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Error Analysis in Free Space Optical Communication System over different Atmospheric Turbulence Channel

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Abstract: The bit-error rate (BER) performance of intensity modulated with direct Detection (IM/DD) in free space optical (FSO) system by using the on-off keying (OOK) and avalanche photodiode (APD) receiver is analyzed. The intensity fluctuations of the received optical signal are modelled by gamma-gamma distribution for strong atmospheric turbulence and Log Normal distribution for weak atmospheric turbulence channel. The BER expression is theoretically derived simulation through MATLAB programming and numerical results are presented in the figures and tables. The results illustrate the bit error rate depend on the turbulence strength and signal-to-noise ratio, in comparison with the weak atmospheric turbulence and strong turbulence, the signal in the weak turbulence shows a better performance as compared to the strong atmospheric turbulence. Numerically, the average BER for 10dB signal to noise ratio is of the order of 10^{-9} as compared with the strong turbulence channel provides BER as 10^{-6}. The factors that affects the signals at receiver and increases the signal-to-noise ratio are C_n^2, refractive index structure constant depend totally on atmospheric turbulence strength and Rytov Variance δ^2, for weak turbulence is less as compare to the strong turbulence channel.

Keywords: Bit-Error Rate, Free Space Optical, On – Off Keying, Matlab , Atmospheric Turbulence.

I. INTRODUCTION

Free-space optical communication (FSO) systems (inside and in space and the atmosphere) was developed in response to the growing need for high-speed and tap-proof communication systems. Links similar to satellites, deep-space probes, ground stations, high altitude platforms (HAPs), in aircraft, unmanned aerial vehicles (UAVs), and other nomadic communication partners are of practical interest. Moreover, all links can be used in both military and civilian contexts. FSO is the next generation for net-centric connectivity, as bandwidth, spectrum and security issues favour its adoption as an adjunct to radio frequency (RF) communications. Applications range from short-range wireless communication links providing network access to portable computers network, to a last-mile links proving paths to gaps between existing fiber optic communications and backbones end users, and even laser communications in free-space links.

A. Overview of Free Space Optical Communication

Optical wireless communication is also known as wireless infrared communication, while outdoor optical communication without using is commonly known as free space optical propagation. In applying wireless infrared communication, non-direct links, which do not require precise alignment between transmitter and receiver, is necessary.

They can be classified as line-of-sight (LOS) or diffuse links. Line of sight links require a direct path for reliable communication, whereas diffuse links depends on multiple optical paths from surface reflections. On the other hand, FSO communication system involves directed Line of sight and point-to-point laser links from source to its destination through the atmosphere. FSO communication over few kilometer distances that has been demonstrated at multi-Giga bit per second data rates [3].

FSO technology provides the potential of broadband propagation capacity using unlicensed optical wavelengths. However, in-homogeneities in the pressure and the temperature of the atmosphere result into refractive index variations along the communication path. These refractive index variations lead to spatial and temporal variations in optical intensity incident at the receiver, resulted in turbulence.

In FSO communication, faded links caused due to atmospheric effects can cause performance degradation manifested by increased in transmission delays and bit error rate (BER).

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B. Background

During the past six years, the commercial use of free space optical system has grown exponentially because the technology provides the potential to connect at extremely high bandwidths (0.1-1Gbit/s or more) the millions of Internet telecom users existing within the "last mile," the term used to describe the bottleneck restricting high speed links into the office and home. Although cable (coax) Television lines offer 1 Gbit/s Internet capability, this bandwidth must be shared among different users and channels within a region, or hub. The recently introduced RF wireless 802.11b house routers have the capability to link office and home with computers wirelessly to a same hub at bandwidths of 11 Mbit/s, but their capacity can become crowded when many computers are being used at the specific time, for example, in a college library .

C. Motivation

A major advantage of free space optics over Radio Frequency (RF) is that no Federal Communications Commission (FCC) licensing or single frequency allocating is required. This is because frequencies ranging 100 THz (less than 1 mm in wavelength) are unregulated. In some urban areas or near airports region it is very difficult and costly to obtain frequency allocation for range 300GHTz (microwave transmission). In addition, the potential customer base is not restricted to frequency license holders. Free space optical links has greatest advantages in their low cost per bit and time to market. In most cases, FSO is an attractive alternative to the prohibitive cost of digging the streets to lay fiber, the logistical complexity for obtaining right-of-way licences, or the re-current costs of leasing optical fiber lines. Radio frequency (RF) has data rate much farther than FSO, but it has a limitation in its bandwidth to only 622 Mb/s. Available FSO systems offers a bandwidth of up to 2.7 Gb/s to 10 Gb/s and has been successfully tested in laboratories; has speed in Terabit range. Commercial Free space optical systems use the intensity-modulation with direct detection (IM/DD) and the on-off keying (OOK) scheme as it is the simplest model for implementation and design. In addition, the potential customer base is not prohibited to frequency license holders. Free space optical links advantages are their low cost per bit and time to market. In several cases, FSO is an attractive alternative to the prohibitive cost of digging the streets to lay fiber, the logistical complexity of obtaining right-of-way licensing, or the recurrent costs of leasing optical fiber lines.

