Effect of Atmospheric Turbulence and Pointing Error on OOK in Free Space Optics

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Abstract— *Free Space Optical (FSO) communication has gained significant importance in several applications and wireless communication. Atmospheric conditions largely affect the performance of FSO system making the transmitted signal susceptible to the degrading effects of atmospheric turbulence and pointing errors. In this paper, an analysis OOK modulated signal is presented under different atmospheric conditions, with and without pointing error and then a brief comparison of the simulated results is done.*

Keywords —*FSO, Optical Wireless, On-Off Keying Pointing Error, Atmospheric turbulence, BER, SNR*

I. Introduction

Free Space Optics (FSO) is a wireless form of communication technology that uses light for the transmission of information through free space, that is, air or vacuum [1]. FSO is often referred to as Fiber-less Optics. In FSO, data is transmitted by propagation of light in free space allowing fiber optical connectivity. Free Space Optics is having the same features as that of fiber optics, but at a lower cost and higher speed [2]. Free Space Optics works on the principle of laser source driven technology which uses light sources at transmitter end and photo detector at receiver end to transmit and receive information, through the atmosphere same as Fiber Optics Communication (FOC) link, which also uses light sources and detectors but transmission is done via optical fiber cable [3]. FSO links have some distinct advantages over conventional radio frequency, microwave and optical fiber communication system by virtue of their very high carrier frequencies. It permits large bandwidth, highly secure connections, high data rate and so on. FSO systems are being considered for military systems application, because of their inherent benefits such as enhanced high security [4].

Nowadays, the main goal of modulation is to squeeze as much data into the least amount of spectrum possible. That objective known as spectral efficiency, measures how quickly data can be transmitted in an assigned bandwidth. Multiple techniques have emerged to achieve and improve the spectral efficiency [5]. There are many different types of modulation schemes which are suitable for FSO communication systems such as On-Off Keying (OOK), Pulse Amplitude Modulation (M-PAM), Differential Phase Shift Keying (DPSK), Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). Since the average emitted optical power is always limited, the performance of modulation techniques is often compared in terms of the average received optical power required to achieve a desired BER at a given data rate[6]. It is very desirable for the modulation scheme to be power efficient, but this is however not the only deciding factor in the choice of a modulation technique. In OOK modulation scheme, the information bits are converted into some specific code pulses (Non Return-to-Zero (NRZ), Return-to-Zero (RZ), Manchester, etc.), presence of a pulse denotes bit 1 and absence of a pulse denotes bit 0, during that slot. OOK is the simple and widely adopted modulation scheme used in commercial FSO communication systems because of ease in implementation, simple receiver design, bandwidth efficiency and cost effectiveness [5].

II. SYSTEM AND CHANNEL MODEL

A. SYSTEM MODEL

On-Off Keying is the most common modulation scheme employed in commercial terrestrial FSO communication systems. This is primarily due to its simplicity and resilience to the innate nonlinearities of the laser and the external modulator. OOK can use either Non Return-to-Zero (NRZ) or Return-to-Zero (RZ) pulse formats. In NRZ-OOK, an optical pulse of peak power "$\alpha_e P_T$" represents a digital symbol "0" while the transmission of an optical pulse of peak power "P_T " represents a digital symbol “1”. The optical source extinction ratio “αe” has the range $0 \leq \alpha e < 1$. The finite duration of the optical pulse is the same as the symbol duration “T” [6]. The probability of error for NRZ-OOK-coded optical data, detected with a photodiode, can be expressed as a function of the Signal-to-Noise Ratio (SNR) as in [6].

$$BER_0 = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right) \quad ()$$

In RZ-OOK, the required SNR is equal to half “- 3 dB ” of the required SNR of the regular NRZ-OOK to achieve the same BER performance, with the expense of doubling the bandwidth , and the BER for RZ-OOK can be expressed as a function of SNR as follows:

$$BER_0 = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2}\right) \quad (2)$$

Block diagram [Fig.1] shows the essential parts that comprise a free space optical communication system. It has a transmitter and a receiver and in between them an atmospheric channel. The binary sequence from the message signal allow the input to be either High or Low. The high signal closes the switch, allowing a carrier wave. Hence, the output will be the carrier signal at high input. When there is low input, the switch opens, allowing no voltage to appear. Hence, the output will be low.
The pulse shaping filter, shapes the pulse depending upon the amplitude and phase characteristics of the filter [10].

