

$$P_e = \int_0^\infty f(I)\left[\mathrm{Q}\left(\frac{\eta I}{2\sqrt{N_0}}\right)\right] dI \qquad (17)$$

Where the value of f(I) is the probability density function of the received intensity.

- **Pulse position modulation (PPM):** In PPM the width and amplitude remains constant the position of each pulse varies. It is used for both digital and analog systems. It is the technique used where the low interference occurs like: fiber optics. It provides better efficiency so to overcome the problems related to OOK, pulse-position modulation is a powerful solution.
- **Phase shift keying (PSK):** In phase shift keying modulation the phase of a light beam varies while the frequency and amplitude kept constant. It is the binary phase shift keying (BPSK) in which the phase of carrier is set to 0 or π according to the modulating signal. If in modulating signal, the 1 is transmitted then the phase of carrier is exactly the same as modulating signal which is 0 and if 0 is transmitted then phase of carrier is π.

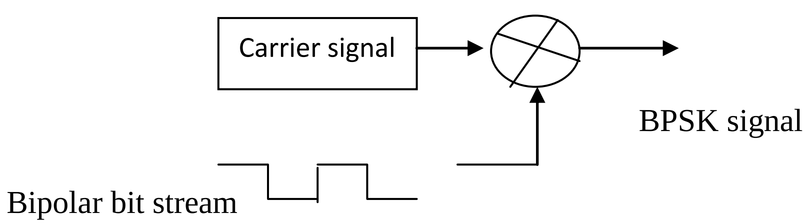


Figure 1.6 Generation of BPSK signal

It is simplest form of PSK modulation. The conditional BER of SISO BPSK system is:

$$P_e = 0.5\mathrm{erfc}\left(\sqrt{SNR}\right) \qquad (18)$$

The erfc(x) in above equation is in terms of Q-function is erfc(x) =2Q($\sqrt{2}\,x$) where Q(.) is the Gaussian-Q function. By substituting the erfc(x) in equation 18 the conditional BER is:

$$P_e = \mathrm{Q}\left(\sqrt{2SNR}\right) \qquad (19)$$

The average BER of BPSK over the fading channel or distribution is:

$$P_e = \int_0^{\infty} f(I) \left[\mathrm{Q}\left(\frac{2\eta I}{\sqrt{N_0}}\right)\right] dI \qquad (20)$$

Where f(I) is PDF for particular channel model.

The differential phase shift keying (DPSK) is in which the transmitted information is represented by the phase difference between adjacent symbols. By using the differential coding the information 1 is transmitted by shifting the phase of modulated signal is 180 with respect to previous phase of modulated signal. Where the 0 is transmitted without shifting the phase with respect to previous signal.

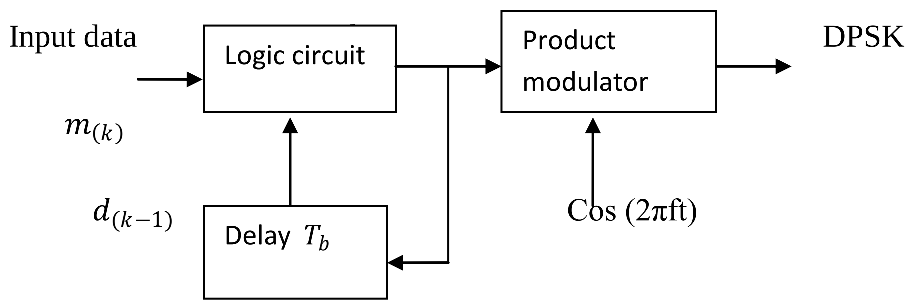


Figure 1.7 Generation of DPSK signal

The conditional BER of SISO DPSK system is:

$$P_e = 0.5\mathrm{erfc}\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right) \qquad (21)$$

The erfc(x) in above equation is in terms of Q-function is erfc(x) =2Q($\sqrt{2}\, x$) where Q(.) is the Gaussian-Q function. By substituting the erfc(x) in equation 21 the conditional BER is:

$$P_e = \mathrm{Q}\left(\sqrt{SNR}\right) \qquad (22)$$

The average BER of DPSK over the fading channel or distribution is:

$$P_e = \int_0^{\infty} f(I) \left[\mathrm{Q}\left(\frac{\eta I}{\sqrt{N_0}}\right)\right] dI \qquad (23)$$

Where f(I) is PDF for particular channel model.

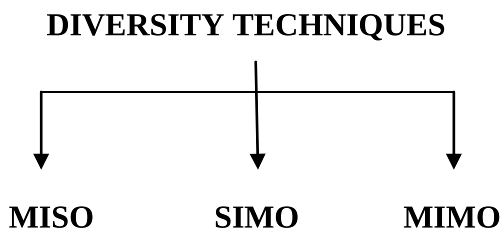
1.8 Spatial diversity

The diversity can be achieved by using multiple beams at transmitter (MISO), multiple apertures at receiver side (SIMO) or using both multiple beams and multiple apertures (MIMO) to increase the error rate performance of FSO links.

1.8.1 SISO-This is the general model in which only single input and single output is there.

Figure 1.8 SISO Link Schematic

It is a effective solution in order to mitigate the fading in FSO. For diversity schemes the number of transmitting beams represented by M and number of apertures represented by N.



1.8.2 MISO-In MISO diversity the system has multiple input single output The multiple beams are used at transmitter (MISO) to implement transmit diversity as given in figure 1.9. The repetition coding (RC) signaling scheme is used for these systems in which same signal can be send over multiple beams.

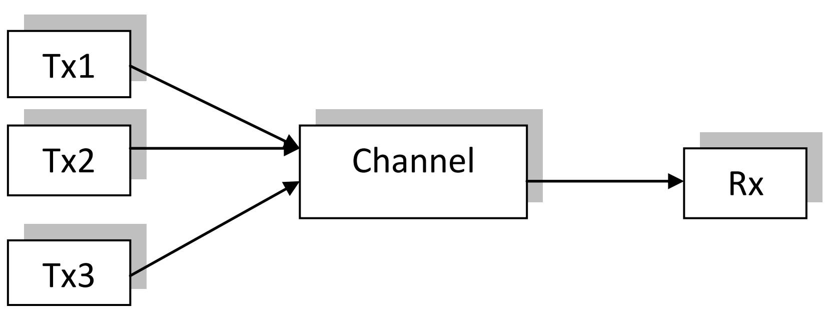


Figure 1.9 MISO diversity (3x1)

- **BER for MISO :** In contrast to link behavior expressed in equation 23, describing SIMO FSO links, BER for MISO FSO links can be determined on similar lines by replacing the I_n

with I_m as in case of MISO links the value of N shall be unity. Thus for given choice of channel model the probability density function $f(I)$ under turbulent atmosphere given the fact that now the normalized intensity $I= (I_{11,}I_{21,}I_{31,} \ldots \ldots \ldots \ldots . I_{MN})$ shall be the function of factor M only. The average BER MISO FSO OOK modulated links is given in equation 24:

$$P_{MISO} = \int f(I)\, Q\left(\frac{\sqrt{\gamma}}{M\sqrt{2}} \sum_{m=1}^{M} I_m\right) dI \qquad (24)$$

1.8.3 SIMO-In SIMO diversity the single input multiple output system is implemented. The multiple apertures are used at receiver side to realize the receive diversity as given in figure 1.10. Multiple apertures with smaller sizes at the receiver can be used instead of using a single large aperture in order to efficiently reduce the fading.

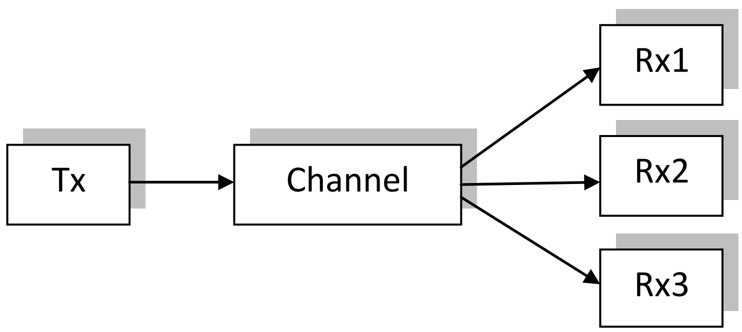


Figure 1.10 SIMO diversity (1x3)

- **BER for SIMO system:** In this section we focus on bit error rate performance over SIMO turbulent channel. In SIMO diversity, at receiver the multiple signals are received which are denoted with N (no. of receivers).
- **BER for optimal combining (OC) technique:** This section provides the BER under assumption of optimal combining with good channel state information where the variance received by each receiver is given by σ^2=No/2N. The number of transmitters is 1(M=1) and BER obtained as[12]

$$P_{SIMO,OC} = \int f(I)\, Q\left(\sqrt{\frac{\gamma}{2N} \sum_{n=1}^{N} I_n^2}\right) dI \qquad (25)$$

Where I_{mn} is the normalized irradiance for m^{th} transmitter and n^{th} receiver.

- **BER for equal gain combining technique:** The technique equal gain combining is considered in this section in which the receiver adds the receiver branches by considering equal weight age from all the signals, the average BER is[15]

$$P_{SIMO,ECG} = \int f(I)\, Q\left(\frac{\sqrt{\gamma}}{N\sqrt{2}} \sum_{n=1}^{N} I_n\right) dI \qquad (26)$$

1.8.4 MIMO-In MIMO system the multiple beams and multiple apertures are used in MIMO as given in figure 1.11.It is widely used technique in communication. Mostly MIMO systems are used RC at transmitter in order to give efficient results for fading.

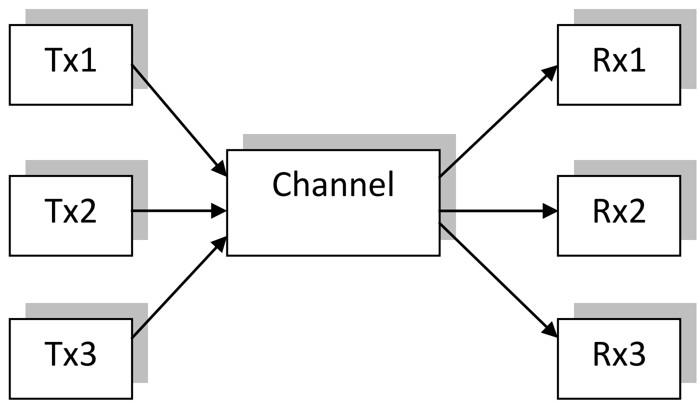


Figure 1.11 MIMO diversity (3x3)

1.9 Fading correlation

For underlying sub channels the diversity techniques are efficient for uncorrelated case. The uncorrelated means the fading of each sub channel is independent from other sub channels .But if we have a case of correlated fading the performance of these diversity techniques is impaired by correlation. In Figure 1.10 shows the sub channels (c1, c2, c3 and c4) for (2x2) MIMO system.

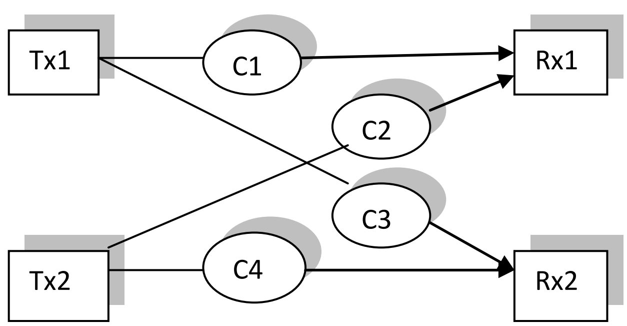


Figure 1.12 MIMO (2x2) - sub-channel representation

1.10 Relay Assisted FSO systems

The relay assisted transmission means multi-hop transmission which is a powerful turbulence mitigation technique in free space optical communication. The serial relay systems are example of multi-hop transmission. The advantage of shorter loops is implemented in FSO to mitigate the turbulence effect.

