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Effect of Atmospheric Turbulences on BPSK

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Abstract: ***FSO (Free-Space Optical Communications) is a type of optical communication that is transmitted over an open space. The irradiance fluctuation in a clear atmosphere is caused by Temperature variations in the atmosphere are minor but erratic. As a result, the Signal-to-Noise Ratio (SNR) is reduced, and performance is reduced. BPSK has the best performance when scintillation is not considered. Thus, BPSK is investigated in this work under the impact of air turbulence and meteorological variables. The comparison of BPSK modulation scheme is done by simulating turbulence in Log Normal and Negative Exponential Channel.***

Keywords: Optical Wireless Communication, Modulation Schemes, BPSK, Turbulence, Log-Normal Distribution, Negative Exponential Distribution.

I. INTRODUCTION

This The Optical Wireless System has a number of benefits, including a high data rate, built-in security, and low battery consumption. It has an unlicensed optical wavelength that allows communication up to several kilometres and can communicate between the ground and satellites [1], [2]. It employs line-of-sight communication, which is widely used in a variety of applications. Inter chip communication, underwater communication, inter-city communication, inter satellite communication, visible light communication, and wireless body area networks are among the communication types [3], [4]. Because of its lower power consumption, FSO systems do not interfere with other wireless communication channels. It satisfies the need for increased data rates while maintaining secure wireless connection. However, atmospheric turbulence and varied weather conditions such as rain, haze, smoke, fog, snow, and mist have an impact on this technology. Fog weather and atmospheric turbulence have a significant impact on the FSO link. The performance of optical wireless communication systems has been studied in the presence of air turbulence [5].

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Under atmospheric and fog circumstances, this research investigates the performance of BPSK in FSO links in weak and strong atmospheric turbulences.

II. LITERATURE SURVEY

As we all know, there are different kinds of phase modulation schemes that fit for FSO communication systems. In this section, we will discuss the SNR, the bandwidth efficiency and power efficiency under different modulation schemes, but the atmospheric turbulence is not taken into consideration.

A. Binary Phase Shift Keying

All Binary Phase Shift Keying (BPSK) is a two-phase modulation system in which the 0s and 1s in a binary message are represented by two separate carrier signal phase states: binary 1 and binary 0[6]. Only one sinusoid is used as the basis function in BPSK.

Modulation is accomplished by adjusting the sinusoid's phase in response to the message bits.

As a result, the two differing phase states of the carrier signal are represented as, inside a bit period.

$$s_1(t) = A_c \, cos(2\pi f_c t), \qquad 0 \le t \le T_b \quad \text{for binary 1}$$
$$s_0(t) = A_c \, cos(2\pi f_c t + \pi), \quad 0 \le t \le T_b \quad \text{for binary 0}$$

The coherent detection technique uses the BPSK modulation technology. The laser is always used as the carrier in optical communication [7]. There are two ways for demodulation: homodyne detection and heterodyne detection.

In BPSK modulation, the phase shift is between 0 and 180 degrees. This technique's BER is given by the equation:

$$BER = 1/2erfc(\sqrt{SNR}$$

For BPSK, each bit of the modulating signal causes a transmitting symbol with Ts duration that is equal with the bit duration Tb. That is, the required bandwidth for BPSK is equal to the bit rate. BBPSK=Rb.

The BER equations can easily be used to calculate the power requirements. Using the normalised average power requirements of BPSK to NRZ-OOK in the situation of equal BER, the power need for BPSK may be stated as:

$$\frac{P_{BPSK}}{P_{NRZ-OOK}} = \frac{1}{2\sqrt{2}}$$

Theoretically, the NRZ-OOK requires as much as 2√2times power than BPSK to obtain a particular BER performance.

B. Log Normal Channel

For weak turbulence conditions, the lognormal distribution is an appropriate distribution model to imitate irradiance changes at the receiver's side due to the scintillation effect. The associated PDF file for is as follows:

$$f_{\gamma}(\gamma) = \left[\frac{1}{2\gamma\sigma\sqrt{2\pi}} exp\left(-\frac{(\ln(\gamma/\mu)+\sigma^2)^2}{8\sigma^2}\right)\right]$$

where $\sigma^2$is the variance of the lognormal distribution's planar wave which is directly proportional to scintillation index (SI).