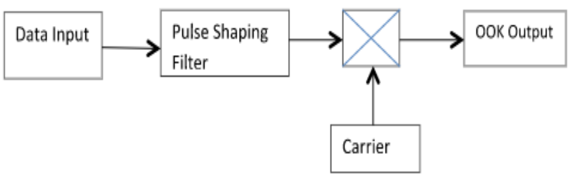

Figure 1: Block diagram of OOK modulator

Synchronous ASK detector consists of a Square law detector, low pass filter, a comparator, and a voltage limiter. Following is the block diagram for the same.

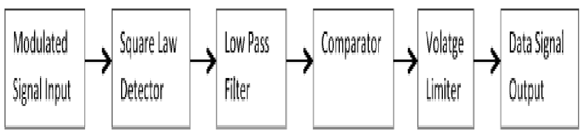

Figure 2: Block diagram OOK detector

The ASK modulated input signal is given to the Square law detector. A square law detector is one whose output voltage is proportional to the square of the amplitude modulated input voltage. The function of low pass filter is to minimize the higher frequencies. The comparator and the voltage limiter help to get a clean digital output.

B. ATMOSPHERIC TURBULENCE AND POINTING ERROR

Atmospheric turbulence refers to a random phenomenon that causes redistribution of the signal energy which results from the inconsistency in the refractive indices of the atmosphere. It results in intensity fluctuations and degradation of the optical beam [8]. For modelling of FSO link we need to account for atmospheric turbulences. The temperature and pressure fluctuation leads to variations in the refractive index which results in atmospheric turbulence. This atmospheric turbulence leads to an increase in the system’s bit error rate, therefore degrading the performance of FSO system [9]. A number of statistical channel models have been proposed to describe atmospheric turbulence conditions. We have used Log-Normal Channel model for simulations in this paper. The Log-Normal channel model is used for weak turbulence condition. It is widely used model due to its simplicity in terms of mathematical calculation. It is applicable for propagation distances less than 100 m. For weak turbulence, scintillation index SI falls in the range of [0,0.75]. Therefore for $\sigma_1^2<1$, log normal distribution is used [14]:

$$f(I)= 1/2\pi I\sigma^2 \exp[-(\ln(I)-m_i)^2/2\sigma_i^2] \quad (3)$$

Where m_i is the mean and σ_i the standard deviation of $\ln(I)$.

Another major challenge in FSO communication is pointing error. It is very important to maintain alignment and acquisition throughout the process of communication. Thermal expansions, dynamic wind loads and weak earthquakes result in the building sway that causes mechanical vibration of the transmitter beam leading to a misalignment between transmitter and receiver [7]. The effect of pointing error consists of three essential parameters: beam width, jitter and boresight displacement. The beam width represents the beam waist, the jitter represents the random offset of the beam center at receive aperture plane and the boresight represents the fixed displacement between beam center and the alignment point [11]. It should, however, be noted that there are two kinds of boresight displacements: the inherent bore sight displacement and the additional boresight error. The first of them is related to the spacing among receive apertures at the receiver. This inherent boresight displacement represents a fixed distance, i.e., the distance between each receive aperture and the corresponding alignment point. The second one is related to the bore sight error that is due to the thermal expansion of the building.

Pointing error can lead to link failure or can significantly reduce the amount of received power at the receiver resulting in high probability of error. To achieve pointing accuracy, proper care has to be taken to maintain sufficient bandwidth control and dynamic range in order to compensate for residual jitter. Also, pointing error loss is more significant at visible wavelength and decreases at higher wavelength due to inherent broadening of beam. The pdf of Hp can be derived using the assumptions and methodology described in [12]. The spatial intensity profile of the beam is assumed to be Gaussian with a beam waist represented as w_z , at the receiver plane at a distance z from the transmitter with a circular aperture of radius r. The fraction of the collected power due to geometric spread with radial displacement from the origin of the detector can be approximated as [13]:

$$H_p(r,z) \sim A_0 \exp\left(-\frac{\alpha.\alpha}{w_{zeq}^2}\right) \qquad (2)$$

where,

$$w_{zeq}^2 = w_z^2 \frac{\sqrt{\pi}\,\mathrm{erf}(v)}{2v \exp(-v.v)} \qquad (3)$$

$$A_0 = [\mathrm{erf}(v)]^2 \qquad (4)$$

$$v = (\sqrt{\pi}a)/(\sqrt{2}\, w_z) \qquad (5)$$

Here, hp is the attenuation due to misalignment and geometric spread of the beam.

