International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 10, October-2014, pp: (204-210), Impact Factor: 1.252, Available online at: www.erpublications.com

Impact of atmospheric turbulence on free space optical (FSO) communication

Sachin Rathee[1], Lokeshwar[2]

[1]M. Tech. Scholar, R. N. College of Engg. & Management. Rohtak, Haryana
[2]Assistant Professor, R. N. College of Engg. & Management. Rohtak, Haryana

---

Abstract: In free-space optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, impairing link performance. Free Space Optical (FSO) communications is the only viable solution for creating a three-dimensional global communications grid of inter-connected ground and airborne nodes. The huge amount of data exchange between satellites and ground stations demands enormous capacity that cannot be provided by strictly regulated, scarce resources of the Radio Frequency (RF) spectrum. Free Space Optical (FSO) communications, on the other hand, has the potential of providing virtually unlimited bandwidth. In this paper, we describe several communication techniques to mitigate turbulence-induced intensity fluctuations, i.e., signal fading. These techniques are applicable in the regime in which the receiver aperture is smaller than the correlation length of fading and the observation interval is shorter than the correlation time of fading. We assume that the receiver has no knowledge of the instantaneous fading state. When the receiver knows only the marginal statistics of the fading, a symbol-by-symbol ML detector can be used to improve detection performance. If the receiver has knowledge of the joint temporal statistics of the fading, maximum- likelihood sequence detection (MLSD) can be employed, yielding a further performance improvement, but at the cost of very high complexity. Spatial diversity reception with multiple receivers can also be used to overcome turbulence-induced fading. We describe the use of ML detection in spatial diversity reception to reduce the diversity gain penalty caused by correlation between the fading at different receivers. In a companion paper, we describe two reduced-complexity implementations of the MLSD, which make use of a single-step Markov chain model for the fading correlation in conjunction with per-survivor processing.

Keywords: Free-space optical communications, link budget, turbulence, fading.

---

1. INTRODUCTION

Free-space optical communication (FSO) systems (in space and inside the atmosphere) have developed in response to a growing need for high-speed and tap-proof communication systems. Links involving satellites, deep-space probes, ground stations, unmanned aerial vehicles (UAVs), high altitude platforms (HAPs), aircraft, 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 frontier for net-centric connectivity, as bandwidth, spectrum and security issues favour its adoption as an adjunct to radio frequency (RF) communications [1]. While fixed FSO links between buildings have long been established and today form a separate commercial product segment in local and metropolitan area networks [2], the mobile and long-range applications of this technology are aggravated by extreme requirements for pointing and tracking accuracy because of the small optical beam divergences involved. This challenge has to be addressed to fully exploit the benefits of optical links. Furthermore, long-haul optical links through the atmosphere suffer from strong fading as a result of index-of-refraction turbulence (IRT) and link blockage by obscuration such as clouds, snow and rain. In this paper an overview of the challenges a system designer has to respond to when implementing an FSO system is provided. Typical gains and losses along the path from the transmitter through the medium, to the receiver are introduced in this article. Some results concerning the qualitative parameters of the links and statistical characteristics of the atmosphere are described. A more detailed discussion and further information on these topics can be found in papers in this special issue of the Radio engineering Journal.

II. FREE SPACE OPTICAL COMMINICATION

FSO technology is relatively simple. It's based on connectivity between FSO units, each consisting of an optical transceiver with a laser transmitter and a receiver to provide full duplex (bi-directional) capability. Each FSO unit uses a high-power optical source (i.e. laser), plus a lens that transmits light through the atmosphere to another lens receiving the information. The receiving lens connects to a high-sensitivity receiver via optical fiber. A source producing data input is to be transmitted to a remote destination. This source has its output modulated onto an optical carrier; typically laser, which is then transmitted as an optic al field through the atmospheric channel [6]. The important aspects of the optical transmitter system are size, power, and beam quality, which determine laser intensity and minimum divergence obtainable from the system. At the receiver, the field is optically collected and detected, generally in the presence of noise interference, signal distortion, and background radiation. On the receiver side, important features are the aperture size and the f/-number, which determine the amount of the collected light and the detector field-of-view (FOV). The modulation of the source data onto the electromagnetic wave carrier generally takes place in three different ways: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), each of which can be theoretically implemented at any frequency. For an optical wave, another modulation scheme is also often used, namely intensity modulation (IM). Intensity is defined as flow energy per unit area per unit time expressed in W/m2, and is proportional to the square of the field amplitude. The light fields from laser sources then pass beam forming optics to produce a collimated beam.