SI is in the [0, 0.75] range for weak turbulence. Multiple scattering effects should be taken into account as turbulence strength increases. In these situations, lognormal statistics show huge variances as compared to data from experiments

C. Negative Exponential Channel

When there are huge irradiance changes and the link length is several kilometres, the number of independent scatters increases dramatically. Signal amplitude follows a Rayleigh distribution in this scenario, resulting in a negative exponential statistic for signal intensity (square of field amplitude). This is provided by:

$$\text{p(I)} = \frac{1}{I_0}\exp\left(-\frac{I}{I_0}\right), \text{I} \geq 0$$

where I_o is the mean radiance. Here σ^2=1 (or in the vicinity of 1).

III. BER UNDER ATMOSPHERIC TURBULENCE

The average bit error rate (BER) is a widely used metric for evaluating the reliability of OWC systems that have been subjected to turbulence-induced fading. This can be done by averaging conditional BER over the probability density function (PDF) of air turbulence statistically. For different modulation methods in an OWC system, the conditional BER can be expressed in terms of a Gaussian Q-function, i.e., Q(x) [10]. As a result, in weak turbulence, the BER of OWC systems is calculated using an integral involving the product of the Q-function and the PDF of the log-normal distribution. For an OWC, the conditional BER (Pec) [11] can be written as:

$$P=Q(\sqrt{\phi}o\gamma)$$

Where Q(.) is the Gaussian Q-function and 0 is a constant, which in OOK is 1=2 and in SIM-BPSK is 1. For two initial laser beam radius 0.03 and 0.09 m, Fig 1 [12] displays typical log (BER) values versus varied turbulent circumstances described by log Cn2. The laser wavelength was estimated to be 14 850 nm, and the computations were done at z 14 1000 m. The BER has relatively modest values during turbulence with weak refractive index variation, as shown in this figure, and climbs substantially with the Cn2. According to this diagram, the BER increases dramatically in turbulence when the refractive index fluctuation is greater, i.e., Cn2> 5x10-13 m-2/3.

The starting beam aperture is also very essential in the outcome, as seen in the figure. The larger the beam size, as shown in the figure, the lower the BER for similar atmospheric turbulence conditions. The effects of beam size on BER become minimal in turbulence with modest refractive index fluctuation, however, and the disparity between the two beams grows smaller. It should be mentioned that in commercial FSO systems, a BER of 10-10 is considered acceptable for reasonable performance.

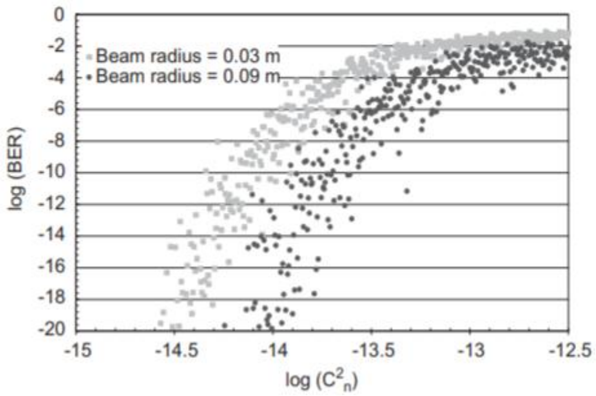

Fig.1. Typical values of BER versus different turbulent conditions characterized by Cn2 for two initial laser beam radius 0.03 and 0.09 m and laser wavelength l ¼ 850 nm for a receiver at distance z ¼ 1000 m. [12]

The average bit error rate (BER) can be described as:

P_e=0 f(I)Q(hI2N$_o$)dI.

Where, N0 represents noise, owing to erfc(x)= 2Q(2x), Q() is the Gaussian-Q function, substituting erfc() the average BER is represented as:

$$\bar{P}_e(I) = \int_0^\infty \frac{1}{2} erfc\left(\frac{1}{2}\frac{hI}{\sqrt{N_0}}\right)\frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})dI$$

For the convenience of the analysis, define h/sqrt(N_o) = δ thus, the average bit error rate can be simplified as:

$$\bar{P}_{e-BPSK} = \frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}} G_{2,3}^{2,2}\left[\frac{\alpha\beta}{\delta}\middle| \begin{matrix} 1-\frac{\alpha+\beta}{2}, \frac{1-\alpha-\beta}{2} \\ \frac{\alpha-\beta}{2}, -\frac{\alpha+\beta}{2}, \frac{\beta-\alpha}{2} \end{matrix}\right]$$

C_n^2 is the refractive index structure parameter that gives the spatial frequency. Values of different turbulence levels are given as below:

C_n^2 = 10^{-17} $m^{-2/3}$ for weak turbulence
= 10^{-15} $m^{-2/3}$ for moderate turbulence
= 10^{-13} $m^{-2/3}$ for strong turbulence

The value varies according on the location, altitude, and time of day. C_n^2 is virtually constant for horizontal path propagation. Because of the varied temperature gradients, the vertical/slant path varies with height. [11].