III. SIMULATION AND RESULTS

The performance of On-Off Keying system under the effect of atmospheric turbulences in the presence and absence of pointing error described above is simulated using Matlab. A number of simulations were carried out using MATLAB R2015b. The system parameters, atmospheric turbulence and pointing errors have been given in Table 1.

TABLE 1:

Parameter	Value
Carrier Frequency	8GHz
Sampling Frequency	20MHz
Standard Deviation	0<sigma<0.75
Distance between Tx and Rx	1km
Receiver Diameter (2a)	40cm
Beam Radius (w_z)	2.5m

Channel matrix, H has been considered to be the product of matrix, H_a incorporating atmospheric turbulences while matrix, H_p incorporating pointing errors [24]. Also, H_a and H_p are considered to be independent of each other. The received signal, Y can be represented as:

$$Y = S*H_a*H_p + N \qquad (6)$$

where S is transmitted signal and N is noise. The figures below [3-5] shows Bit Error Rate versus Signal to Noise ratio curve for different atmospheric turbulences in the presence and absence of pointing error. Different turbulences simulated are 0.05,0.20 and 0.60 in figures [3-5]. It can be clearly seen that inclusion of pointing errors at a specific turbulence condition has increased the BER. Also, an increase in the individual curves for pointing error can be observed. Here, Table 2 represent gradual increase of σ, increases BER at SNR=5 db.

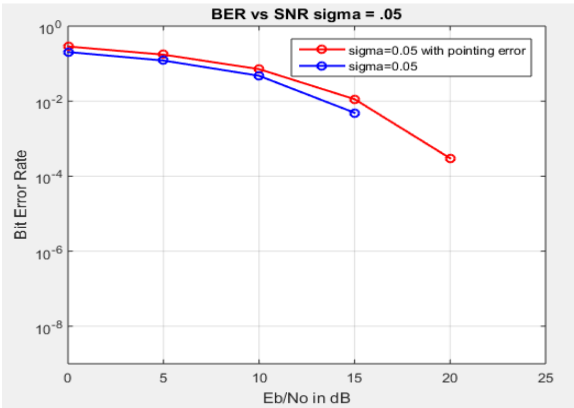

Figure 3: OOK Simulation with and without Pointing Error with σ = 0.05

In figure 3, the plot for BER vs SNR is shown for OOK modulated FSO signal for a particular value of σ=0.05 with and without pointing error. It can be seen that BER increases as we introduce pointing error.

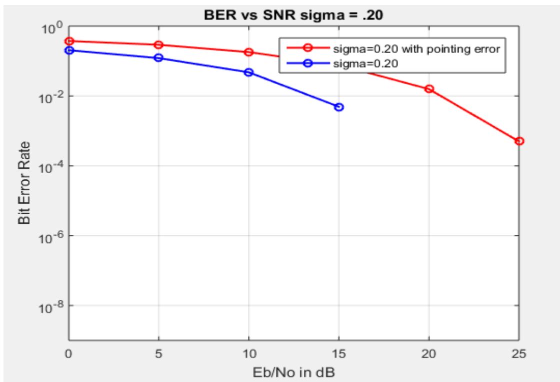

Figure 4: OOK Simulation with and without Pointing Error with σ = 0.20

In figure 4, the plot for BER vs SNR is shown for OOK modulated FSO signal for a particular value of σ=0.2 with and without pointing error. It can be seen that BER increases as we introduce pointing error, same as above.

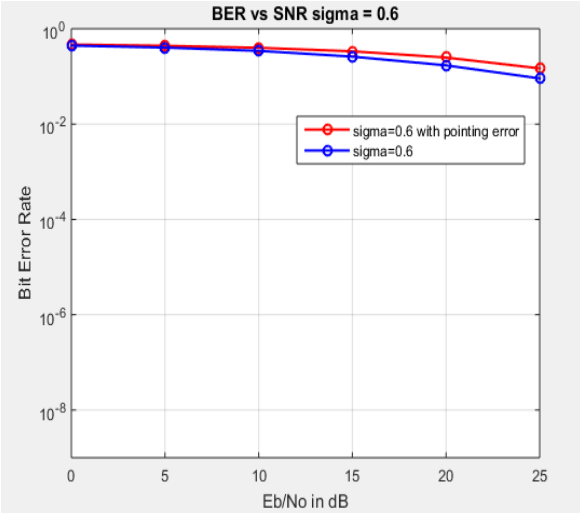

Figure 5: OOK Simulation with and without Pointing Error with σ =0.60

In figure 5, the plot for BER vs SNR is shown for OOK modulated FSO signal for a particular value of σ = 0.6 with and without pointing error. It can be seen that BER increases as we introduce pointing error.

