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Analysis the effect Atmosphere Turbulence in Free-Space Optical (FSO) Communication Systems

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***Abstract:* Over the last two decades free-space optical communication (FSO) has become more and more interesting as an adjunct or alternative to radio frequency communication. 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. Light travels through air faster than it does through glass. Different factors that affect the performance of the communication channel in free space optical communication system is presented with different channel model such as Rayleigh, Rice and Nakagami models. 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. A comparison of BER is also presented with the changing value of the channel turbulence with gamma-gamma channel model in FSO system.**

Index Terms: **free-space optical communication (FSO), Nakagami-m channel model, bit error rate (BER), gamma-gamma channel model, Atmospheric Turbulence.**

I. INTRODUCTION

FSO is wireless laser-based point-to-point communications in which the points have clear line-of-sight between them. Atmospheric turbulence has a significant impact on the quality of a laser beam propagating through the atmosphere over long distances. In the presence of atmospheric turbulence, the received signal exhibits random intensity fluctuations which increase the BER. Performance evaluated under considering the effects of the atmospheric turbulences which is the great challenges for the FSO.

Free space optical (FSO) communications, is a cost-effective and high bandwidth access technique, which is receiving growing attention with recent commercialization application [1]. Major impairment over FSO links is the atmospheric turbulence [2], which results in fluctuations at the received signal, severely degrading the link performance.

In this paper, performance of free space optical (FSO) communication in the presence of atmospheric turbulence is presented. Different factors that affect the performance of the communication channel in free space optical communication system is presented with different channel model such as Rayleigh, Rice and Nakagami models. 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.

FSO is now common for point-to-point communications between fixed locations on land, and is also used for communications between moving platforms on land, the surface of the sea and in air. Despite the major advantages of FSO communications, there are several challenges in a practical deployment. Aerosol scattering, caused by rain, snow and fog, leads to performance degradation [4]. Another possible impairment over FSO links is building-sway as a result of wind loads, thermal expansion and weak earthquakes [3]. But the major problem is that FSO links suffer from atmospheric turbulence because of in homogeneities in the index of refraction known as scintillation, which leads to stochastic amplitude (and power) fluctuations [6][8]. This phenomenon, which is known as fading or scintillation, degrades the link performance particularly for distances of 1 km and above [6]. To overcome such limitations, both error control coding [9] [10] and multiple input multiple output techniques have been proposed for FSO systems [11]-[13].

The rest of the paper is organized as follows: In Section II, basic of free space optical (FSO) communication is explained. In section III, explains the factors that affect the performance of free space optical communication that includes scattering, absorption and atmospheric turbulence. Section IV introduces the Nakagami-m distribution used for the analysis of the performance of the system. In Section V, simulation results will be explained with the help of graphical representation to analysis the affect of different level of turbulence. Section VI, conclusions will be put forward.

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.

FSO communication systems are illustrated in Fig. 1. A source producing data input is to be transmitted to a remote destination. This source has its output modulated

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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/m^2, 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.

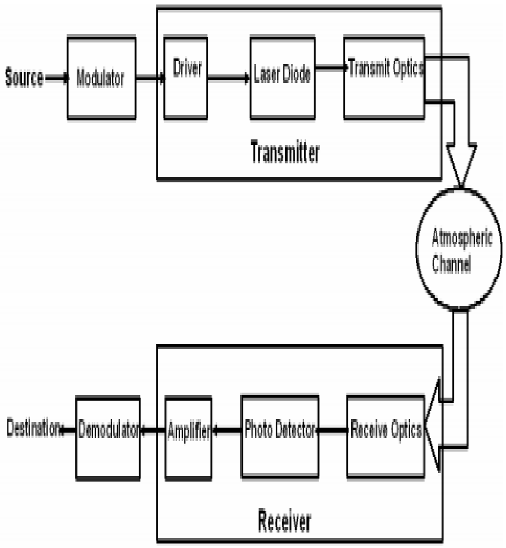

Fig. 1 Block diagram of FSO communication system

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:

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

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. NAKAGAMI- M DISTRIBUTION

The Nakagami-m distribution is a versatile statistical model because it can model fading amplitudes that experience either less or severe fading than that of Rayleigh variates. The Nakagami-m distribution is suitable for describing statistics of mobile radio transmission in complex media such as the urban environment. The Nakagami distribution is related to the gamma distribution. The Nakagami distribution can be generated from the chi distribution. The Nakagami distribution or the Nakagami-*m* distribution is a probability distribution related to the gamma distribution. It has two parameters: a shape parameter m and a second parameter controlling spread, Ω. The Nakagami-m random process is defined as an envelope of the sum of 2m independent Gauss random processes, the Nakagami-m distribution is described by the pdf

$$p_z(z,\Omega)=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m z^{2m-1}\exp\left(-\frac{m}{\Omega}z^2\right),$$

$$z>0, m\geq\frac{1}{2} \qquad (1)$$

where z is the received signal level, Γ(.) is the gamma function, m is the parameter of fading depth, defined as:

$$m=\frac{E^2[z]}{Var[z^2]} \qquad (2)$$

while Ω is average signal power:

$$\Omega=E[z^2] \qquad (3)$$

A. Amount of Fading

The AoF is defined as the ratio of the variance to the square average SNR per symbol.

$$A_F=\prod_{i=1}^{N}\left(1+\frac{1}{m_i}\right)-1 \qquad (4)$$

From the above equation, it may be concluded that, since m_l >1/2, then

$$0<A_{\bar{F}}\leq 3^N-1 \qquad (5)$$

B. Outage Probability

The outage probability, P_{out}, is defined as the probability that the received SNR per symbol falls below a given threshold-Y_{th}. This probability can be obtained as

$$P_{out}(\gamma_{th})=F_\gamma(\gamma_{th}). \qquad (6)$$

Where

$$F_\gamma(\gamma)=\frac{1}{\prod_{i=1}^{N}\Gamma(m_i)}G_{1,N+1}^{N,1}\left[\frac{\gamma}{\bar{\gamma}}\prod_{i=1}^{N}m_i\,\middle|\,\begin{matrix}1\\ m_1,m_2,\dots,m_N,0\end{matrix}\right], \qquad (7)$$

C. Average Symbol Error Probability

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The most straightforward approach to obtain the ASEP, $\overline{P}_{se}$, is to average the conditional symbol error probability $P_{se}(\gamma)$ over the PDF is

$$\overline{P}_{se} = \int_{0}^{\infty} P_{se}(\gamma)\, f_{\gamma}(\gamma)\, d\gamma \tag{8}$$

V. SIMULATION RESULTS

The analysis of free space optical communication system in the presence of atmospheric turbulence is presented with the channel modelling 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.

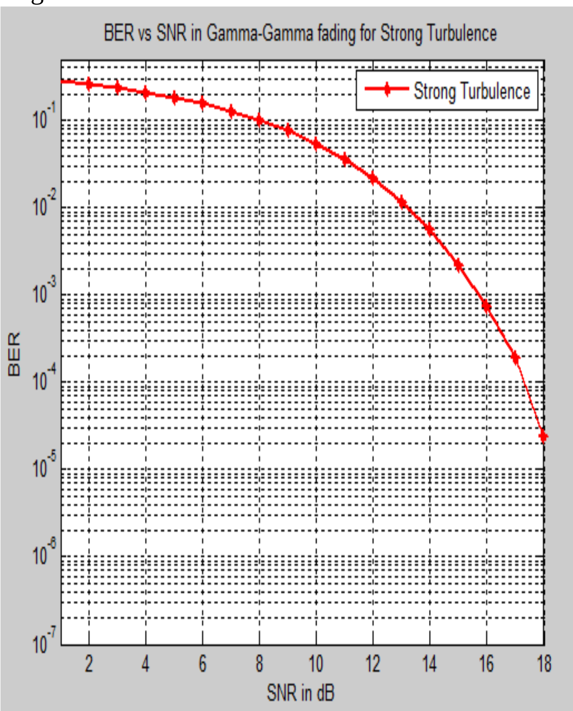

Fig. 2 Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with strong turbulence in free space optical communication system.