A. Scintillation Index

The main cause of scintillation is changes in the index of refraction (due to temperature variations), also known as optical turbulence.

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The Scintillation Index (SI), also known as "amount of turbulence caused fading," is used to describe the received intensity fluctuations. [12] is the SI, the main parameter indicating the strength of turbulence:

$$\sigma_{SI}^2 = \frac{\sigma 2}{E[I]^2} = \frac{E[I^2]}{E[I]^2} - 1$$

where I is the received intensity of the optical field after passing through a turbulent medium, and the square bracket "[ ]" signifies the ensemble average or equivalently a long time average. We can classify turbulence as weak or strong based on the SI value. Weak turbulence is defined as SI< 0.75, whereas high turbulence is defined as SI=1.

IV. SIMULATION AND DISCUSSION

We'll use the BER measure to demonstrate the impact of scintillation and noise on system performance under various channel circumstances. It should be noted, however, that while both subcarrier channels are BPSK modulated, their error performance will be similar, hence we will only show findings for one of them.

In plot 2 the BER vs. SNR curve was analyzed in it. Also, from that analysis' reference, the lognormal and negative exponential channel model was analyzed in MATLAB software. When the Log-normal distribution and the Negative Exponential Distribution are compared over the same SNR value, both simulations show that the data rate increases as the BER increases. Weak turbulence is represented by the Log-Normal channel, but high turbulence is represented by the Negative Exponential channel.

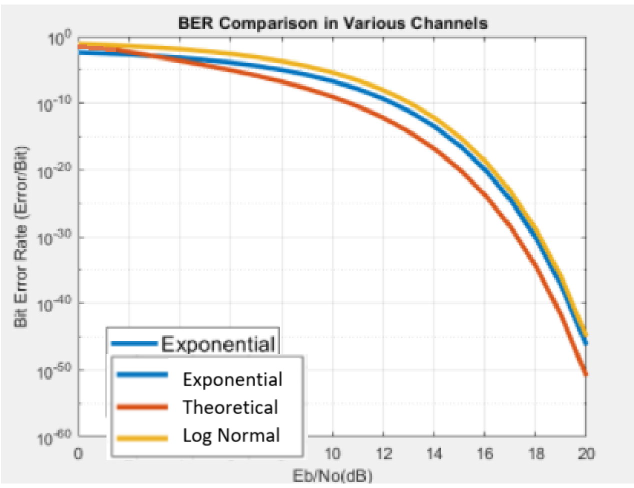

Fig.2. Simulation Of BER vs SNR for Log Normal and Negative Exponential Channel

From Fig. 2 it is clear that the modulation schemes work better in the negative exponential channel rather than in the log normal channel.

Fig. 3 illustrates the calculated BERs performance against the SNR in a weak atmospheric turbulence channel for BPSK with {σ^2 =0.16,0.30,0.42,0.64}.

Only modest turbulence conditions and propagation distances less than 100 m are suitable for this turbulence model. SI (Scintillation index) varies between 0 and 0.75 for weak turbulence. BER analysis of BPSK is simulated in MATLAB for different values of log irradiance (σ^2) using the lognormal model.

The SNR necessary to reach a desired BER increases with the intensity of atmospheric turbulence, as can be seen. In comparison to the channel where σ^2= 0.3025, an additional 3.4 dB of SNR is required to attain a BER of 10^{-3}. With increasing scintillation levels, the SNR necessary to obtain a BER of 10^{-6} increases further.

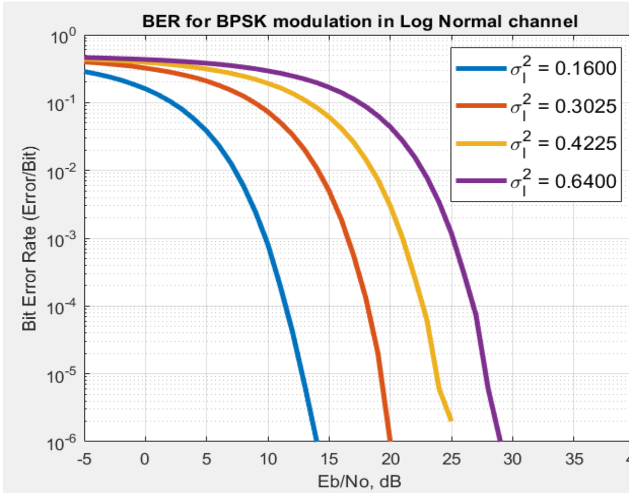

Fig. 3. The Simulated BER against the SNR in a weak atmospheric turbulence FSO channel with a scintillation {σ^2 =0.16,0.30,0.42,0.64}