D. Objective

The main objective of this dissertation is to analyse the bit error rate in free space optical system over different atmospheric turbulence channel, specifically the analysis of the bit error rate with the change in average signal-to-noise ratio SNR (dB). Although Free Space Optics (FSO) has received a great deal of attention recently both in the military and civilian information society because of its potentially high capability, quickly deployable, portability and high security from deception and jamming. Optical free-space communication system is intended for sort-range communication 1 km (in a clear weather). Field tests were made to investigate availability and error performance under the influence of different atmospheric weather conditions. Atmospheric impact due to turbulence related effects have been studied in detail. The main advantage of an all-optical design, compared to commercially available electro-optical FSO-systems, is the potentially lower cost.

II. LITERATURE REVIEW

X. Zhu et.al (Aug. 2003) "Performance bounds for coded free-space optical communications through atmospheric turbulence channels"[5], described that Error-control codes can help to mitigate atmospheric turbulence-induced signal fading in free-space optical communication links using intensity modulation/direct detection (IM/DD). Error performance bound analysis can yield simple analytical upper bounds or approximations to the bit-error probability. We first derive an upper bound on the pair wise codeword-error probability for transmission through channels with correlated turbulence-induced fading, which involves complicated multidimensional integration. To simplify the computations, they derive an approximate upper bound under the assumption of weak turbulence. The accuracy of this approximation under weak turbulence is verified by numerical simulation.

A. K. Majumdar et.al (Oct. 2005) "Free-space laser communication performance in the atmospheric channel" [6], described the major limitation of free-space laser communication (laser com) performance is due to the atmosphere, because a portion of the atmospheric path always includes turbulence and multiple scattering effects. Starting from a fundamental understanding of the laser communications system under diverse weather conditions, this chapter provides a comprehensive treatment of the evaluation of parameters needed for analyzing system performance. The significance of higher-order statistics of probability density functions of irradiance fluctuations due to turbulence to performance analysis is explained. Starting from link analysis, the necessary expressions relating link margin, bit-error-rate, signal-to-noise-ratio, and probability of fade statistics are presented. Results for laboratory-simulated atmospheric turbulence and multiple scattering are presented.

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M. Karimi et.al (Jan. 2011) "Free space optical communications via optical amplify-and-forward relaying" [7], described the Fading and path loss is the major challenges in practical deployment of free space optical communication systems. In this paper, a cooperative free space communication via an optical amplify-and-forward relay is considered to deal with these challenges. They use photon counting approach to investigate the system bit error probability (BEP) performance and study the effects of atmospheric turbulence, background light, amplified spontaneous emission, and receiver thermal noise on the system performance. They compare the results with those of the multiple-transmitter (MT) system. The results indicate that the performance of the relay-assisted system is much better than that of the MT system in different cases considered.

Manav R. Bhatnagar (May 2012), "Performance analysis of Decode and Forward Relaying in Gamma- Gamma Fading Channels" [8], he described decode-and-forward (DF) based free space optical (FSO) cooperative communication system over Gamma-Gamma fading channels. He analyzed performance of the DF protocol in the FSO links following the Gamma- Gamma distribution. The cumulative distribution function (CDF) and probability density function of a random variable containing mixture of the Gamma-Gamma and Gaussian random variables is derived. By using the derived CDF and PDF, average bit error rate of the DF relaying is obtained.

Milica I. Petkovic, et.al (Feb 2014), "BER Analysis of IM/DD FSO System with APD Receiver Over Gamma-Gamma Turbulence" [9], they investigate that the bit-error rate (BER) performance of intensity modulated with direct detection (IM/DD) free space optical (FSO) system using the on-off keying (OOK) and avalanche photodiode (APD) receiver is analyzed. The intensity fluctuations of the received optical signal are modeled by gamma gamma distribution, while both zero and nonzero inner scale models are observed. The total receiver noise includes APD shot noise and thermal noise. The BER expression is theoretically derived and numerical results are presented. The results illustrate the BER dependence on the turbulence strength, propagation path length, and APD gain and noise temperature.

III. FREE SPACE OPTICAL SYSTEM DESIGN AND MODULATION TECHNIQUES

The modulation of the source information onto the electromagnetic wave carrier generally takes place in three different techniques: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), each of which can be theoretically implemented at different range of frequency. For an optical signal, another modulation technique is also often used is called as intensity modulation (IM). Intensity is defined as flow energy per unit area per unit time and is proportional to the square of the field's amplitude.

A. Free Space Optical Communication Systems

The major subsystems in free space optical communication system. A source generating data input is to be transmitted to a remote destination. The source has its output modulated onto an optical carrier frequency; typically laser, which is then transmitted as an optical field through the communication channel. The important aspects of the free space optical transmission system are size, beam quality and, power which determine minimum divergence and laser intensity obtainable from the system. The field is optically collected and detected at the receiver, generally in the presence of noise, signal interference, and background radiation. At the receiver, important characteristics are the aperture size, which determine the amount of the collected light and the detector field-of-view (FOV) . There are two basic forms of optical receivers: non-coherent receivers and coherent receivers. Non-coherent receivers can detect the instantaneous power of the collected optical field directly as it arrives at the receivers, thus they are called direct or power detection receivers. These receivers represent the simple implementation and installation that can be used whenever the transmitted information occurs in the power variation (i.e. IM) of the optical field. Coherent receivers are also known as heterodyne receivers, received signal is optically mix, a locally generated light wave field with the received signal field, and the combined wave is photo detected by a APD detector.