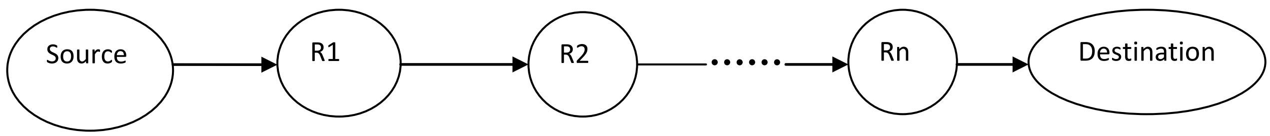


Figure 1.13 Serial relay FSO system

Transmitter using OOK modulation:

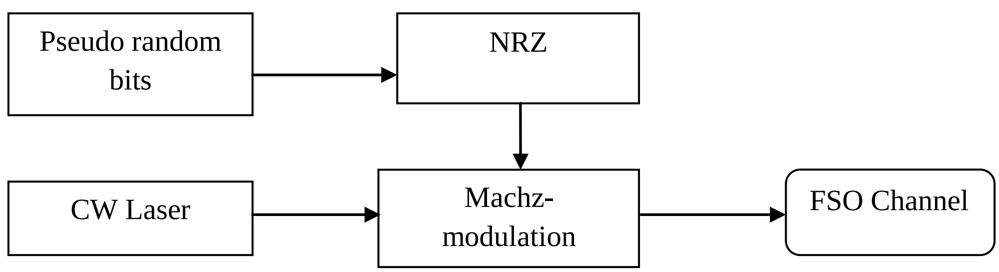


Figure 1.14 Transmitter of serial relay FSO system

Receiver in Relay node:

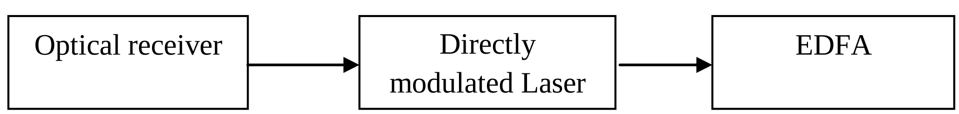


Figure 1.15 Receiver of serial relay FSO system

CHAPTER 2

REVIEW OF LITERATURE

In free space optical communication the main hurdle is atmospheric turbulence which overcomes by various techniques. The modulation, diversity and coding techniques are applied by considering different channel models to mitigate the effect of turbulence.

Zhu. X.,(2002),et. al. in paper entitled **"Free-Space Optical Communication Through Atmospheric Turbulence Channels"** gives the detection techniques to overcome the effect of atmospheric turbulence. The ML detection scheme is applied on the basis of turbulence if the initial states are un known and marginal are known then symbol by symbol ML detection can be applied to reduce turbulence. In this paper the use of spatial diversity is also considered and it has been shown that if there is correlation between sub channels is exist due to less gap then ML detection is applied to reduce the losses [16].

Uysal. M.,(2004),et. al. in paper "**BER Performance of Coded Free-Space Optical Links over Strong Turbulence Channels"** derived the error performance bounds of coded FSO systems over strong turbulence i.e. K-distribution model. The upper bounds for K-distribution is derived and then combined with transfer function to obtain the bit error rate expressions [17].

Navas. J.A.,(2006),et. al. in paper **"Efficient Channel Model for Free Space Optical Communications"** proposed new expressions by considering atmospheric turbulence and negative effect of wind velocity. The expression provided for approximation in this article has less computational load. The lognormal channel model declared as best for weak turbulence regimes [18].

Bayaki.E, (2009), et al. in paper entitled "**Performance Analysis of MIMO Free–Space Optical Systems in Gamma–Gamma Fading"** present the pair wise error probabilities of SISO and MIMO FSO system by considering Gamma-Gamma channel model. The bit error rate performance for Gamma-Gamma channel for on-off keying and pulse position modulation is presented for both

SISO and MIMO systems with EGC and MRC techniques. The RF communication based concepts diversity and combining gain are also applied to FSO link. Hence the gain performance for EGC is more efficient than MRC and complexity to implement EGC is also low [19].

Tsiftsis. T.A,(2009),et. al. **in paper entitled "Optical Wireless Links with Spatial Diversity over Strong Atmospheric Turbulence Channels"** provides the bit error rate analysis over K-distribution model by considering diversity configurations. It has been concluded that in comparison to SISO links the MIMO links has efficient performance in strong turbulence. It has been also shown that in order to reduce the effect of strong turbulence the required number of apertures are more than 5[20].

Tang.X.,(2010),et al. in paper **"Free-space Optical Communication Employing Polarization Shift Keying Coherent Modulation in Atmospheric Turbulence Channel"** proposed a binary polarization shift keying techniques with equal gain combining and maximum ratio combining spatial diversity techniques to reduce the effect of turbulence. The bit error rate calculations done for these two techniques over Gamma-Gamma channel model. The maximum ratio combining has been shown better than equal gain combining but with high implementation complexity [21].

Henniger. H., (2010), et. al. in paper **"An Introduction to Free-space Optical Communications"** shows that the FSO systems gains attraction of researchers more than RF communication. Its various advantages are described in this article which is no interference between sub-channels, high bit rate, unlicensed communication and small size of components also makes it usable for mobile devices. The challenges in FSO communication are also defined here which are atmospheric turbulence ,rain, fog etc. which are reduced by spatial diversity, channel coding and hybrid RF-FSO systems[22].

Zambrana. A.G.,(2010),et. al. in paper entitled **"On the Capacity of FSO Links over Gamma - Gamma Atmospheric Turbulence Channels Using OOK Signaling"** the author proposed a new method and derives the new upper bounds on capacity over Gamma-Gamma channel model with direct detection intensity modulation .unlike the RF communication where upper bounds are derived only for average electrical SNR here in contrast to FSO links the mutual information from average optical power and average electrical power is used. These new bounds provide tighter information as compared to previous described bounds [23].

Farid. A.A.,(2011), et. al. in paper entitled **“Outage Capacity for MISO Intensity-Modulated Free-Space Optical Links With Misalignment”** in this paper the outage capacity of turbulent free space optical systems is analyzed by considering multiple input single output configuration. The closed form expressions are obtained using repetition coding at transmitter side. The asymptotic and closed form expressions are analyzed in this article [24].

Peppas. K.P,(2011),et al. in paper entitled **“A Simple, Accurate Approximation to the Sum of Gamma–Gamma variates and Applications in MIMO Free-Space Optical Systems”** provides a new simple close form approximation to the independent Gamma-Gamma distribution and shown that the PDF of α-μ distribution provides efficient approximation to PDF of Gamma-Gamma distribution. The results are further applied to MIMO system to analyze the system performance [25].

Mofidi. M.,(2012),et. al. in paper **“Error Performance of SIMO and MISO FSO Links over Weak and Strong Turbulent Channels”** provides the performance analysis of FSO system with MIMO over weak and strong turbulence regime. It has been described that as SIMO and MISO configurations have less complexity and more applicability in comparison to MIMO systems. The channel model for weak turbulence is lognormal and for strong K-distribution is considered. The symbol error rate performance is analyzed for these two models using Q-ary PPM modulation. It has been concluded that SIMO performs better than MISO diversity [26].

Lakshmi. M.S,(2012),et. al. in paper entitled **“A Literature Survey on Performance of Free Space Optical Communication Links under Strong Turbulence”** gives a brief survey on free space optical communication and its mitigation techniques. It has been concluded that the performance of coherently detected techniques is better than non-coherent detected techniques [27].

Hanzra. T.S, (2012), et. al. in paper **"Performance of Free Space Optical Communication System with BPSK and QPSK Modulation"** shows the performance analysis of BPSK(binary phase shift keying) and QPSK (quardature phase shift keying) modulation techniques over rician and nakagami channel model. It has been concluded from this article that the QPSK performs better than BPSK and OOK modulation and the better bit error rate is achieved over rician channel with QPSK modulation [28].

Yang. F, (2012), et al. in paper**, "Coherent Free-Space Optical Communications in Lognormal-Rician Turbulence"** proposed two channel models lognormal and rician channel models with two diversities equal gain combining and maximum ratio combining. The bit error rate expression for maximum ratio combing with binary phase shift keying and for equal gain combing for differential binary phase shift keying has been calculated and proposed the comparison of these techniques [29].

Kashani. M. A., (2013), et al. in paper entitled **"A novel statistical model for turbulence-induced fading in free-space optical systems"** presents a new channel model double generalized gamma in free space optical communication and the closed form expressions are derived for SISO system. This channel model declared as better model than existing models for its performance to match simulation data [30].

K. Prabhu, (2013), et. al. in paper entitled **"BPSK based Subcarrier Intensity Modulated Free Space Optical System in Combined Strong Atmospheric Turbulence"** proposed BPSK-SIM FSO model over K-distribution with strong turbulence condition. It has been shown that as the turbulence decreases the BER performance improves and the channel capacity increases with SNR. The outage probability analysis also shown in this study and observed that for lower SNR the detector has weaker signals and less outage probability[31].

Bhatnagar M.R.,(2013), et. al. in paper **"Differential Decoding of SIM DPSK over FSO MIMO Links"** derives the differential decoder for SIM based (differential phase shift keying) DPSK modulation in MIMO FSO system. The channel model considered in this paper is Gamma-Gamma model. It has been concluded that the proposed work outperforms the non-coherent detection systems[32].

Luong. D.A,(2013),et. al. in paper entitled **"Average Capacity of MIMO/FSO Systems with Equal Gain Combining over Log-Normal Channels"** proposed the expressions for capacity of multiple input multiple output FSO system. The channel model considered in this work is Lognormal with equal gain combing technique. It has been concluded that the use of MIMO systems is reduce the effect of turbulence and the provide the significant capacity gain over SISO system[33].

Mounika. G.,(2013), et. al. in paper entitled **"Convolution Coded On-Off Keying Free-Space Optical Links over Fading Channels"** carried out the performance analysis of free space optical communication for using intensity modulation/direct detection OOK and pulse position modulation(4-PPM) over the turbulent channel model collaborating with channel coding. It has been observed that the low BER is achieved at high SNR[34].

Rani. S.,(2013),et. al. in paper entitled **"MIMO Channel Capacity of Free Space Optical Communication system of OOK and M-PPM"** in this paper it is described that the performance of multiple pulse position modulation (MPPM) is better for single input single output FSO systems but as the number of transmitters or receivers are increased as multiple input multiple output the performance of MPPM modulation reduces because of high complexity. The OOK modulation performs better in case of MIMO FSO systems than MPPM. The channel capacity is more in case of OOK than MPPM[35].

Benkhelifa F., (2013), et. al. in paper entitled **"Low SNR Capacity of FSO Links over Gamma-Gamma Atmospheric Turbulence Channels"** shows the capacity analysis of free space optical communication by considering low signal to noise ratio and full channel state information at transmitter and receiver. It has been shown that the capacity using only 1 bit of channel state information is achieved[36].

Abaza. M.R.,(2013),et. al. in paper **"MIMO Techniques for High Data Rate Free Space Optical Communication System in Log-Normal Channel"** enhances the data rates of FSO communication system by employing the MIMO diversity over lognormal channel model. The modulation technique considered here is MPPM. It has been concluded that the data rates achieved up to 850Mbps when 2x2 MIMO configuration is employed and with 4x4 configuration the data rates of 1Gbps has been obtained[37].