It can we visually deduced from Fig 3 below, that the value of BER for BPSK is far below when the value of log irradiance variance (σ^2) is taken as 0.16 for the overall range of SNR (-5dB to 30dB). This low value of σ^2 implies lesser atmospheric turbulence and hence the value of BER is expected to be low for a particular SNR(5dB) for BPSK. However, as we tend to increase the variance of channel to 0.64, the amount of turbulence increases which causes degradation of link, thus, the efficiency of BPSK decreases as tabulated is Table I. BPSK is preferred when there's no channel turbulence.

TABLE I BER for BPSK Modulation when SNR= 5dB using Log Normal Channel.

Irradiance Variance (σ^2)	BER Values ($\times 10^{-3}$)
0.1600	0.0381
0.3025	0.2080
0.4225	0.3127
0.6400	0.3804

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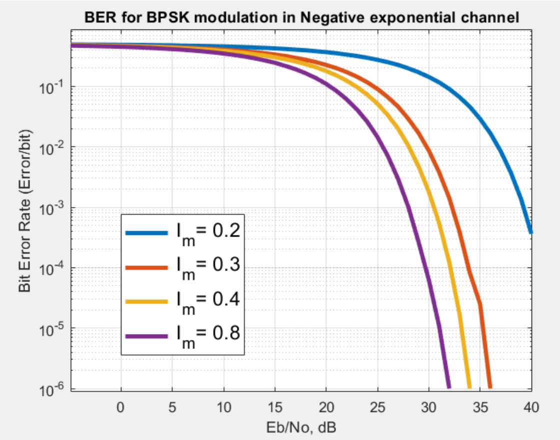

Fig. 4. BER for BPSK modulation in the Negative Exponential Channel.

TABLE II BER For BPSK Modulation when SNR= 5dB using Negative Exponential Channel.

Mean Radiance (I_m)	BER Values ($\times 10^{-3}$)
0.8	0.4137
0.4	0.4347
0.3	0. 4471
0.2	0.4764

Here in Fig. 4, we have varied the parameter I_m which is, mean irradiance in negative exponential channel. Inferring from the simulations we can say that to attain the same BER performance for log normal (weak) very large amount of SNR in required in Negative Exponential (strong). There is a decrease in normalized efficiency and there is typically a maximum value of normalized efficiency which is achieved when the irradiance is somewhere below a certain stated point. When we compare Table I and Table II for the same value of SNR i.e., 5dB, BER of Log-normal Channel is far low for the all values of irradiance (σ2) as compared to Negative Exponential Channel. Efficiency of BPSK is greatly affected as atmospheric turbulence is increased.

Thus, we may deduce that as atmospheric turbulence increases, the performance of the FSO link decreases, the predicament is made worse by the turbulence.

V. CONCLUSION

This research examines the BER expression for FSO communication systems using BPSK modulation across turbulence channels. Log Normal and Negative Exponential models are used to treat the atmospheric channels in this case. The performance disparity is due to differences in the methods used to encode information signals on the optical carrier. The received BPSK irradiance in negative exponential represents digital information, and any variation in the irradiance raises the risk of an error. In the Log Normal Channel, however, information is transferred by modulating the BPSK, which is less influenced by irradiance fluctuations. From the overall analysis, it is clear that the BER of BPSK modulation increases as scintillation increases and is more affected by strong turbulence. The average BER performance of the modulation schemes shows a direct drop after accounting for atmospheric changes. BPSK does not have tolerance for strong atmospheric turbulence and is preferred for weak atmospheric turbulence.

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AUTHORS PROFILE

Dr. Priyanka Bhardwaj, has done her Ph.D and M.Tech from IIT Delhi and B.Tech Hons. as university ranker from UPTU. She is currently working as Associate Professor in ECE department with ABES Engineering College and leading Research and Innovation group of her department. She has got three patents and published more than 30 research articles in reputed Journals and Conferences. She has more than 13 years of academic and research experience and is reviewer of various Journals. Her area of interest is Optical Wireless, Nano photonics and Plasmonic. She has recently been felicitated by AICTE for her Excellence in Teaching and Research.

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