B. Comparison of Free Space Optical and Radio frequency technologies

Although, Wireless technology is almost always associated with radio transmission, transmission by carriers other than RF waves, such as optical waves, are more advantageous for some applications. The principal advantage of free space optical technology is availability of very high bandwidth, which could provide broadband wireless extensions to Internet backbones for providing service to end-users. This could enable the prospect of delay in web browsing and video, video on-demand, video teleconferencing, real time medical imaging transfer, enterprise networking data library access, electronic commerce, streaming audio and work-sharing capabilities, which could be as much as a 100 Mbps data rate on a sustained basis. In addition, FSO permits the use of narrow beam divergence with beam divergence (0.1mrad), directional laser beams, which if deployed carefully will offer very secure channels with low possibility of interception or detection (LPI/LPD)..

Parameter	FSO Links	RF Links
Typical Data Rate	2.5Gps to 10Gbps	Less than 100 Mbps
Channel Security	High	Low
Component Dimension	Small	Large
Networking Architecture	Scalable	Non-scalable

Table No.3.1 Properties of Terrestrial Fso and Rf Communication

C. Optical Sources and their Transmitted Fields

The key element in a free space optical communication system is an optical source that can easily be modulated at the transmitter stage. Such a source should produce energy concentrated in a narrow beam having ~ 0.1mrad wavelength, and are capable of being modulated at very high rates. The primary sources of light in modern free space optical systems are the semiconductor laser. The basic principles and characteristics that is the output beam profile, is important in assessing their performance when used in a free space optical (FSO) communication system.

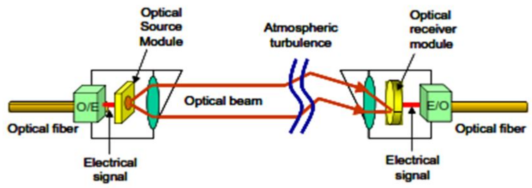

Fig.2.2 FSO system using O/E and E/O conversion .

D. Wave Propagation in Free Space

The transverse modes of a laser take the form of narrow beams of light that are confined between the mirrors of the laser resonator and near the axis of the system and maintain a field distribution that remains distributed around. While there are several solutions to this problem and the simplest solution to the problem is called a Gaussian beam, which is appropriate to the laser under normal conditions. These beams have a radial intensity profile that expands laterally as they propagate through channel. Gaussian beams are unique solutions to the electromagnetic or EM wave equation, which are restricted under paraxial conditions of the system. The free space optical propagation of a single mode laser beam can be modelled as the lowest order Gaussian beam wave, also called a TEM_{00} wave. Assuming the source is located the origin at z = 0,

$$U(r, M) = U_o \frac{w_o}{w_M} \exp\left[-j(kM - \emptyset) - r^2\left(\frac{1}{w_L^2} + \frac{jk}{2R_M}\right)\right]$$

where r is the transverse distance from the beam center, w_o is the minimum spot size, $\emptyset$ is the phase shift, and $k = \frac{2\pi}{\lambda}$ is the wave number. The beam parameters, w_L and R_M, are the spot size and the radius of curvature of phase front at M, respectively.

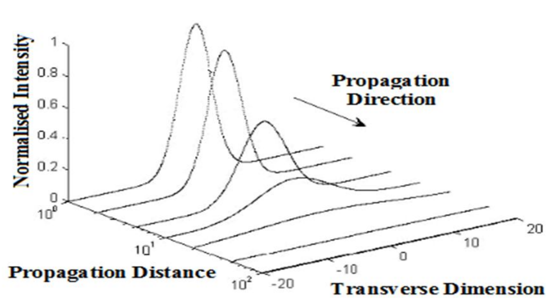

Fig 2.3 Intensity distribution profile in propagating Gaussian beam

E. Beam Forming Optics

In long-range free space optical communications system, light fields from optical sources can be collected and refocused through beam forming optics, which will produce the light in particular directions. A combination of diverging lenses and converging lenses placed at the source is used to produce a collimated beam. Fig. 2.4 shows a simple type of beam collimation commonly required in long- range links. For short range links, in order to fulfil Omni directionality, the optical light required to emerge over a beam wider angle, but at the expense of rapid beam expansion along a communication channel

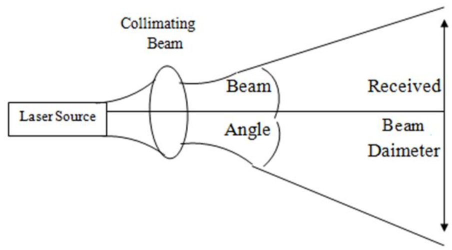

Fig.2.4 Example of beam collimation in long-range FSO links

F. Bit Error Rate in OOK

In practice, the FSO systems usually use Intensity modulated /direct detection with on-off keying because it is simple in design and implementation. However, there is need to set a threshold value for detection at receiver, which is a major problem in this system realization.