Abaza. M.R,(2014),et. al. in paper entitled **“Spatial Diversity For FSO Communication Systems Over Atmospheric Turbulence Channels”** investigates the bit error rate performance of spatial diversity over lognormal channel model by considering sub channel correlation using intensity modulation direct detection. The expressions using moment generating functions for repetition coding and orthogonal space time block coding are derived. As the number of transmitters are increases, the performance of RC is also improves. It has been concluded that the RC outperforms the OSTBC[38].

Luong. D.A,(2014), et al. in paper entitled **“Average Capacity of MIMO Free-Space Optical Gamma-Gamma fading Channel”** gives analyses to mitigate the effect of turbulence in free space optical communication the by considering average capacity for MIMO system for both EGC and MRC techniques. The average capacity improves with spatial diversity and MRC provides only moderate gains in comparison to EGC.EGC is preferable over MRC to implement [39].

Pernice. R,(2014),et al. in paper **“Indoor free space optics link under the weak turbulence regime: measurements and model validation”** presents the performance analyses is carried out using an indoor atmospheric chamber and the various turbulence conditions has been generated to demonstrate that the weak turbulence is also affects largely to FSO links. The turbulence strength and performance metrics like bit error rate has been calculated to test evaluate the performance of FSO links. The correlation between sub channels also has serious affect on performance of FSO system also carried out in this paper [40].

Yang. G, (2014), et al. in paper entitled **“Performance analysis of space-diversity free-space optical systems over the correlated Gamma-Gamma fading channel using Padé approximation method”** a new power series proposed to generate the approximate closed form expression of probability density function for Gamma-Gamma channel model. The performance of spatial diversity is analyzed by considering correlation between sub-channels by using this newly generated probability density function [41].

Shah. D., (2014), et. al. in paper **"Study of Different Atmospheric channel models"** defines the analysis of three different turbulence channel models. They concluded that lognormal model efficiently defines the weak turbulence condition, K-distribution defines strong turbulence regime where I-K distribution is valid for all types of turbulence from weak to strong regime and I-K model also has less complexity than Gamma-Gamma model[42].

Kaur. A., (2014), et. al. in paper entitled **"Analysis the effect Atmosphere Turbulence in Free-Space Optical (FSO) Communication Systems"** the author makes analytical results by considering turbulence channel model i.e. Gamma-Gamma the BER and outage probability analysis is carried out and concluded that as signal to noise ratio increases the bit error rate decreases and approaches to theoretical values[43].

Khalighi. M.A,(2014),et. al. in paper **"Survey on Free Space Optical Communication: A Communication Theory Perspective"** gives a vast survey on free space optical communication including its applications, challenges and mitigation techniques. It has been concluded that atmospheric turbulence is most dominating effect in FSO. In order to reduce the turbulence various mitigation techniques are applied which are higher modulations, spatial diversity, hybrid RF/FSO systems and channel coding techniques. The channel models are also reviewed here and conclude that Gamma-Gamma model is widely accepted for all types of turbulence regimes [44].

Abadi. M.M,(2014),et. al. in paper entitled **"Comparison of Different Combining Methods for Space-Diversity FSO Systems"** gives the comparative analysis of different combining schemes at receiver using spatial diversity over lognormal channel. A new technique of logical combining has been introduced which as bi-majority combining scheme (BMC).It has been shown that selection combing has more implementation complexity where EGC also outperformed by BMC in weak turbulence regime. It offers the best performance for more than three receiver apertures [45].

Rathee. S. (2014), et. al. in paper entitled **"Performance Analysis of Free Space Optical communication In Presence of Atmospheric Turbulence"** provides analysis of free space optical communication over turbulent channel models: lognormal and Gamma-Gamma model. The analysis carried out in terms of bit error rate (BER) and outage probability and it has been shown that BER and outage probability both are the function of variance. When high values of variance are considered then more is the turbulence effect. For better BER and low outage probability the variance should be low [46].

Prabhu. K.,(2014),et. al. in paper entitled "**BER Analysis for BPSK Based SIM–FSO Communication System Over Strong Atmospheric Turbulence with Spatial Diversity and Pointing Errors"** the performance of the subcarrier intensity modulation using bipolar phase shift keying FSO system is analyzed over Gamma-Gamma channel model. Along with turbulence effect the pointing errors are also considered in this article. The bit error rate expressions are derived by considering single input multiple output (SIMO) diversity for different combining configurations. It has been concluded that selection combining provides better results than other combing techniques and also concluded that as the number of receiver apertures are increased the system performance also increases [47].

AlQuwaiee. H.,(2014), et. al. in paper entitled **"On the Performance of Free-Space Optical Communication Systems over Double Generalized Gamma Channel"** derives the bit error rate expressions over double generalized gamma model with pointing errors. It can be noticed that if the effect of pointing errors are assumed to negligible the performance of this channel model matches with performance described in paper by Kashani. Also in this paper the bit error rate for single FSO link and for hybrid RF/FSO are derived [48].

Rajbhandari. S.,(2015), et al. paper entitled, **"Experimental Error Performance of Modulation Schemes Under a Controlled Laboratory Turbulence FSO Channel"** proposed experimental results for different modulation techniques ,the turbulence introduced with hot air. The analyses carried out for different modulation techniques and it has been shown that the efficient results has been given by pulse position modulation [49]

Song.X.,(2015),et al. in paper entitled **"BER of Subcarrier MPSK and MDPSK Systems in Atmospheric Turbulence"** provides the analyses of bit error rate for M-ary phase shift keying(MPSK) and M-ary differential phase shift keying(MDPSK) over Gamma-Gamma and lognormal channel models. The exact and approximate bit error rates relation is obtained by dividing the symbol error rate with number of bits per symbol. The channel conditions affect the performance of approximated bit error rates. The weak turbulence condition scenarios give better bit error rate, as the turbulence goes to strong regimes the performance of bit error rate influenced by turbulence. The comparative analyses also defined for MPSK and MDPSK [12].

Kaushal. H.,(2015), et. al. in paper **"Free Space Optical Communication: Challenges and Mitigation Techniques"** in presented paper the author gives a comprehensive review on challenges faced by free space optical communication and turbulence mitigation techniques. The study concludes that FSO communication provides various admirable properties which are not fulfilled by RF communication but the major performance degrading factor is atmospheric turbulence. In order to reduce the effect of turbulence the author discussed various techniques like: channel coding, higher modulations, spatial diversity and relay systems. The hybrid RF/FSO systems are also discusses in this article in which RF systems are deployed as a backup for FSO systems [50].

Kashani. M. A., (2015), et al. in paper entitled **"A novel statistical channel model for turbulence-induced fading in free-space optical systems"** proposed the extension of existing work on double generalized gamma for SIMO diversity. The performance is analyzed by outage probability and bit error rate for both plane and spherical waves. It covers most of the existing models as special cases. The SIMO diversity covers two combining algorithms OC (optimal combining) and EGC (equal gain combining) for this channel model and EGC gives better performance as receiver diversity order increases [13].

Sarita,(2015),et. al. in paper **"Performance Analysis of FSO System using Nakagami- m Fading Channel"** provides the performance analysis of free space optical communication over nakagami m channel. The weak turbulence is modeled by lognormal distribution of nakagami m distribution where strong turbulence modeled by Gamma-Gamma distribution. The analysis carried out using bit error rate and outage probability and it has been noticed that as signal to noise ratio increases the bit error rate decreases [51].

Kavitha. M .R, (2016), et. al. in paper entitled **"A Gamma exponential distribution channel model for turbulence in Free Space Optical Communication"** proposed a new channel model known as Gamma-distribution model and its performance is analyzed for QAM and QPSK modulation techniques under all turbulence conditions. It has been concluded that this channel model performs better than Gamma-Gamma for all turbulent regimes [52].

Mishra. N.,(2016),et. al. in paper titled **“Outage Analysis of Relay Assisted FSO Systems over K-Distribution Turbulence Channel”** the performance of relay assisted optical wireless communication has been investigated over strong turbulence condition by considering K-distribution model. The decode and forward relaying system was employing from source to destination. It is concluded that as the relay nodes are increased the outage probability decreases and system performance improves [53].

N. A. M. Nor,,(2017),et. al. in paper entitled **“Experimental Investigation of All-Optical Relay-Assisted 10 Gbps FSO Link over the Atmospheric Turbulence Channel”** employing a triple-hop based relay FSO system with 10Gbps data rates. On the basis of relay system the bit error rate has been calculated for weak, medium and strong turbulence regime. It is concluded that as the relay nodes are increases the performance became better for all turbulence conditions [54].

CHAPTER-3

PROBLEM FORMULATION

- The major degrading factor in free space optical links is atmospheric turbulence which ranges from weak to strong regimes. To understand this degrading impact of turbulence there is need to investigate an efficient channel model which can provide accurate knowledge about the impact of atmospheric turbulences.

- The atmospheric turbulence also causes irreversible fluctuations in received signal intensity which in turn results in poor SNR at the receiver. Thus there is need to investigate means to strengthen the received signal intensity.

- The conventional optical modulation technique i.e. OOK, though simple in nature but exhibits poor channel capacity and downgraded immunity against turbulence effects. Thus the use of higher modulation technique as measure to improve link immunity against the atmospheric degradation must be investigated.

- Extremely strong turbulence conditions may negate the effect of diversity techniques. An appropriate signal collimation/combination at receiver may enhance the performance of receiver diversity, delivering reasonable SNR in conditions of strong turbulence.

- The single FSO system performance is not appropriate to cover all the advantages so there is need to increase the link distance by employing relay system with decode and forward technique.

CHAPTER 4

OBJECTIVES

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1. To study the channel characteristics and link behavior of FSO communication system under strong turbulence.

2. To investigate and propose an efficient channel modeling method that best describes various turbulence regimes ranging from weak to strong..

3. Taking cue from the success of MIMO techniques in RF communication the same will implemented in FSO links using Gamma-Gamma channel model to analyze the enhancement in link performance, if any.

4. To investigate the effect of use of higher modulation techniques in improving error performance of FSO links when coupled with spatial diversity techniques.

5. To evaluate the performance of FSO links operating under strong turbulence regime with inclusion of different diversity combinational techniques at receiver end.

6. To evaluate the performance of FSO system by employing the multi-hop system with relay technique.

CHAPTER 5

RESEARCH METHODOLOGY

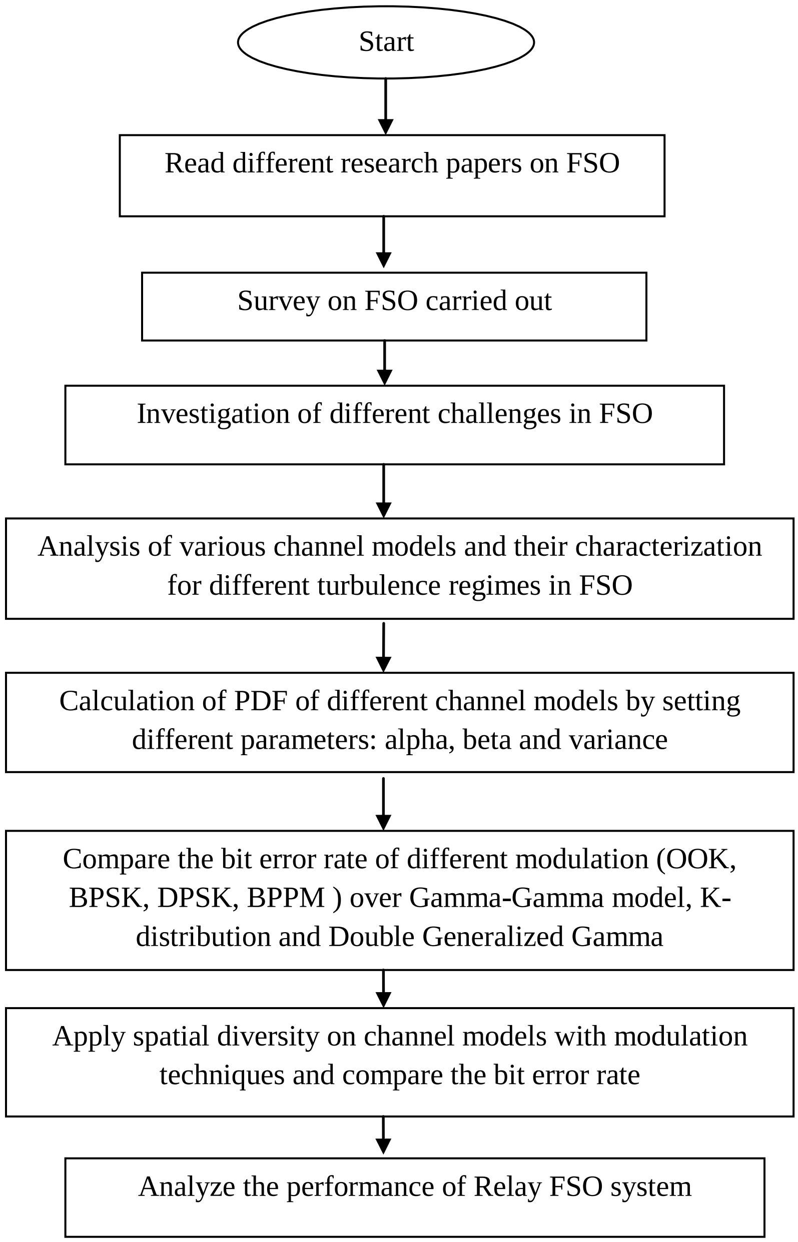


Figure 1.13 Flow chart of research methodology

The work is carried out in following phases:

Phase-I: PDF based analysis of different channel models: In this first phase the prime objective is to study the turbulence conditions for different channel models like Lognormal, Rayleigh, Rician, Negative exponential and Gamma-Gamma model. The analysis is carried out by varying the parameters: alpha, beta and variance.

Phase-II: BER analysis of different modulation technique over turbulent channel models: In this phase the bit error rate analysis using different modulation techniques over different channel models has been carried out. The bit error rate of Gamma-Gamma model using OOK, BPSK and BPPM modulation techniques are analyzed and compared with K-distribution model.

Phase-III: BER analysis of MIMO FSO system using different modulations: In this phase the configurations of spatial diversity are implemented over different channel models using OOK, BPPM, BPSK and DPSK. The combining techniques of SIMO diversity which are OC and EGC are also compared. The Double Generalized Gamma model and Gamma-Gamma model under strong turbulence with MISO and SIMO using OOK, BPSK and DPSK are compared.

CHAPTER 6

RESULT AND DISCUSSION

6.1 Comparison of different channel models in free space optical communication.

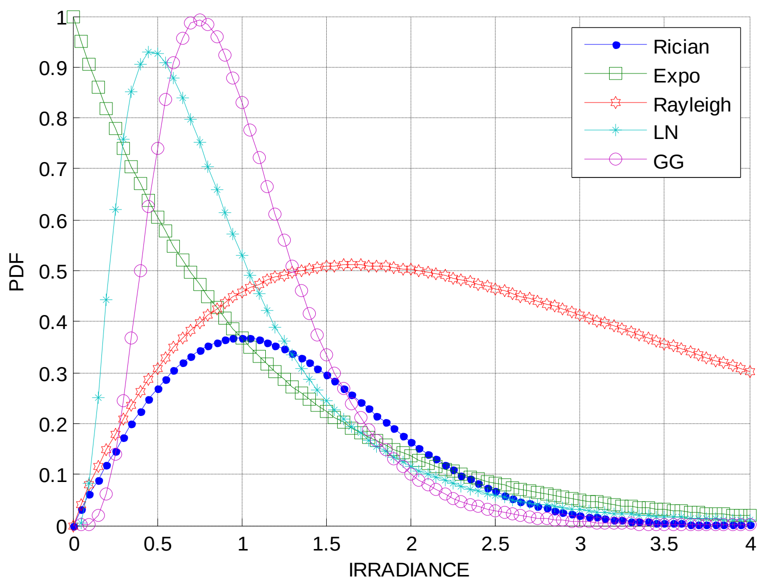


Figure 6.1 Probability density functions vs. irradiance of different channel models

The plot of figure 6.1 gives performance comparison of different channels models under turbulent atmospheric conditions. It was an obvious observation that Gamma-Gamma channel model is most appropriate model to describe fading effects and determination of irradiance PDF, irrespective of turbulence regimes. From above figure it is concluded that as irradiance increases the PDF of channel models first increases then decreases. At irradiance =1, i have calculated PDF to analyze the turbulence effect in all channel models. The PDF for Gamma-Gamma channel model at this irradiance is 0.99 where rician and negative exponential has very low value only up to 0.38 because negative exponential gives PDF value in negative region where rician has line of sight components. It concludes that the Gamma-Gamma performs better than all models and rician and negative exponential has poor performance and has very strong turbulence regimes. The table below gives a comparison of PDF at intensity =1.The Gamma-Gamma channel model has higher PDF in comparison to others and the key factors on which the turbulence depends is also included in this table.

Table 6.1 PDF based comparison of different channel models

Channel model	**Key factor**	**PDF(at intensity=1)**
Lognormal	Variance(σ^2)	0.52
Rayleigh	Variance(σ^2)	0.47
Negative exponential	Average irradiance(I_o)	0.38
Rician	k_d	0.38
Gamma-Gamma	Alpha(α),beta (β)	0.99

The table 6.1 gives the mathematical value of PDF at irradiance =1 for different models and the parameters are also defined which are used to define the turbulence for particular channel model. The Gamma-Gamma channel model gives the highest PDF value. So it is concluded that Gamma-Gamma is better than others.

6.2 Performance of SISO Gamma-Gamma model with different modulation

This graph represents the performance of Gamma-Gamma channel model with different modulation techniques in which OOK, BPPM and BPSK techniques are compared for SISO system. It is concluded that the BPSK modulation performs better than other techniques and gives low BER.

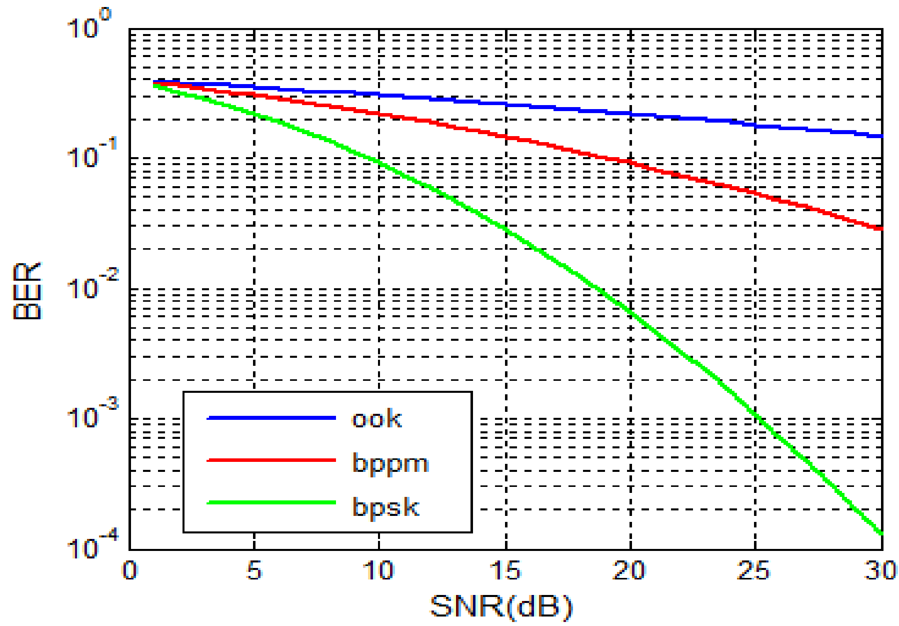


Figure 6.2 BER vs. SNR for SISO Gamma-gamma model under different modulation techniques

6.3 Performance of MIMO Gamma-Gamma model with different modulation

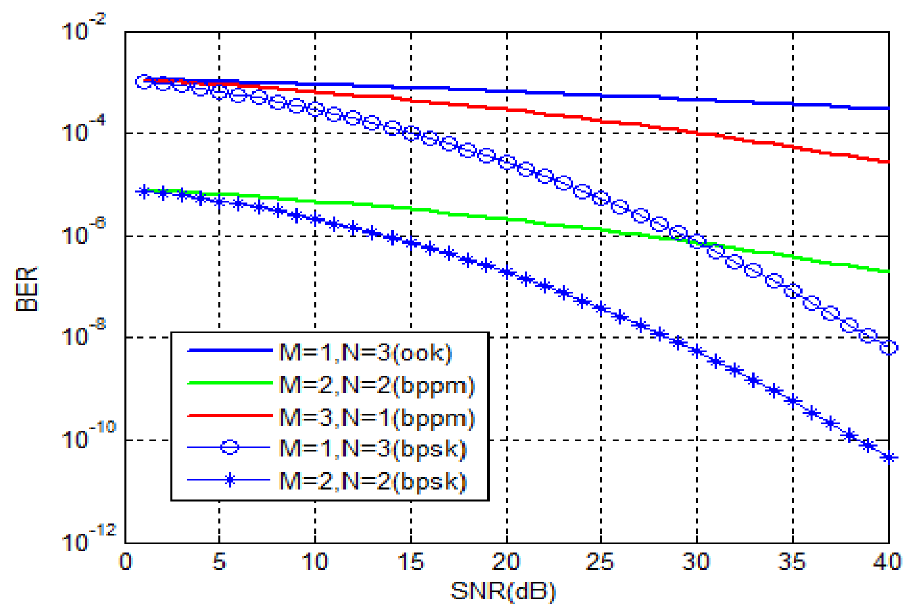


Figure 6.3 BER vs. SNR for MIMO Gamma-Gamma channel model with modulation

The figure 6.3 presents the comparison of different modulation techniques for MIMO Gamma-Gamma channel. The different diversity techniques are assumed here. The BPSK modulation with higher diversity order has better performance than all other combinations.