III. FACTOR AFFECTING FSO

Many factors affect the performance of the FSO system. It is important to keep these factors and their effect on the system performance while designing the system to achieve maximum performance.

Scattering: Scattering refers to the pinball machine nature of light trying to pass through the atmosphere. Light scattering can drastically impact the performance of FSO systems [7]. Scattering is not related to a loss of energy due to a light absorption process. Rather, it can be understood as a redirection or redistribution of light that can lead to a significant reduction of received light intensity at the receiver location.

 Rayleigh scattering: A radiation incident on the bound electrons of an atom or molecule induces a charge imbalance or dipole that oscillates at the frequency of the incident radiation.

 Mie Scattering: The Mie scattering regime occurs for particles about the size of the wavelength. Therefore, in the near infrared wavelength range, fog, haze, and pollution (aerosols) particles are the major contributors to the Mie scattering process.

Absorption: Atoms and molecules are characterized by their index of refraction. The imaginary part of the index of refraction, k, is related to the absorption coefficient, α, by the following:

Rain: Rain has a distance-reducing 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 FSO light sources [8]. Typical rain attenuation values are moderate in nature.

Snow: Snowflakes are ice crystals that come in a variety of shapes and sizes. In general, however, snow tends to be larger than rain. Whiteout conditions might attenuate the beam, but scattering doesn't tend to be a big problem for FSO systems because the size of snowflakes is large when compared to the operating wavelength. The impact of light snow to blizzard and whiteout conditions falls approximately between light rain to moderate fog, with link attenuation potentials of approximately 3 dB/km to 30 dB/km.

Fog: Fog is the most detrimental weather phenomenon to FSO because it is composed of small water droplets with radii about the size of near infrared wavelengths. The particle size distribution varies for different degrees of fog.

Visibility: Low visibilities will decrease the effectiveness and availability of FSO systems. Long-term weather observations show that some cities, such as Seattle, WA, have lower average visibilities than cities such as Denver, CO. This means that for the same distance, the same FSO system in Denver will experience a higher availability than a system installed in Seattle. Low visibility can occur during a specific time period within a year or at specific times of the data.

Distance: Distance impacts the performance of FSO systems in three ways. First, even in clear weather conditions, the beam diverges and the detector element receives less power. For a circular beam, the geometrical path loss increases by 6 dB when the distance is increased by a factor of two. Second, the total transmission loss of the beam increases with increasing distance. Third, scintillation effects accumulate with longer distances.

Bandwidth: In standard FSO systems, two elements limit the bandwidth of the overall system. These elements are the transmission source and the photo detector. When LEDs are incorporated into FSO systems, the bandwidth is typically limited to 155 Mbps. When laser sources are used, the speed can be much higher.

IV. OPTICAL COMMUNICATION THROUGH ATMOSPHERIC TURBULENCE

In this section, we first review the theories used to model atmospheric turbulence. We then use these to derive the spatial and temporal coherence properties of the optical field in weak turbulence channels. Finally, we present the joint spatial and temporal distribution of turbulence-induced fading.

A. Modeling of Atmospheric Turbulence

Atmospheric turbulence can be physically described by Kolmogorov theory [7]–[10]. The energy of large eddies is redistributed without loss to eddies of decreasing size until finally dissipated by viscosity. The size of turbulence eddies normally ranges from a few millimeters to a few meters, denoted as the inner scale and the outer scale , respectively. We can express the refractive index as, where is the average index and is the fluctuation component induced by spatial variations of temperature and pressure in the atmosphere.