In BPSK system the received signal at the receiver can be written as.

$$y = x + n$$

The Bit error rate expression of free space optical system using IM/DD with BPSK is calculated as

$$P_e = P(1)P(0/1) + P(0)P(1/0),$$

Where, P(0) and P(1) represent the probabilities of transmitting "*off*" and "*on*" bits, respectively. The probability of detecting "*on*" bit when "*off*" bit is sent is P(1|0), and P(0|1) is the otherwise. It is considered that P(0) = P(1) = 0.5. Since the noise variance are different in "*off*" and "*on*" states, the probabilities P(1|0) and P(0|1) are not equal and they depend on threshold value. So, in the decision device the threshold affects the BER. Under condition that P(1/0)= P(0/1), according to the BER can be expressed as

$$P_{e/h} = \frac{1}{2}\mathrm{erfc}\left(\frac{Q(h)}{\sqrt{2}}\right), \qquad \gamma_b = \frac{E_b}{N_0} = \frac{A^2}{N_0} = \frac{d_{min}^2}{4N_0}$$

The average bit error rate over gamma gamma distribution channel is depend on H, so it can be found as

$$P_e = \frac{1}{2}\mathrm{erfc}\left(\frac{gRaH}{\sqrt{2(\sigma_{n,on} + \sigma_{n,off})}}\right),$$

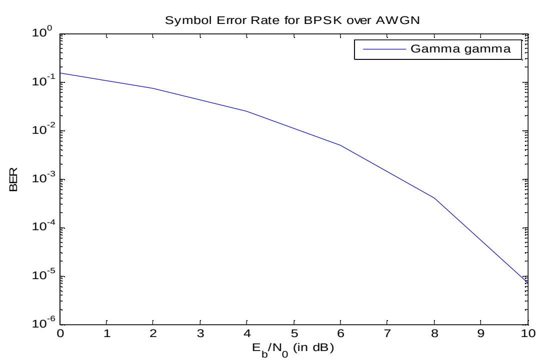

Fig. 2.9 Bit error rate for BPSK over additive Gaussian noise

G. Modulation Techniques in FSO

Free space optical communication systems are carrier systems it means that a wave of a carrier frequency much higher than that of the information (signal) is used to enable the information to be transported through an atmospheric channel. The carrier characteristics should be suitable to propagate in the channel under consideration and the next thing is how can an information carrying signal is "loaded" on a carrier wave to go through the channel. The process that achieves this aim is called "modulation" and has been a subject of intensive study since the inception of electronic communications system back in the 1920s. The optical carrier can be modulated in its amplitude, frequency, phase, and polarization. The most commonly used is amplitude modulation techniques because of their relatively simple implementation with direct detection and phase modulation in combination with a non coherent receiver. The technically simplest digital modulation technique is amplitude-shift keying (2 ASK).

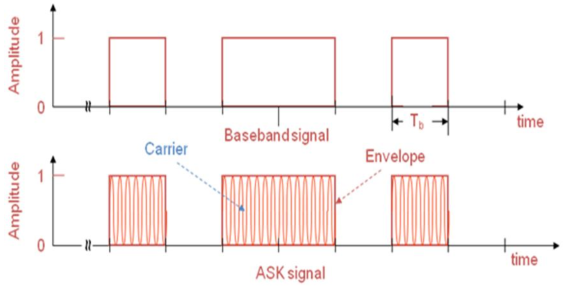

Fig. 2.10 The ASK format with a binary NRZ baseband signal

IV. THE EFFECTS OF ATMOSPHERIC TURBULENCE ON LINK PERFORMANCE IN FSO SYSTEM

Fee space optical communication system requires direct line of sight between the transmitter and receiver. Light travels through air faster than it does through glass. Different factors that affect the performance of the FSO communication channel is presented with different channel distribution such as log Normal and gamma-gamma distribution. The performance controlling parameters are bit error rate (BER) and outage probability. Simulation output shows the performance of different channel distribution with different level of atmospheric (channel) turbulence in FSO system.

A. Turbulence Overview

A comparison of bit error ratio is also presented by changing value of the atmospheric turbulence channel with Log Normal model and gamma-gamma channel model in FSO system. Atmospheric turbulence can cause variations in the received signal level, which increases the bit errors in a digital communication system. In order to quantify the performance limitations, a good understanding of the effect of the intensity variations on the received signal at all turbulence levels is needed. The local density of the atmosphere is constantly varying because of in homogeneities in temperature and pressure. This is atmospheric turbulence

B. Atmospheric Optical Channel

In free space optical communication system, absorption of the laser beam by the atmosphere can be important, especially in adverse atmospheric conditions of heavy rain, fog, snow, or obscuration. The combined effects of direct absorption and scattering of laser beam can be described by a single path-dependent attenuation coefficient $\alpha(z)$