Table 6.2 BER comparison of MIMO Gamma-gamma for different modulation techniques

Diversity	Modulation	SNR at BER (10^{-6})
M=1,N=3	OOK	>40dB
M=2,N=2	BPPM	27dB
M=3,N=1	BPPM	>40dB
M=1,N=3	BPSK	29dB
M=2,N=2	BPSK	13dB

Table 6.3 is based on figure 6.4 and figure 6.5 in which the performance comparison for MIMO Gamma-Gamma channel under different diversity orders and modulation techniques are analyzed. In order to achieve the BER 10^{-6} the system with diversity order M=2 and N=2 under BPSK modulation requires less SNR value 13dB than other systems where for diversity order M=1 and N=3 under OOK modulation requires large SNR values more than 40dB

6.4 Comparison of Gamma-Gamma with K-distribution channel model

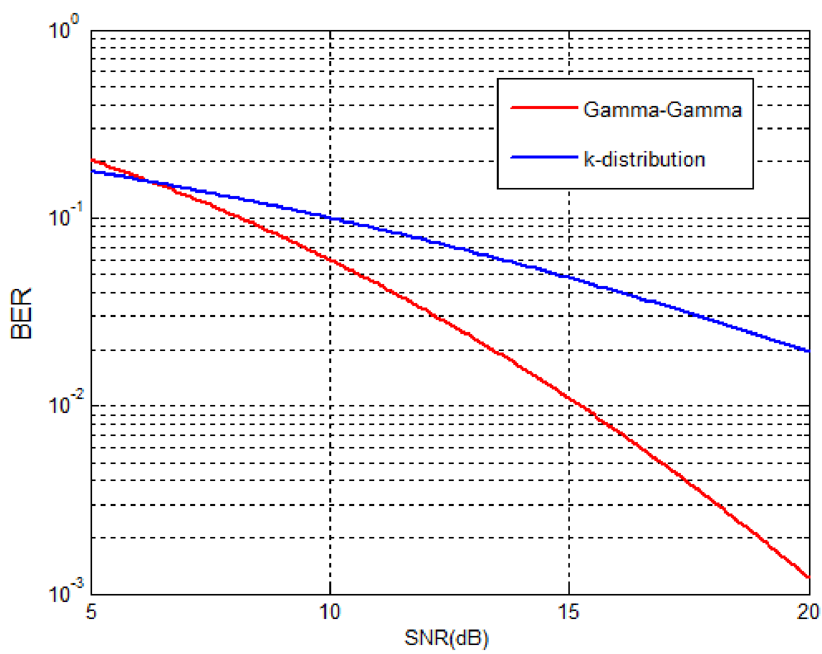


Figure 6.4 Comparison of Gamma-Gamma model with k-distribution model under BPPM modulation

Table 6.3 Performance comparison of Gamma-Gamma and K-distribution for different modulation techniques

Channel Model	**Modulation**	**SNR at BER(10^{-2})**
Gamma-Gamma	BPPM	15.1dB
	BPSK	7.2dB
K-distribution	BPPM	>20dB
	BPSK	11.3dB

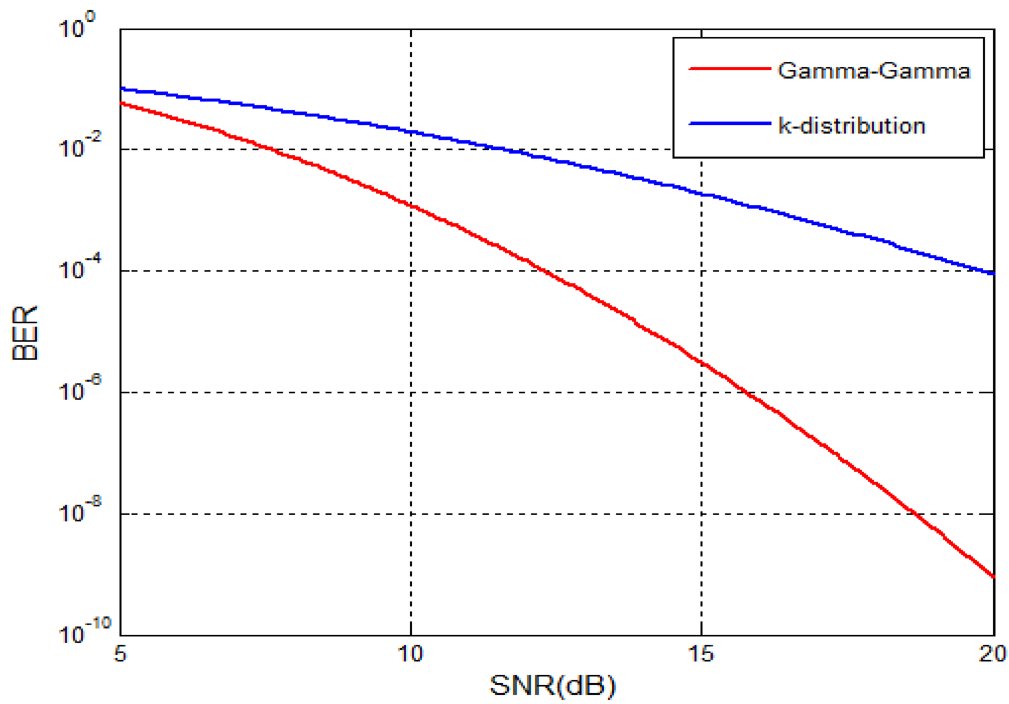


Figure 6.5 Comparison of Gamma-Gamma model with K-distribution model under BPSK modulation

In figure 6.4 the comparison of Gamma-Gamma channel model with K-distribution is presented for SISO system by considering BPPM modulation. It is concluded that Gamma-Gamma channel performs better than k-model as it is widely accepted model in literature. The figure 6.5 provides comparison between both channel models for BPSK modulation and in this the Gamma-Gamma channel model performs better. It is also analyzed that the BPSK performs better than BPPM.

6.5 Base Paper implementation

The new channel model Double generalized gamma is included in this section, as this model is declared as better than Gamma-Gamma model. The performance of this channel model is also compared with Gamma-Gamma channel model by considering both SISO and SIMO cases. The modulation technique used here is simple on-off keying. In figure 6.6 the performance of double generalized gamma channel is analyzed for SISO and SIMO system and it is concluded that as the diversity order increases the BER performance became better.

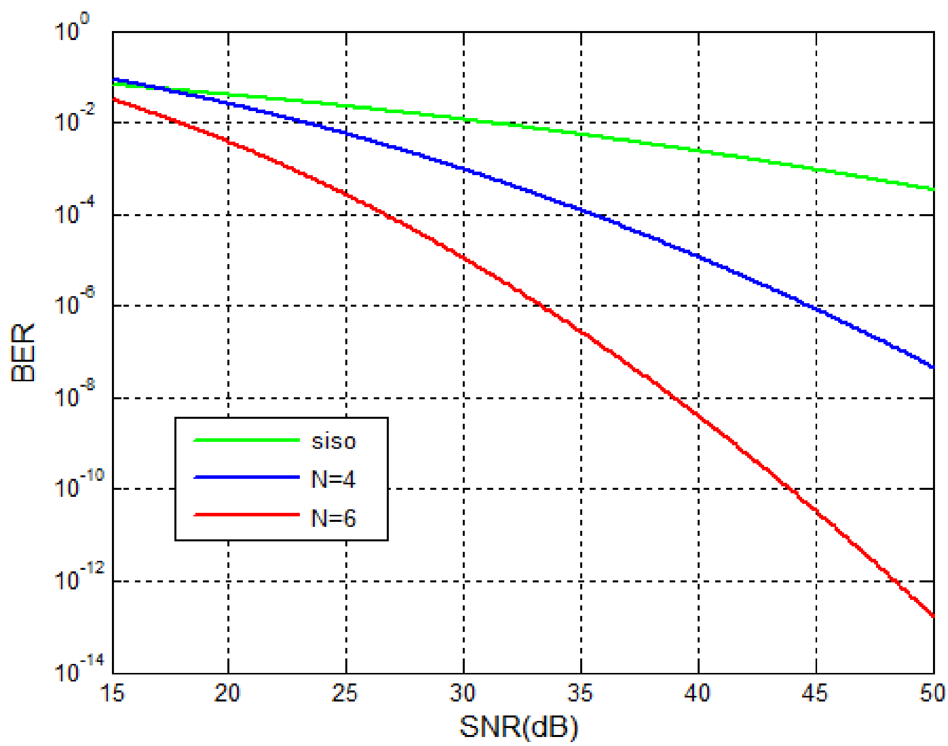


Figure 6.6 Performance of Double Generalized Gamma channel in SISO and SIMO diversity

The figure 6.7 gives the comparison of EGC (equal gain combining) and MRC (maximum ratio combining) receiver diversity techniques by considering SIMO (1X3) system over Double Generalized Gamma model under strong turbulence regime and it is concluded that the performance of MRC technique is better than EGC.

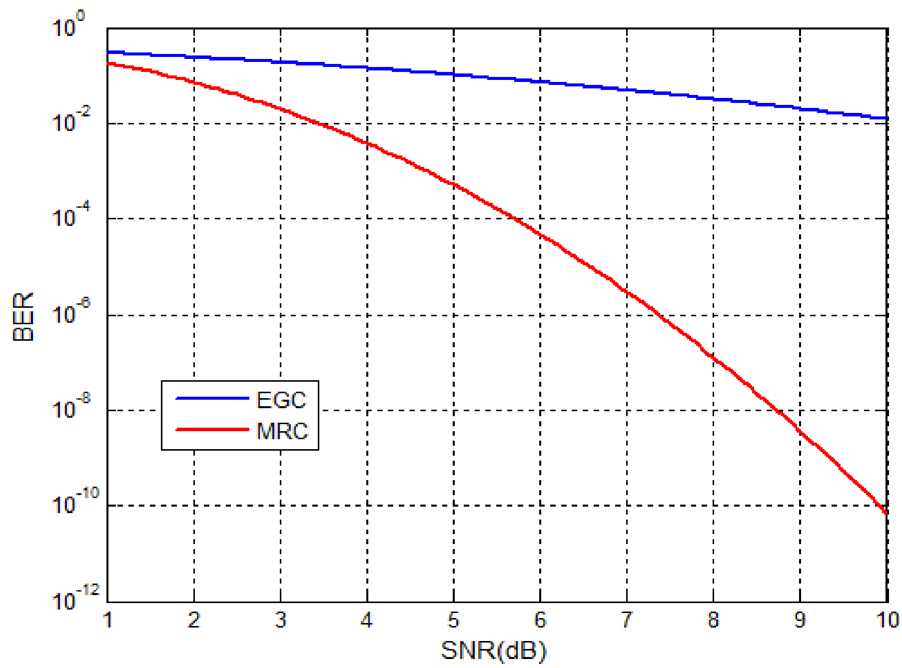


Figure 6.7 Comparison of EGC and MRC over SIMO Double Generalized Gamma channel

6.6 Base Paper extension

Based on error channel model analysis for different modulation techniques presented in previous [13], the numerical results obtained from these mathematical models have been presented in this section. For uncovering the behavior of FSO links over turbulent atmospheric conditions, Gamma-Gamma and Double Generalized Gamma channel model have considered as standard channel with both of them being tested for strong turbulence regimes only. The performance analysis of using spatial diversity techniques along with gain combining techniques like OC and EGC has also been carried out in this section using following set parameters:

Case a: Plane wave and strong irradiance fluctuation over Double Generalized Gamma with $\gamma_1 = 1.8$, $\gamma_2 = 0.75$, $m_1 = 0.5$, $m_2 = 1.8$, $\Omega_1 = 1.5$ and $\Omega_2 = 0.92$ with SIMO (OC) diversity

***Case b*:** Plane wave and strong irradiance fluctuation over Gamma- Gamma with $\alpha = 4.5$ and $\beta = 1.5$ with SIMO (OC) diversity.

Case c: Plane wave and strong irradiance fluctuation over Double Generalized Gamma with $\gamma_1 = 1.8$, $\gamma_2 = 0.75$, $m_1 = 0.5$, $m_2 = 1.8$, $\Omega_1 = 1.5$ and $\Omega_2 = 0.92$ with SIMO (EGC) diversity.

Case d: Plane wave and strong irradiance fluctuation over Gamma- Gamma with α = 4.5 and β = 1.5 with SIMO (EGC).

Case e: Plane wave and strong irradiance fluctuation over Double Generalized Gamma with γ_1 =1.8, γ_2 = 0.75, m_1 = 0.5, m_2 = 1.8, Ω_1 = 1.5 and Ω_2 = 0.92 with MISO.

Case f: Plane wave and strong irradiance fluctuation over Gamma- Gamma with α = 4.5 and β = 1.5 with MISO.

The Figure 6.8 represents BER performance of FSO link with different order of receiver diversity. It can be seen that BPSK modulated FSO link performs far better than either of two modulation techniques i.e. DPSK and OOK for all forms of diversity orders, be it *N=2 or N=3*.The analysis in Figure 6.8 also shows that as the order of diversity increases from *N=2* to *N=3* the BER performance across all sets of modulation improves. This claim can be supported by considering 25dB received signal SNR as benchmark for comparison. For this value of SNR and receiver diversity order of 3, we witness that the BER of order 10^{-11} can be achieved for BPSK FSO links whereas for DPSK and OOK links BER is limited to 10^{-5} and 10^{-8} respectively. It is worth full to mention here that figure corresponds to SIMO FSO links aided with optimal combining (OC) technique used at receiver for signal addition with Double Generalized Gamma channel model.