B. Spatial and Temporal Coherence of Optical Signals through Turbulence

To describe spatial coherence of optical waves, the so-called mutual coherence function (MCF) is widely used [8] where is the complex optical field. In most free-space optical communication systems with visible or infrared lasers and with propagation distance of a few hundred meters to a few kilometers, (10) is valid. We note that aerosol forward scattering can further degrade the coherence of the optical field and thus affect the correlation length. In this paper, however, we focus only on atmospheric turbulence effects. Atmosphere turbulence also varies with time and leads to intensity
fluctuations that are temporally correlated. Modeling the movement of atmospheric eddies is extremely difficult and a simplified "frozen air" model is normally employed, which assumes that a collection of eddies will remain frozen in relation to one another, while the entire collection is translated along some direction by the wind.

C. Probability Distributions of Turbulence-Induced Intensity Fading

When the propagation distance is long, log-amplitude fluctuations can become significant. In this section, we will derive the statistical properties of the log-amplitude fluctuations, which we refer to as "intensity fading" or simply "fading." The marginal distribution of fading is derived in Section I, while the joint spatial and temporal distribution of fading are derived in Section II.

1) Marginal Distribution of Fading:

In this section, we derive the marginal distribution of fading at a single point in space at a single instant in time. For propagation distances less than a few kilometers, variations of the log-amplitude are typically much smaller than variations of the phase. Over longer propagation distances, where turbulence becomes more severe, the variation of the log-amplitude can become comparable to that of the phase. Based on the atmosphere turbulence model adopted here and assuming weak turbulence.

2) Joint Spatial and Temporal Distributions of Fading:

In this section, we derive the joint spatial and temporal distributions of fading. The joint spatial distribution describes the fading at multiple points in space at a single instant of time and is used. The joint temporal distribution describes the fading at a single point in space at multiple instants of time.

V. FREE SPACE OPTICAL COMMUNICATION

The analysis of free space optical communication system in the presence of atmospheric turbulence is presented with the channel modeling is selected to be of nakagami fading channel. We are considering basically to parameters to analysis the performance of nakagami fading channel are bit error rate and outage probability. The outage probability, Pout, is defined as the probability that the received SNR per symbol falls below a given threshold-Yth. If the SNR of the received signal fall be the given threshold than outage is occur at the receiver. This is one of the important parameter that is used for the analysis the performance of fading channel. Here, we are using Nakagami fading channel with log normal distribution and gamma-gamma distribution. Simulation is performed in the presence of atmospheric turbulence. This experiment is performed in different level of channel turbulence. The performance of the system is affect more due to the presence of more atmospheric turbulence in the channel. Outage probability of the fading channel is the function of channel variance. As the channel variance changes outage probability also changes. With the increase in the SNR of system outage probability of the system also goes on increasing behavior. The Simulation has been done in MATLAB. Simulation results of lognormal distributed and gamma-gamma distributed fading channel is presented with changing level of turbulence. If the level of turbulence is small system behave in a better manner. As the level of turbulence increase the performance of the system degraded.

Example 1: Bit Error Rate Performance of Log normal distribution in free space optical communication system In this experiment, bit error rate parameter is considered for the performance analysis of the Log normal distribution channel. Here, we are considering the channel to be free of all kings of noises. .

Fig. 1 demonstrates the ideal Bit error rate analysis of Log normal distribution channel in free space optical communication system.