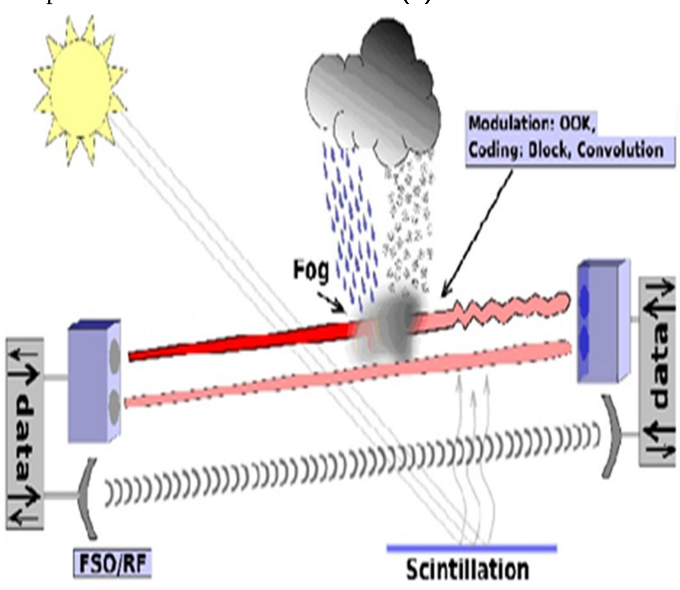

Fig.3.1 FSO system using seamless connections in FSO beam to fiber

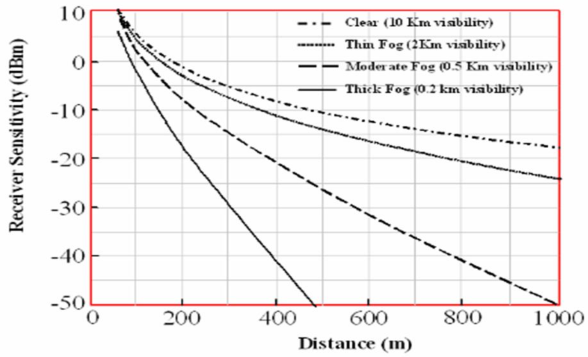

Fig 3.2 FSO link has loss due to various atmospheric conditions

In addition to the power loss, the atmosphere may also changes the optical wave shape during propagation through dense clouds. If an optical pulse is transmitted from the transmitter, the optical pulse signals and its scattered paths arrive with delays relative to the direct communication path and combine to yield a wider, broadened optical field pulse from that transmitted.

C. The effect Atmosphere Turbulence in Free Space Optical (FSO)

Atmospheric turbulence has an important impact on the quality of a laser beam propagating through the atmosphere over longer links. In the presence of atmospheric turbulence, the signal received at the receiver exhibits random intensity fluctuations which increase the Bit error rate. Performance checked under considering the effects of the atmospheric turbulences which is the great challenges for the free space optical system. FSO communication systems, is a high bandwidth access and cost effective technique, which is receiving growing attention with recent commercialization applications. Major barriers in FSO links is the atmospheric turbulence [33], which results in severely degradation of the link performance.

The performance of free space optical (FSO) communication system in the presence of atmospheric turbulence channel can be presented through different models. Different parameters that affect the performance of the communication channel in FSO communication system can be modeled with different channel model such as Log Normal, Rayleigh, Rice and Gamma distribution models. The performance controlling parameters are bit error rate (BER) and outage probability. Simulation results show the performance of different channel distribution models with different level of atmospheric turbulence in FSO system.

D. Factors Affecting Fso

Several factors affect the performance of the FSO links. It is important to keep these factors and their effect on the system performance while designing the system to achieve better efficiency.

1) *Scattering:* Scattering means the pinball machine nature of light trying to penetrate through the atmosphere. Light scattering can largely impact the performance of FSO systems [34]. Scattering is not associated with a loss of energy due to a light absorption process. Rather, it can be better understood as a redirection or redistribution of light beam that can lead to a significant decrease in the received light intensity at the receiver location.
2) *Rayleigh scattering:* A beam of light incident on the bound electrons of an atom or molecule induces a charge imbalance (dipole) that oscillates at the frequency of the incident light beam.
3) *Mie Scattering:* The Mie scattering regime occurs for particles about the size of the wavelength. Therefore, in the near infrared wavelength range, pollution (aerosols) fog, and haze particles are the major contributors to the Mie scattering process.
4) *Absorption:* Atoms and molecules are characterized by the refractive index. The imaginary part of the index of refraction, k, is related to the absorption coefficient, α, by the following:

   $$\alpha = \frac{4\pi k}{\lambda} = \sigma_a N_a$$

5) *Rain:* Rain has a distance-limiting impact on FSO, although its impact is significantly less than that of fog. This is because the radius of raindrops (200–2000 μm) is significantly larger than the wavelength of typical free space optical sources. Practically rain attenuation values are moderate in nature.
6) *Snow:* Snowflakes are ice crystals that come in a variety of sizes and shapes. In general, however, snow tends to be lower than fog but larger than rain. Whiteout conditions might reduce the beam, but scattering doesn't tend to be a big issue for free space optical systems because the size of snowflakes is large as compared to the operating wavelength of the beam. The impact of

light snow to whiteout conditions and blizzard falls approximately between light rain to moderate fog, with link attenuation potentials of approximately 3 dB/km for rain to 30 dB/km for fog.