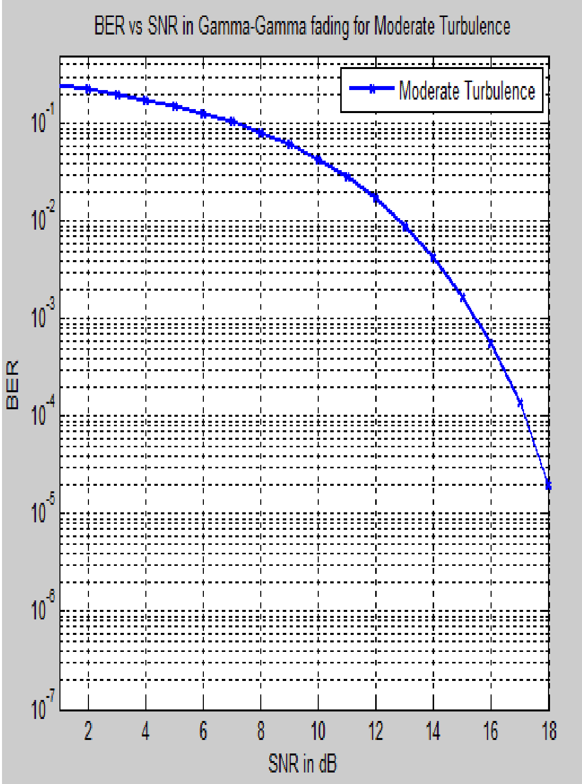

Fig. 3 Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with moderate turbulence in free space optical communication system.

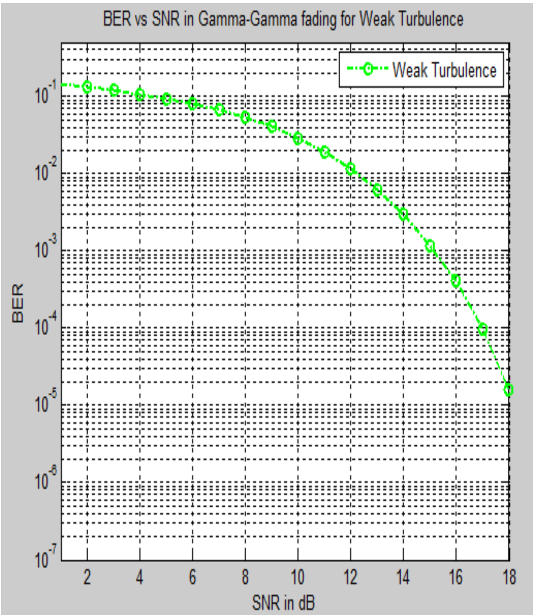

Fig. 4 Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with Weak turbulence in free space optical communication system.

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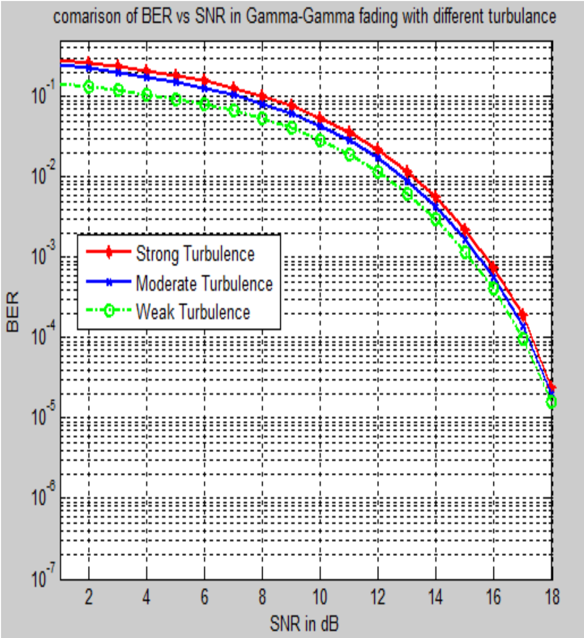

Fig. 5 Comparison of Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with different level of turbulence in free space optical communication system

Fig. 2 shows the Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with strong turbulence in free space optical communication system. Fig. 3 demonstrates the Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with moderate turbulence in free space optical communication system. Fig. 4 shows the Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with Weak turbulence in free space optical communication system. Fig. 5 reveals the Comparison of Bit error rate analysis of gamma-gamma distribution of Nakagami fading channel with different level of turbulence in free space optical communication system.

VI. CONCLUSIONS

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.

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