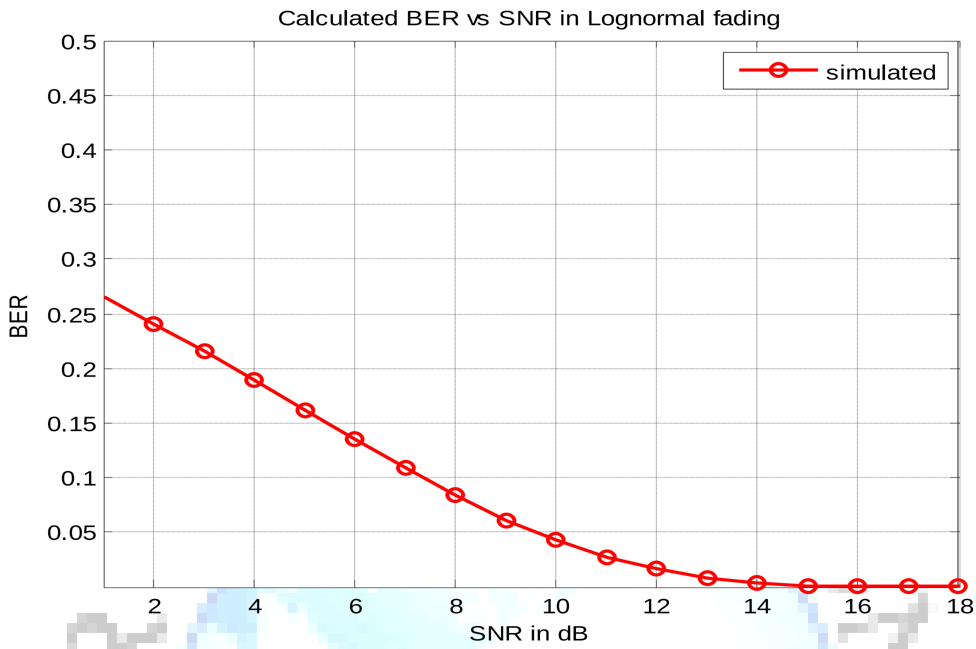

Fig.1 Simulated Bit error rate analysis of Log normal distribution in free space optical communication system

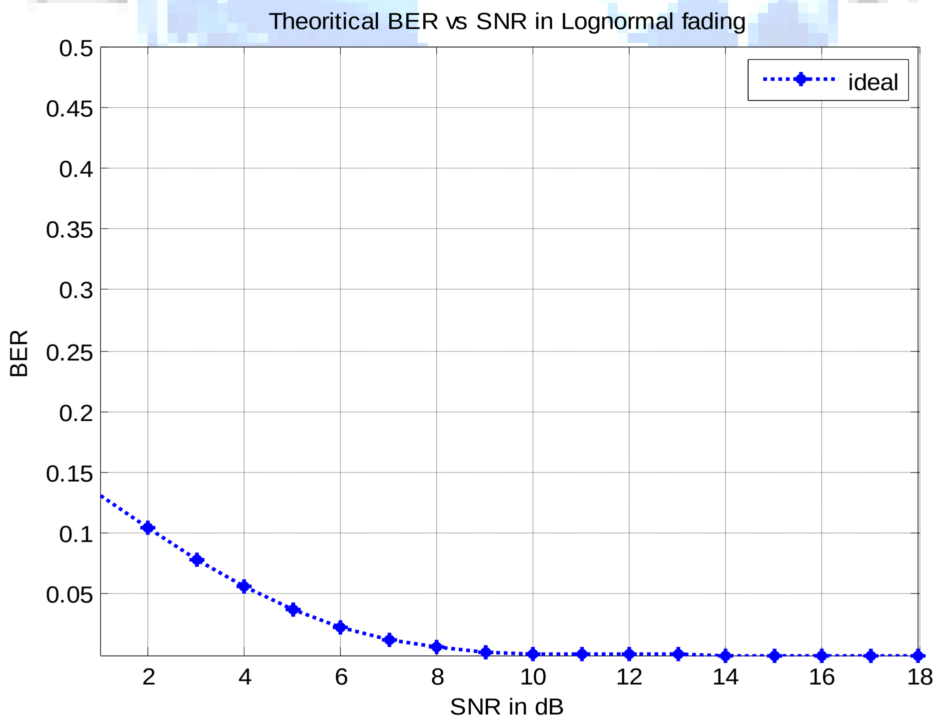

Fig. 2 Ideal Bit error rate analysis of Log normal distribution channel in free space optical communication system