7) *Fog:* Fog is the most challenging weather conditions to FSO because it is composed of small water droplets with radii about the size of near infrared wavelengths. The particle size distribution changes for different degrees of fog.
8) *Visibility:* Low visibilities will decrease the availability and effectiveness of free space optical systems. Long-term weather conditions show that some cities, such as WA, Seattle have lower average visibilities than cities such as CO, Denver. This means that for the same distance, the same free space optical system in Seattle will experience a lower availability than a system installed in Denver. Low visibility can occur during a specific time period within a year or at specific times of the data.

V. ERROR ANALYSIS OF SINGLE USER FSO SYSEM IN WEAK AND STRONG TURBULENCE CHANNEL

The laser beam propagates through a direct line of sight path in the turbulence-induced channel corrupted at the receiver side by an additive white Gaussian noise (AWGN). The inhomogeneties in pressure and temperature can be modeled as log-normal and Gamma gamma distribution. A direct line-of-sight free space optical communication system uses intensity modulation/direct detection (IM/DD).

A. System and Channel Model

We are considering a point-to-point free space optical communication system using intensity modulation/direct detection which is the combination of laser and photo detector (APD). The laser beam from a transmitter propagates through a direct line of sight path in the turbulence-induced channel corrupted at the receiver by an additive white Gaussian noise (AWGN). The channel model can be given by

$$y = sx + n = \eta Ix + n$$

where x is the input of the channel, y is the output of the channel, $s = \eta I$ is the instantaneous channel gain, where η is the effective photo-current conversion ratio and I is the normalized irradiance of the receiver, and n is the AWGN with a zero mean and a variance N normalized to unity. A free space optical communication system with single transmitter and receiver as depicted in figure 4.1. The users are only equipped with single apertures, which is directed to the optical receiver. Signals are transmitted from the transmitting aperture to the target user through the turbulence-induced fading channels and are corrupted at the receiver by the additive noise.

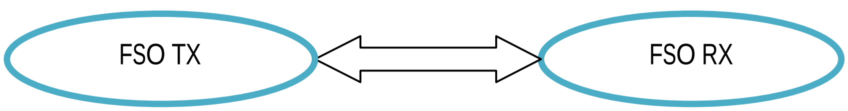

Fig.4.1. Diagram of single user FSO system.

In this work, we restrict our analysis to be background noise limited and the noise is modeled as additive white Gaussian noise with power spectral density N_0 and zero mean. We also assume that the system uses intensity modulation direct-detection (IM/DD) with on-off keying (OOK) modulation.

B. Channel Model

We are considering the channel model where both the turbulence-induced fading and path-loss are included. For single link between the aperture at the transmitter and the user at the receiver, the channel with distance d can be modeled as

For single user, N =1 link. $h = L(d)\check{h}$,

where, h denoted as Turbulence-induced fading, $\tilde{h}$ is the Atmospheric fading, L(d) path loss. The path loss, L (d) and can be written as

$$L(d) = \frac{D_R^2}{(D_T + \theta_T d)^2} e^{-vd}$$

where, D_R and D_T are Receiver and Transmitter Aperture diameters respectively, v denotes Weather dependent attenuation coefficient and θ_T is optical beam's divergence angle. From Eq. (the instantaneous signal to noise (SNR) can be defined $\gamma = \tilde{\gamma}|\tilde{h}|^2$.

where, $\tilde{\gamma}$ is Average SNR for single link and γ is Instantaneous SNR for link, In the FSO communication context, such a fading can be modeled by two different distributions, i.e., gamma-gamma distribution for strong atmospheric turbulence and log-normal distribution for weak atmospheric turbulence. In what follows, and for notation simplicity, we use LN and GG to denote the log-normal distribution and gamma-gamma distribution respectively.

C. Gamma-Gamma Distribution (for Strong Turbulence)

The Gamma-gamma (GG) distribution has been found to be the most appropriate modelling of the optical channels for moderate-to-strong turbulence channels. This distribution is produced from the product of two Gamma random variables and is also known as the gamma-gamma or generalized K distribution.

The gamma distribution is defined by two factors; scale (β) and the shape (α) factors. The probability density function for random variable x can be expressed as

$$f(x) = \frac{(x/\beta)^{\alpha-1}\exp(-x/\beta)}{\beta\Gamma(\alpha)},$$

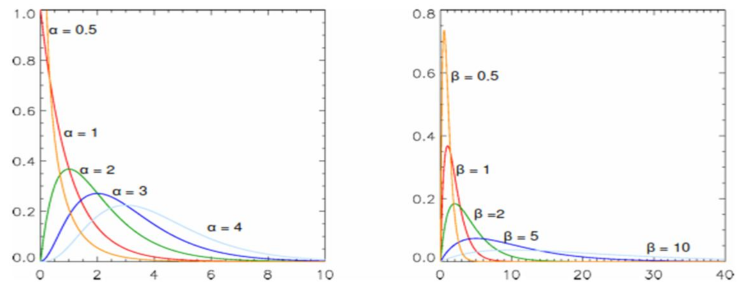

Fig. 4.2 Gamma distribution for different values of α and β

The developed scheme allows aggregation of Radio frequency/microwave signals and a conversion to the optical domain in a very natural way and may be a good candidate for hybrid radio frequency/microwave-FSO systems. The Bit error probability (BEP) is evaluated with fading in the presence of background radiation. It is also assumed that APD photodiodes are used, and the channel is modeled using Gamma-Gamma distribution for strong turbulence channel.