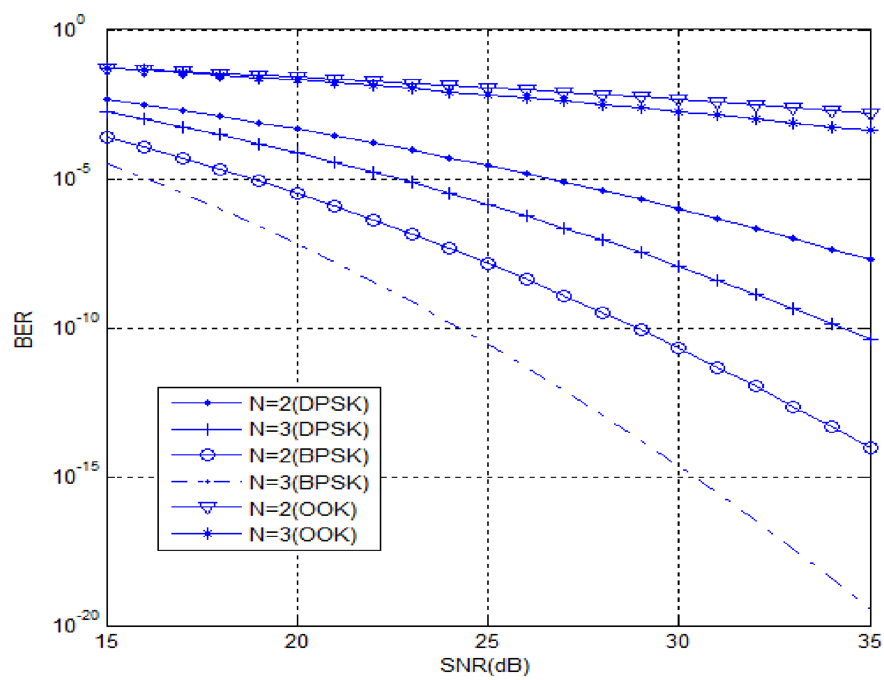


Figure 6.8 Comparison of average BER for SIMO OC as defined in case a for strong turbulence

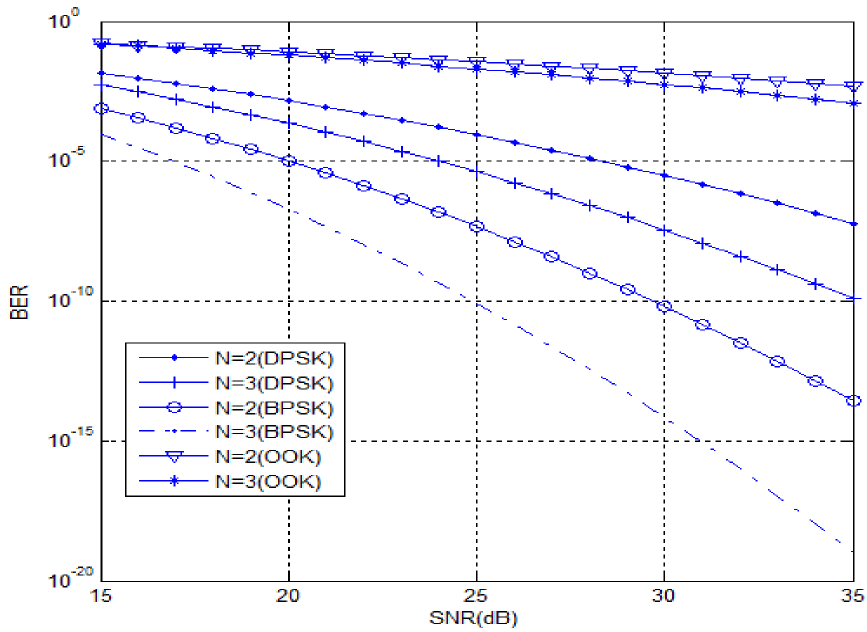


Figure 6.9 Comparison of average BER for SIMO OC as defined in case b for strong turbulence

Similarly comparative analysis of FSO links using SIMO-OC technique for Gamma-Gamma channel (strong turbulence) have been presented in Figure 6.9. As seen in analysis of *case a*, the BER performance for BPSK modulated FSO links with receiver diversity order N=3 performs way better than DPSK and OOK modulated FSO links of similar diversity order by factor 10^{-5} and 10^{-9} respectively when measured at 25dB of SNR. To make the vis-à-vis analysis more lucid, Table 6.4 presents comparison as seen from analysis of Figure 6.8 and Figure 6.9.

Table 6.4 Comparison of Double Generalized Gamma and Gamma-Gamma for SIMO OC diversity

Modulation	**Diversity order**	**BER at SNR=25dB**	
		D-GG	**G-G**
OOK	N=2	$1.1 x 10^{-2}$	$3.6 x 10^{-2}$
	N=3	$6.6 x 10^{-3}$	$2.0 x 10^{-2}$
DPSK	N=2	$2.7 x 10^{-5}$	$8.8 x 10^{-5}$
	N=3	$1.3 x 10^{-6}$	$4.1 x 10^{-6}$
BPSK	N=2	$1.4 x 10^{-8}$	$4.4 x 10^{-8}$
	N=3	$2.7 x 10^{-11}$	$8.3 x 10^{-11}$

The table 6.4 illustrates the comparative values of BER for different modulation techniques when measured taking received signal SNR of 25dB as reference for SIMO (OC) diversity scheme. It shows that BPSK modulation outperforms OOK and DPSK modulated FSO links for both diversity orders (N=2 and N=3).

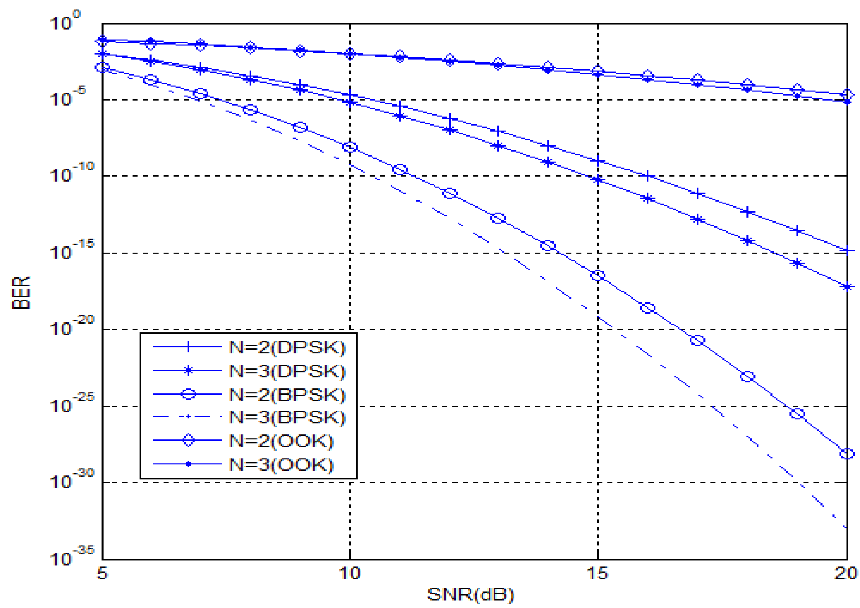


Figure 6.10 Comparison of average BER for SIMO EGC as defined in case c for strong turbulence

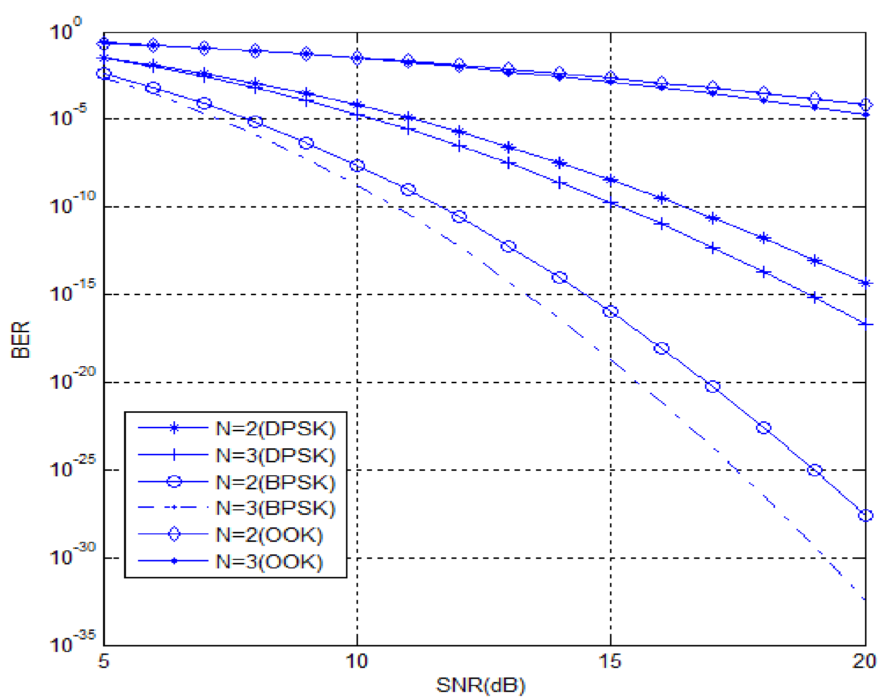


Figure 6.11 Comparison of average BER for SIMO EGC as defined in case d for strong turbulence

The link performances for SIMO (EGC) diversity for different orders of receiver in conjunction with parameters listed in *case c and d*, are illustrated using Figure 6.10 and 6.11 respectively. The previous trends make their mark in these cases as well and this can be seem from the fact that for reference SNR of 15dB, BPSK (N=3) delivers BER of 10^{-20} which is way better than DPSK and OOK modulated FSO links by factor 10^{-9} and 10^{-16} respectively, while assuming Double Generalized Gamma link model. The similar observations can also be made from Table 6.5 for Gamma-Gamma FSO link as well.

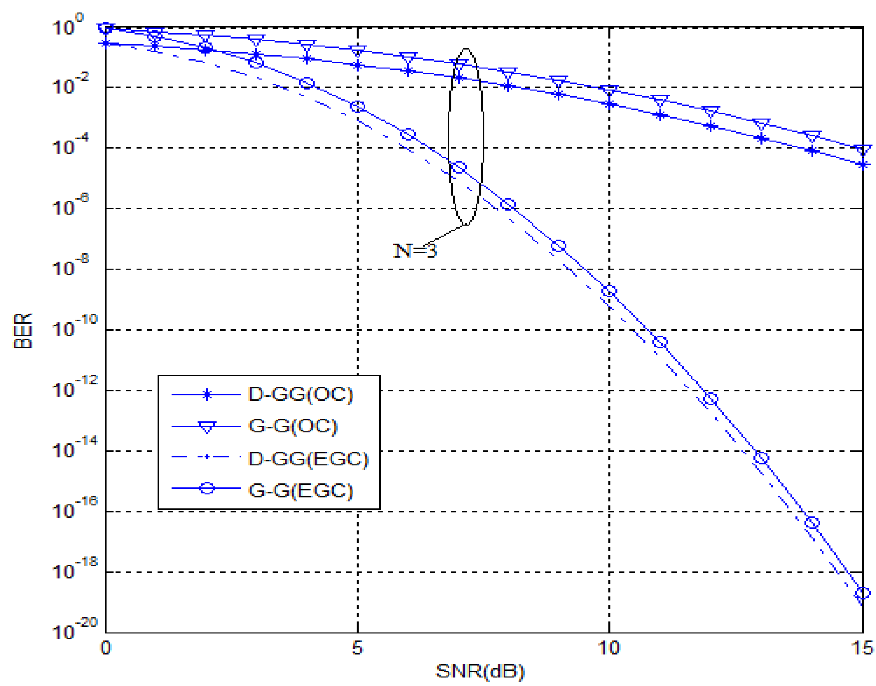


Figure 6.12 Comparison of BER for SIMO (OC) and SIMO (EGC) for BPSK for N=3 order as defined in case a, b, c and d for strong turbulence

The cumulative comparison and analysis of all four *cases a, b, c and d* are shown in Figure 6.12, for following set of assumptions: receiver diversity of order 3 (N=3), modulation scheme: BPSK and Double Generalized Gamma and Gamma-Gamma channel models. It can be distinctly noticed that the error performance case c i.e. D-GG SIMO (EGC) link delivers most reliable performance among all other cases that were analyzed here. For e.g. at received SNR of 15dB, the BER for EGC based SIMO system is way better than OC based SIMO by least margin of 10^{-8} . Figure 6.13 illustrates the BER performance of FSO link by with transmitter diversity (MISO) of order 2 and 3 (M=2, 3) as defined in case e. At SNR 10dB the BER for BPSK is better than DPSK and OOK by factor 10^{-9} and 10^{-16} respectively.