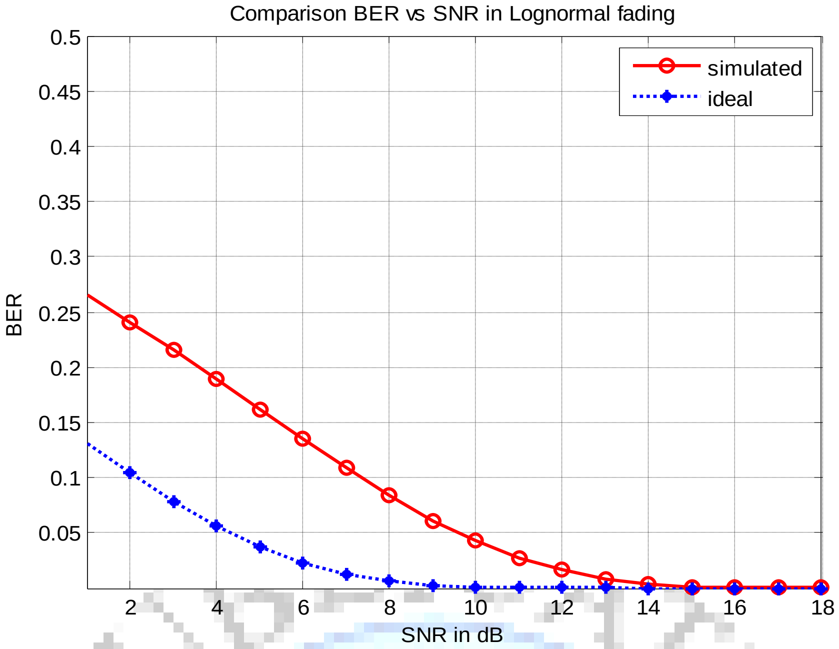

Fig. 3 Comparison of ideal and simulated Bit error rate analysis of Log normal distribution channel in free space optical communication system .

In this experiment, bit error rate parameter is considered for the performance analysis of the gamma-gamma distribution channel in free space optical communication system. Fig.4 shows the Bit error rate analysis of gamma-gamma distribution channel with strong level turbulence in free space optical communication system. Fig. 5 demonstrates the Bit error rate analysis of gamma-gamma distribution channel with moderate level turbulence in free space optical communication system. Fig.5.1 shows the Bit error rate analysis of gamma- gamma distribution channel with Weak level turbulence in free space optical communication system. Fig. 5.2 reveals the Comparison of Bit error rate analysis of gamma-gamma distribution channel with different level of turbulence in free space optical communication system.

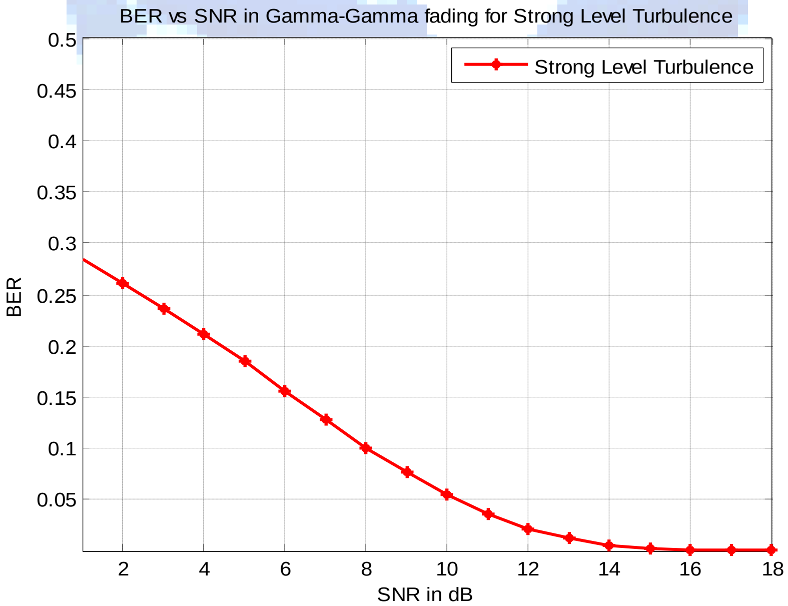

Fig. 4 Bit error rate analysis of gamma-gamma distribution channel with strong level turbulence in free space optical communication system

.