D. Log Normal Distribution (for Weak Turbulence)

In probability theory, a log-normal distribution is defined as the probability distribution of a random variable Y whose logarithm is normally distributed. If Y is a random variable with a normal distribution, then $X = \exp(Y)$ has a log-normal distribution; similarly, if X is log-normally distributed, then $Y = \log(X)$ is normally distributed. Log-normal is also written log normal or lognormal. It is occasionally known as the Galton distribution or Galton's distribution, after Francis Galton [44]. For weak turbulence conditions, the turbulence is commonly modeled by a log-normal distribution. Namely, $|\tilde{h}| = e^x$ and $|\tilde{h}|^2 = e^{2X}$, where x is normally distributed with mean μ_X and variance σ_x^2. To guarantee that the fading coefficients conserve the power, which implies that $E[|\tilde{h}|]^2=1$, $\mu_X = -\sigma_x^2$ [44].

Probability density function PDF of

$$f_{1,1}^{LN}(\gamma) = \frac{1}{2\gamma\sqrt{2\pi\sigma_x^2}}\exp\left(-\frac{(\ln\left(\frac{\gamma}{\bar{\gamma}}\right)+2\sigma_x^2)^2}{8\sigma_x^2}\right),$$

E. Strong Turbulence Condition

We are focusing on the gamma- gamma distribution model and the CDF can be evaluated by using, the CDF in Eq. can be rewritten as

$$F_\gamma^{GG}(\gamma) = \frac{1}{\Gamma(\alpha)\Gamma(\beta)}\frac{\pi}{2\sin((\alpha-\beta)\pi)}\sum_{s=0}^{\infty}\left[\frac{2}{(s+\beta)\Gamma(\beta-\alpha+1+s)s!}\left(\frac{\alpha\beta}{\sqrt{\bar{\gamma}}}\right)^{s+\beta}\gamma^{\frac{s+\beta}{2}} - \left(\frac{\alpha\beta}{\sqrt{\bar{\gamma}}}\right)^{s+\beta}\gamma^{\frac{s+\beta}{2}}\right]$$

It should be noted that $\beta-\alpha$ is not an integer in Eq. (4.16). In practice, it is sufficient to use a high enough number M of items to compute the CDF .

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VI. RESULT ANALYSIS AND CONCLUSION

The bit error rate (BER) performance of free space optical (FSO) communication systems employing on-off keying (OOK) modulation format is derived. The improvement is different for different turbulence strength i.e for strong and weak turbulence strengths and modulation formats. Based on the gamma–gamma distribution and log-normal distribution, the BER performances for intensity modulation direct detection with OOK formats has been derived. For OOK modulation format, the BER performance employing an optimal threshold is superior to that employing a fixed threshold. The performance of Bit error rate (BER) with respect to change in Average Signal to Noise Ratio (SNR) [dB] is shown in Fig 4.6. The above figure shows that in free space optic system, when the signal propagates in the strong turbulence medium, the behaviour of SNR is inversely proportional to that of Bit error rate. It can be noted when SNR(dB) is 10dB the bit error rate is 0.9497 for strong turbulence channel, and further increase in average SNR (dB) to 20dB the BER in strong turbulence channel is approx 0.7122.

A. Bit error Rate Analysis over Different Wavelength

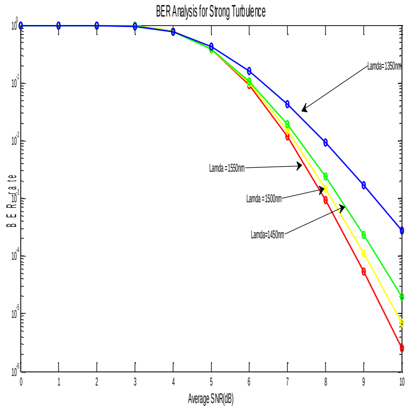

Fig. 4.8 Analysis of Bit error rate over different wavelength in strong turbulence channel

Wavelength (nm)	Path Loss (dB/km)	Rytov variance δ^2_{Weak}	Rytov variance δ^2_{Strong}	Variance σ^2	Alpha, α	Beta, β
1600	-47	0.187	3.7	0.204	10.41	9.9
1550	-47	0.194	3.8	0.206	10.02	9.6
1400	-47	0.218	4.6	0.243	8.87	8.5
1300	-47	0.238	4.8	0.268	8.08	7.7
1200	-47	0.262	5.2	0.299	7.33	6.9
800	-47	0.420	8.4	0.521	4.37	4.18

Table 5.1 Parameters used for analysis of Bit error rate over different wavelength

B. Conclusion

The performance of Bit error rate (BER) with respect to Average Signal to Noise Ratio (SNR) [dB] is shown in above for weak and strong turbulence respectively and the comparison of both the turbulence. It may be noted that from these figures and the data calculated in the that as the signal to noise ratio increases the bit error rate decreases in both the turbulence conditions. Due to the decrease in bit error rate, the system performance increases. It may be also noted that when the signal is propagating in weak turbulence condition, BER is decaying very rapidly as compared with strong turbulence conditions. Hence, signal in weak turbulence condition will provide better performance in the FSO system for different applications. It is interesting to note that, also in the even further increase in signal-to-noise ratio by a factor of 10, also the signal through weak turbulence shows reliable communication. When SNR (dB) is 10dB the bit error rate is 1 for strong turbulence channel, and 0.947 for weak turbulence channel and again increase in average SNR (dB) to 20dB the corresponding BER in strong turbulence channel is approx 0.9834 while, in weak turbulence it is around 0.7122 and further increase in the average SNR to 30dB the BER decreases to 0.9778 in strong turbulence channel whereas, the 0.298 and so on.