Table 6.5 Comparison of Double Generalized Gamma and Gamma-Gamma for SIMO EGC diversity

Modulation	Diversity order for SIMO	BER At SNR =15dB	
		D-GG	G-G
OOK	1x2	$7.1\text{x}10^{-4}$	$2.3\text{x}10^{-3}$
	1x3	$4.3\text{x}10^{-4}$	$1.3\text{x}10^{-3}$
DPSK	1x2	$1.0\text{x}10^{-9}$	$3.4\text{x}10^{-9}$
	1x3	$5.8\text{x}10^{-11}$	$1.7\text{x}10^{-10}$
BPSK	1x2	$3.1\text{x}10^{-17}$	$1.0\text{x}10^{-16}$
	1x3	$6.7\text{x}10^{-20}$	$2.0\text{x}10^{-19}$

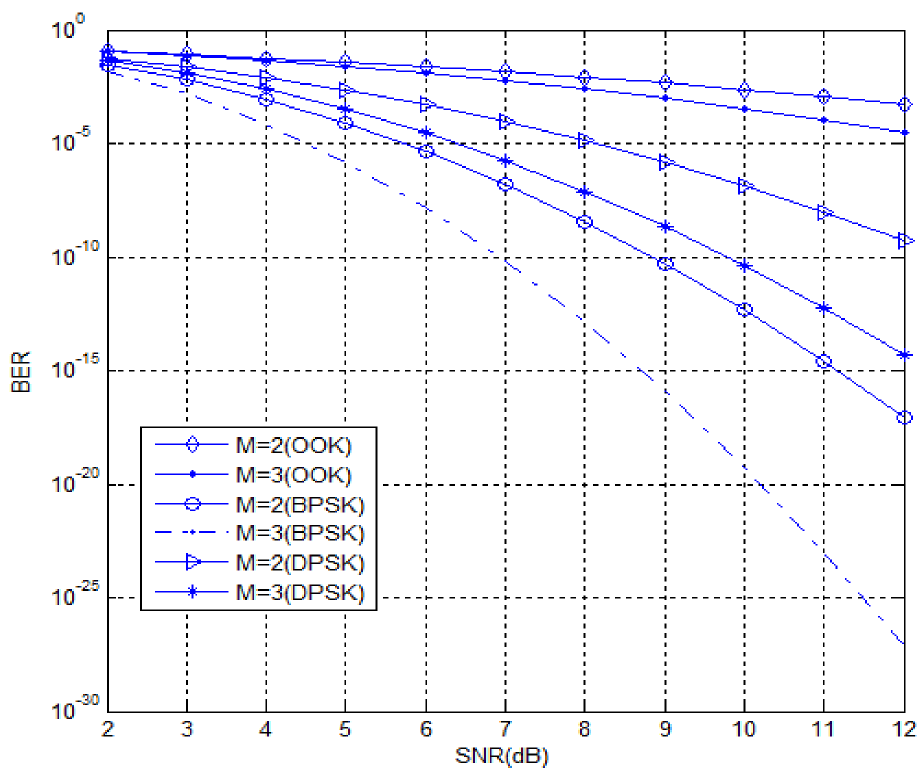


Figure 6.13 Comparison of average BER of MISO as defined in case e for strong turbulence

Figure 6.14, represents BER vs. SNR characteristics for FSO link as per factors listed in *case f* with MISO diversity order of 2 and 3. The BPSK with M=3 has BER 10^{-19} while for DPSK and OOK it is 10^{-10} and 10^{-4} respectively, which shows that BPSK is better performer.

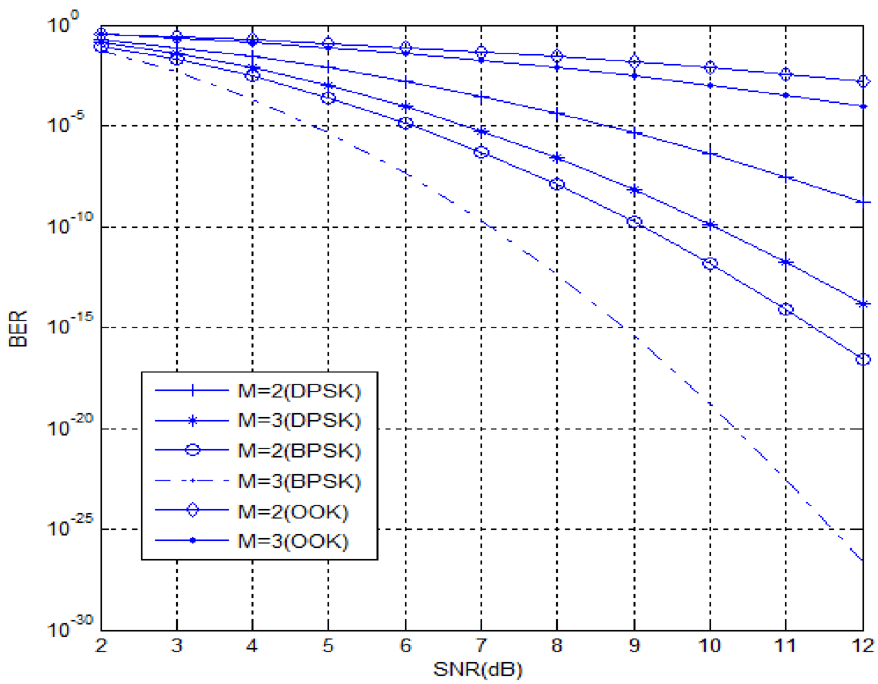


Figure 6.14 Comparison of BER of MISO as defined in case f for strong turbulence

Table 6.6 Comparison of Double Generalized Gamma and Gamma-Gamma for MISO diversity

Modulation	**Diversity order for MISO**	**BER At SNR=10dB**	
		D-GG	**G-G**
OOK	2x1	2.4×10^{-3}	7.3×10^{-3}
	3x1	3.2×10^{-4}	9.9×10^{-4}
DPSK	2x1	1.3×10^{-7}	4.0×10^{-7}
	3x1	4.3×10^{-11}	1.3×10^{-10}
BPSK	2x1	4.5×10^{-13}	1.4×10^{-12}
	3x1	5.0×10^{-20}	1.5×10^{-19}

The comparison of case e and case f for MISO (M=3) by considering BPSK modulation is presented in Figure 6.15. At SNR 10dB it is observed that Double Generalized Gamma model is better performer than Gamma-Gamma model by factor 10^{-1}.

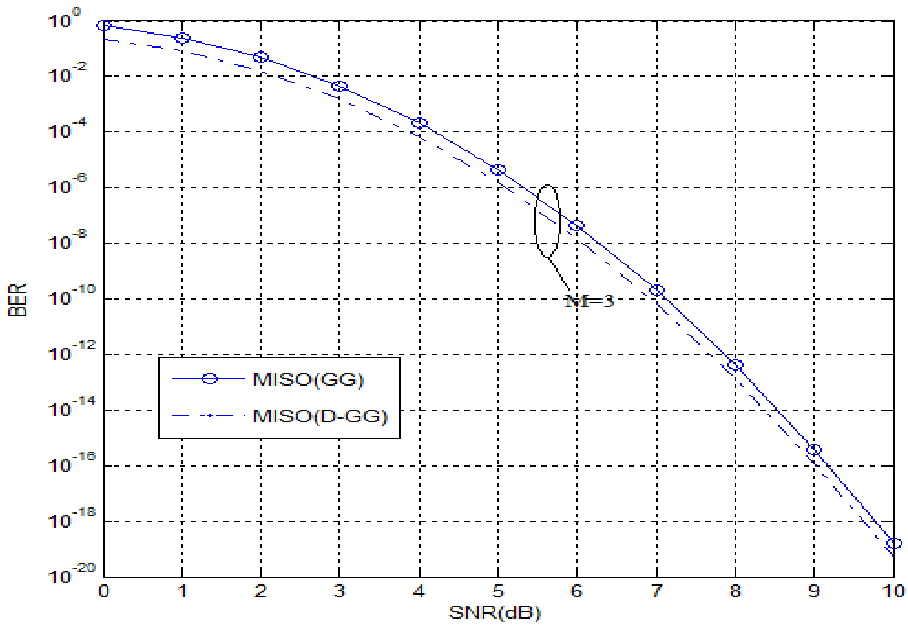


Figure 6.15 Comparison of BER of MISO (M=3) for BPSK modulation as defined in case e and f for strong turbulence

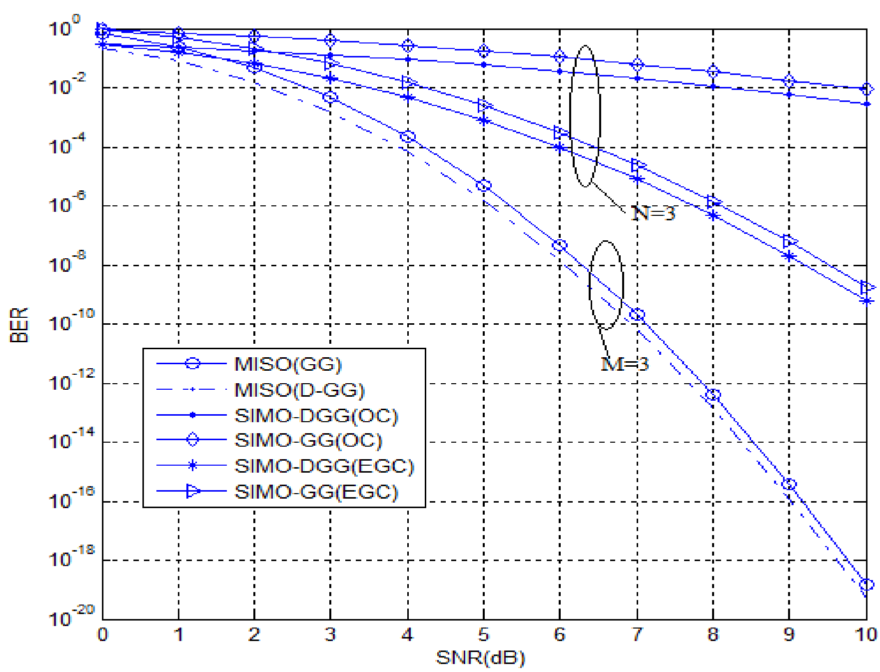


Figure 6.16 Comparison of BER of MISO (M=3), SIMO (N=3) with BPSK modulation as defined in cases a, b, c, d, e, f for strong turbulence

As from Figure 6.16 it has been observed that at SNR 10dB the BER for MISO (M=3) for case e is 10^{-20} where for SIMO (OC) and SIMO (EGC) for order N=3 it is 10^{-3} and 10^{-10} for cases a and c. From these results it has been shown that the MISO performs better than SIMO (OC and EGC) with Double Generalized Gamma model.