International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 10, October-2014, pp: (204-210), Impact Factor: 1.252, Available online at: www.erpublications.com

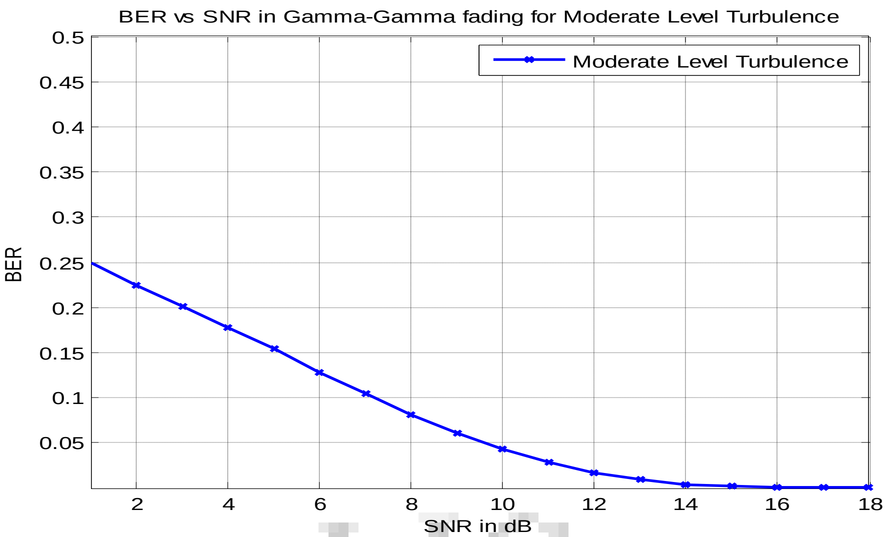

Fig.5 Bit error rate analysis of gamma-gamma distribution channel with moderate level turbulence in free space optical communication system.

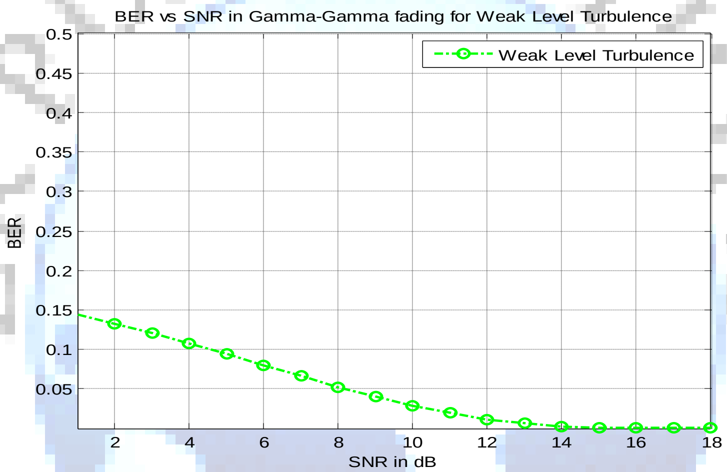

Fig. 5.1 Bit error rate analysis of gamma-gamma distribution channel with Weak level turbulence in free space optical communication system.