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C. Future Works

For future we can also calculate the capacity coverage with the help of above derivations. And also we can utilize these equations for more than one user. In other words, we can increase the number of transmitter and receiver for reliable communication but by increasing the users there will be network complexity.

As in this dissertation Intensity modulated and Direct detection scheme and APD detectors has been used, truly because of their simplicity in result, for future work we can utilize other modulation and detection schemes. Better Error correcting codes can be used for efficient output at the receiver. Multiple Transmitters and multiple receivers can also be used for reliable communication and with the help of large number of transmitter and receiver can use spatial diversity techniques to choose the best signal but, system may get complex and the derivation for the Probability density function and CDF for BER will become a challenge.

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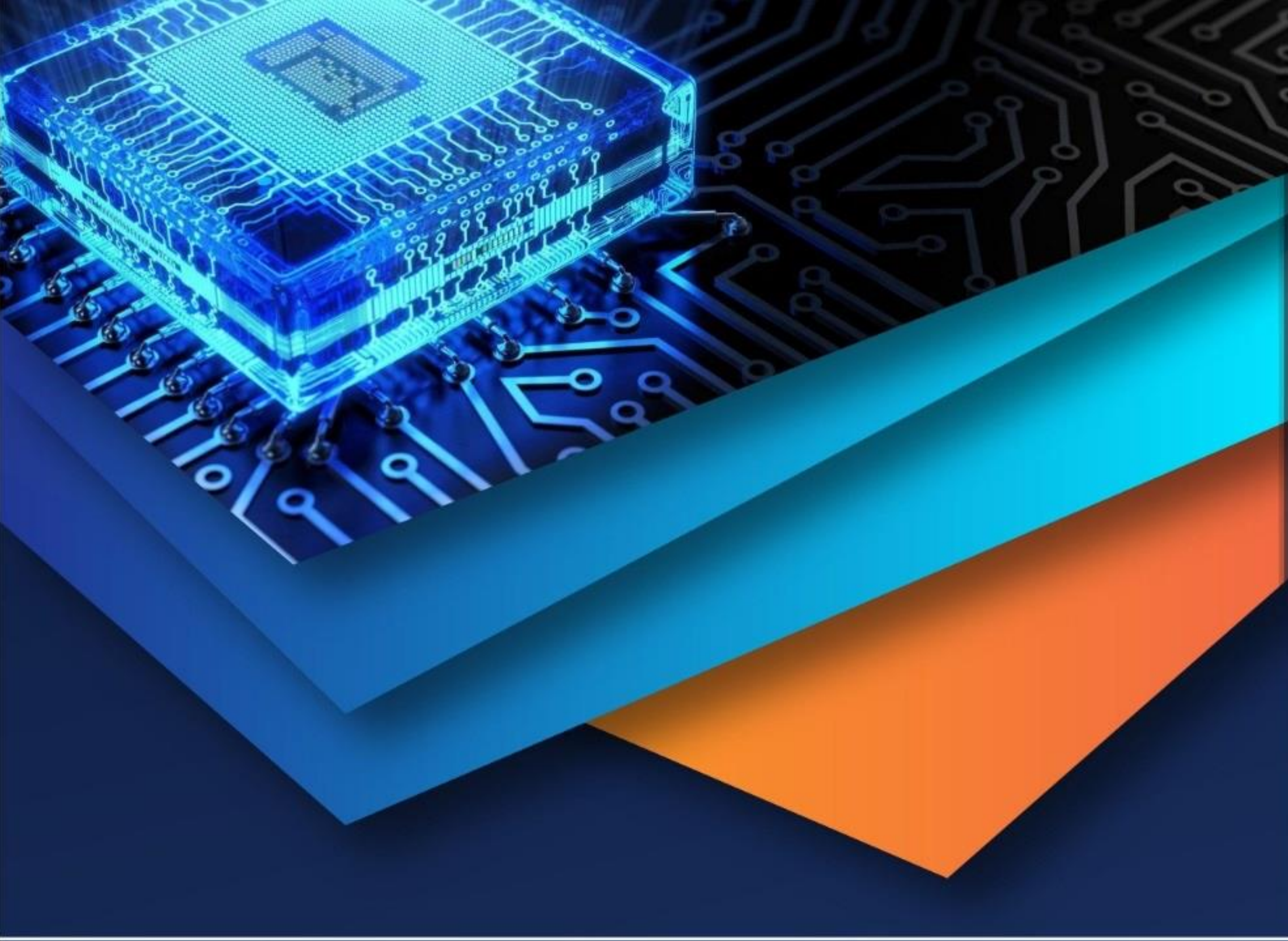

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