The comparison of SIMO OC, SIMO EGC and MISO diversity with BPSK modulation for Gamma-Gamma and Double Generalized Gamma has been shown in Figure 6.16. The analysis shows that the MISO performs better than SIMO for Double Generalized Gamma than for Gamma-Gamma channel model.

6.7 Relay assisted FSO

The performance of relay FSO for up to three nodes is analyzed with respect to link distance. The BER decreases as the link distance increases with respect to relay nodes.

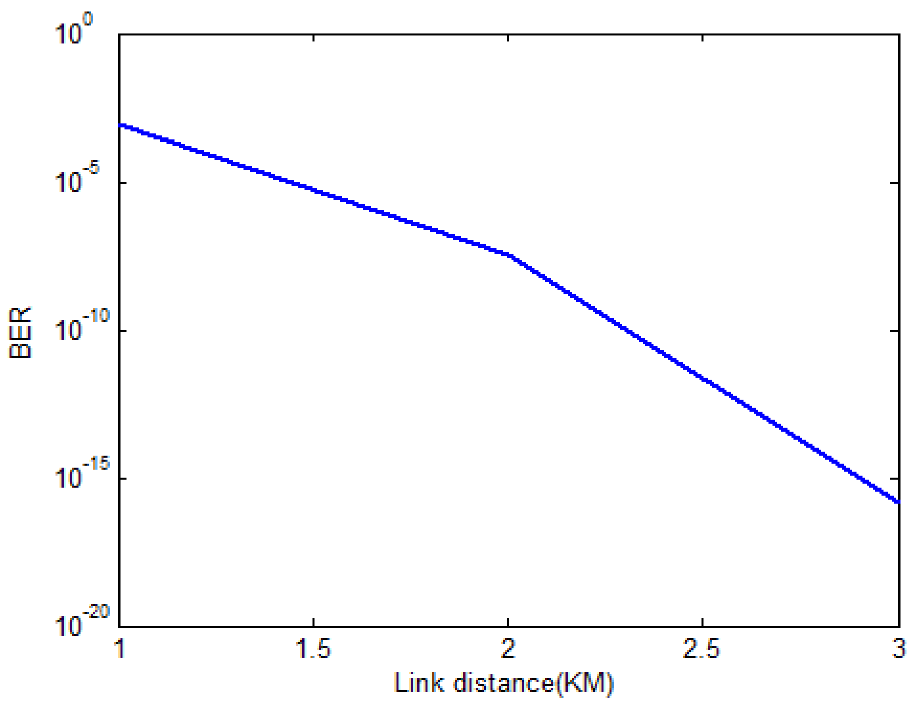
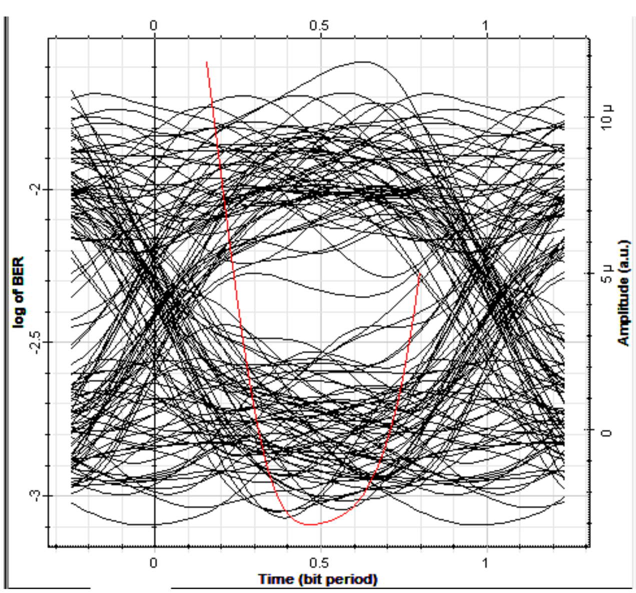


Figure 6.17 BER vs. link distance of relay FSO

The BER at relay first node1 is 10^{-4} , at second node BER is 10^{-8} and at third relay node the BER is 10^{-16}.It improved by margin of 10^{-20} at link distance 3km.



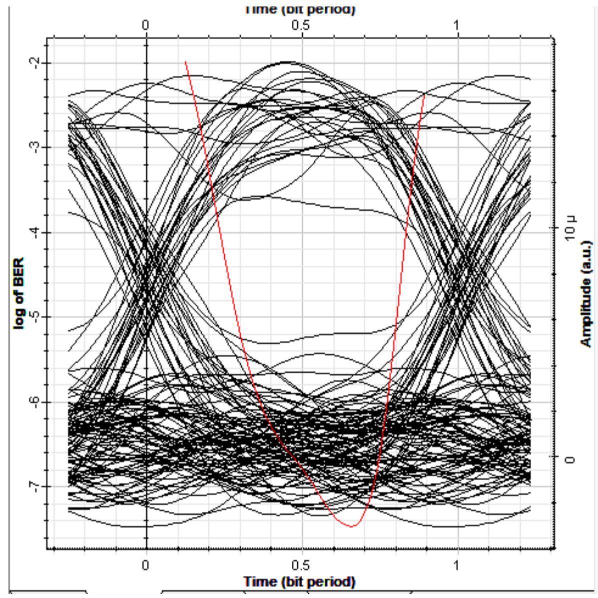


Figure 6.18 Performance at relay node 1

Figure 6.19 Performance at relay node 2

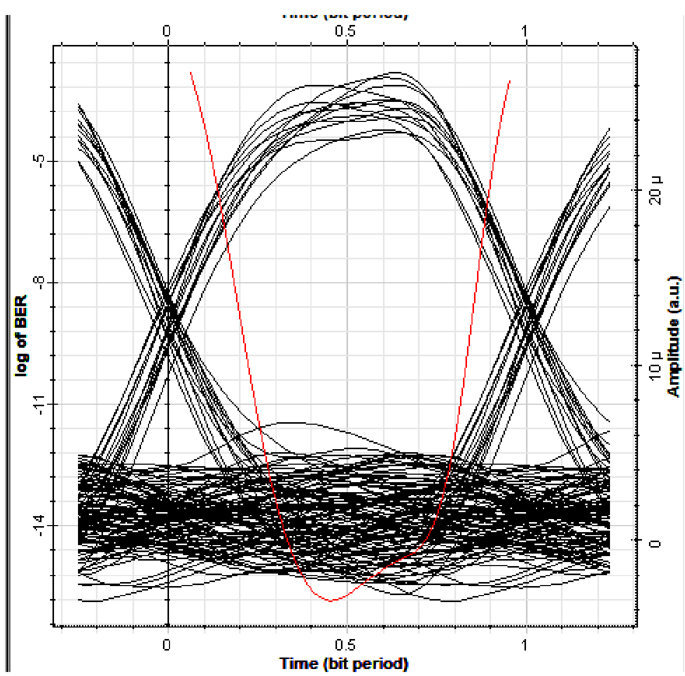


Figure 6.20 Performance at relay node 3

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

The free space optical communication has supreme properties over RF communication but atmospheric turbulence is a major performance degrading factor in FSO. To define the extent of turbulence in a particular FSO link various models have been proposed.

To analyze the turbulence condition for different channel models the PDF with respect to irradiance have plotted for all channel models and concluded that the Gamma-Gamma model has better PDF of received irradiance as compared to other channel, as at irradiance=1 it give PDF= 0.99 which is higher than the PDF of other channel models. However the later investigation revealed that Double Generalized Gamma model provides excellent approximation of received signal intensity under strong turbulence conditions.

The performance of Gamma-Gamma model is further analyzed with different modulation techniques and MIMO system where BPSK with M=2, N=2 diversity order has high BER as compared to other modulation techniques and diversity orders. The comparative analysis of Gamma-Gamma and K-distribution channel shows that Gamma-Gamma performance better than K-distribution.

The extension of base paper over Double Generalized Gamma model is then analyzed over strong turbulence and following conclusions can be deduced::

(a) The use of spatial diversity helps to improve the performance of SISO FSO links with margin of 10^{-3} when implemented for SIMO (N=6) and also improved the performance of EGC combining technique by margin of 10^{-8} when implemented with MRC.

(b) The performance of Double Generalized Gamma and Gamma-Gamma was analyzed over strong turbulence with modulations OOK, BPSK and DPSK for SIMO (OC) and SIMO(EGC) and it was observed that BPSK modulated Double Generalized Gamma modeled FSO link when implemented with SIMO (N=3) EGC techniques gives the better performance than all other combinations of channel model and modulation technique.

(c)The transmit diversity (MISO) was analyzed over Double Generalized Gamma and Gamma-Gamma model and it is concluded that MISO outperforms the SIMO (EGC) by BER margin of 10^{-10} when evaluated at received SNR of 10dB. It is also analyzed that MISO over Double Generalized Gamma again performs better than MISO over Gamma-Gamma model.

The FSO system performance is further analyzed by using relay assisted system employing decode and forward technique. It is concluded that as relay nodes are increases the link distance increases and the performance improves with margin of 10^{-12} from relay node 1 to relay node 3.

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APPENDIX 1
PROPOSED WORK PLAN WITH TIME LINE

Timeline defines the work in week-wise manner which means that in which week what type of work has been completed. The timeline is followed as:

Week ► Month ▼	Week 1	Week 2	Week 3	Week 4
January-17	Survey on diversity and modulation techniques	Survey on diversity and modulation techniques	Implementation of spatial diversity techniques over Double Generalized Gamma and Gamma-Gamma model	Implementation of spatial diversity techniques over Double Generalized Gamma and Gamma-Gamma model
February-17	Implementation of modulation techniques	Implementation of modulation techniques	Familiarization with relay FSO and its implementation on opti wave software	Familiarization with relay FSO and its implementation on opti wave software
March-17	Investigation of FSO links operating under relay mode	Investigation of FSO links operating under relay mode	Simulation and result compilation	Simulation and result compilation
April-17	Writing paper on Double Generalized Gamma with	Writing paper on Double Generalized Gamma with	Report writing	Report writing

	spatial diversity	spatial diversity		

APPENDIX 2

AUTOBIOGRAPHY

Kulvir Kaur is currently pursuing M. Tech in Electronics and Communication Engineering from Lovely Professional University, Phagwara with communication as specialization. Areas of interest include, Free space optical communication. She is pursuing thesis on MIMO Free space channel models with modulation. She has following publications related to free space optical communication:

Published papers

1.**Kaur K**., Miglani R., Gaba G.S., "Communication Theory Review Perspective on Channel Modeling, Modulation And Mitigation Techniques In Free Space Optical Communication" in International Journal of Control Theory and Applications, vol. 09, no. 11, pp. 4969-4978, 2016. Presented in conference Shannon100 organized by Lovely Professional University.

2.**Kulvir Kaur**, Rajan Miglani, Jagjit Singh Malhotra, "Gamma-Gamma channel model-A survey" presented in ICICS2016 organized by Lovely Professional University.

Communicated papers

1.**Kulvir Kaur**, Rajan Miglani, Jagjit Singh Malhotra, "Performance Analyses of MIMO Gamma-Gamma and K-distribution channel model with Different Modulation Techniques" in Pertanika journal of science and technology(JST).

2.**Kulvir Kaur**, Rajan Miglani, Jagjit Singh Malhotra, "Performance Analysis of FSO links over Double Generalized Gamma Channel using Spatial" in journal of optics.