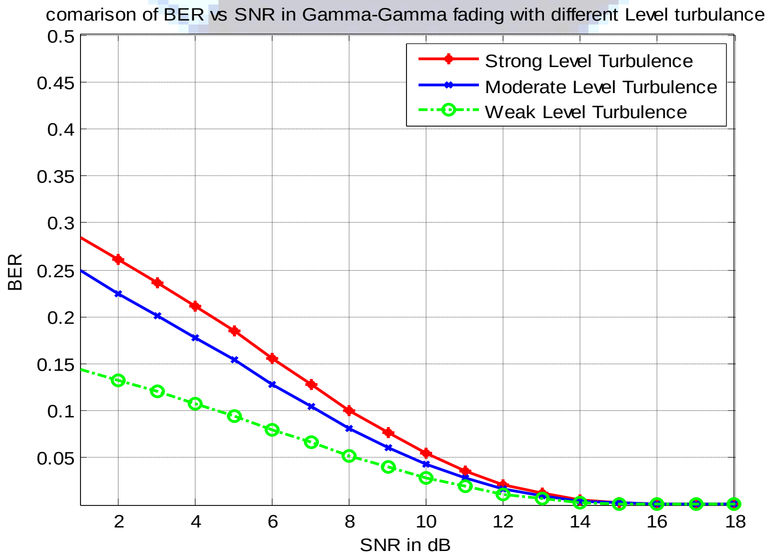

Fig 5.2 Comparison of Bit error rate analysis of gamma-gamma distribution channel with different level of turbulence in free space optical communication system

Conclusion

In this paper, performance of free space optical (FSO) communication in the presence of atmospheric turbulence is presented. FSO system required free line of sight between the transmitter and receiver. The performance controlling parameters are outage probability and bit error rate (BER). Simulation results show the performance of different channel models with different level of channel turbulence in FSO system. Results also show that as the signal to noise ratio increase, BER goes on decreasing and try to approaches the theoretical value. performance analysis of the system model in free space optical communication system. Bit error rate analysis is performed with both the lognormal and gamma-gamma distributed fading channel whereas outage probability analysis is done with gamma-gamma distributed channel in free space optical communication system. Here, the performance is analysis with different level of turbulences in free space optical communication system. Results shows that the performance is better with small value of the turbulence in the fading channel in free space optical communication system

References

[1]. H. Willebrand and B. S. Ghuman, Free Space Optics: Enabling Optical Connectivity in Today‟s Networks. Indianapolis, IN: Sams, 2002.

[2]. X. Zhu and J. M. Khan, "Free-space optical communication through atmospheric turbulence channels," IEEE Trans. Commun., vol. 50, pp.1293–1300, Aug. 2002.

[3]. Kedar D., Arnon S.: „Urban optical wireless communications networks: the main challenges and possible solutions‟, IEEE Commun.Mag., 2003, 42, (5), pp.2–7

[4]. Strickland B.R., Lavan M.J., Woodbridge E., Chan V.: „Effects of fog on the bit-error rate of a free space laser communication system‟, Appl. Opt., 1999, 38, (3), pp. 424–431

[5]. Willebrand H., Ghuman B.S.: „Free space optics: enabling optical connectivity in today‟s networks‟ (Sams Publishing, 2002)

[6]. Andrews L.C., Phillips R.L., HOPEN C.Y.: „Laser beam scintillation with applications‟ (SPIE Press, Bellingham, WA, 2001)

[7]. Zhu X., Kahn J.M.: „Free-space optical communication through atmospheric turbulence channels‟, IEEE Trans. Commun., 2002, 50, (8), pp. 1293–1300

[8]. Kim I.I., Woodbridge E., Chan V., Strickland B.R.: „Scintillation measurements performed during the limited-visibility lasercom experiment‟, Proc. SPIE, 1998, 3266, pp. 209–220

[9]. Zhu X., Kahn J.M.: „Performance bounds for coded free space optical communications through atmospheric turbulence channels‟, IEEE Trans. Commun., 2003, 51, (8), pp. 1233–1239

[10]. Uysal M., Li J., Yu M.: „Error rate performance analysis of coded free-space optical links over gamma– gamma atmospheric turbulence channels‟, IEEE Trans. Wirel. Commun., 2006, 5, (6), pp. 1229–1233

[11]. Lee E.J., Chan V.W.S.: „Optical communication over the clear turbulent atmospheric channel using diversity‟, IEEE J. Sel. Areas Commun., 2004, 22, (9), pp. 1896–1906

[12]. Wilson S.G., Brandt-Pearce M., Cao Q., Leveque J.: „Free space optical MIMO transmission with Q-ary PPM‟, IEEE Trans. Commun., 2005, 53, (8), pp. 1402–1412

[13]. Navidpour S.M., Uysal M., Korevaar E.: „BER performance of free-space optical transmission with spatial diversity‟, IEEE Trans. Wirel. Commun., 2007, 6, (8), pp. 2813–2819