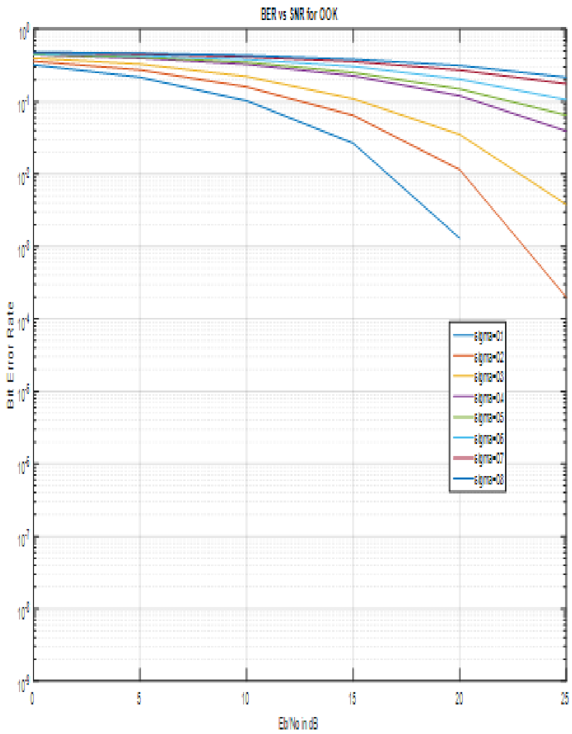

Figure 6: BER vs SNR for varying atmospheric turbulence

Figure 6 shows BER vs SNR curves for different values of atmospheric turbulence factor that is, for sigma values [0.1, 0.8]. It is observed as the value of sigma increases from 0.1 to 0.8, the BER also increases.

The following table shows the results obtained from above simulations for different values of atmospheric turbulence factor with and without pointing error. The values for BER at a particular SNR are stated in tabular form.

TABLE 2:

SNR (dB)	BER without Pointing Error	BER with Pointing Error
5	0.175	0.215
10	0.076	0.094
15	0.007	0.015

Table 2 shows the values of BER for corresponding SNR from the Figure 3 with the value of atmospheric turbulence factor, σ = 0.05

TABLE 3:

SNR (dB)	BER without Pointing Error	BER with Pointing Error
5	0.235	0.495
10	0.078	0.350
15	0.006	0.085

Table 3 shows the values of BER for corresponding SNR from the Figure 3 with the value of atmospheric turbulence factor, σ = 0.2

TABLE 4:

SNR (dB)	BER without Pointing Error	BER with Pointing Error
5	0.755	0.785
15	0.575	0.605
25	0.090	0.135

Table 4 shows the values of BER for corresponding SNR from the Figure 3 with the value of atmospheric turbulence factor, σ = 0.6

VII. CONCLUSION

This research paper provides a detailed analysis of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR) for Free Space Optical signal. OOK modulation scheme has been analyzed regarding both atmospheric turbulence and pointing error effects and simulations are done by incorporating different values of atmospheric turbulence and pointing error. It can be observed from the simulations obtained that there is an increase in the Bit Error Rate as the Atmospheric Turbulence factor (σ) is increased which means FSO link is highly dependent on atmospheric conditions. This can be concluded from Figure 6 showing the BER vs SNR for varying values of sigma.

In the first set of simulations in Figure 3 also shown in Table 2, we compare the BER-SNR curves of OOK modulation scheme with and without pointing error for sigma value equal to 0.05. It was observed that the BER in the presence of pointing error is slightly increased as compared to BER without pointing error at a particular value of E_b / N_o.

For the next plot of BER vs SNR in Figure 4 also shown in Table 3, two plots are simulated showing the value of BER with and without pointing error at a slightly higher value of sigma equal to 0.2. Here it was observed that BER is increases on introducing pointing error. And the BER at a particular SNR for sigma=0.2 is higher than sigma = 0.05.

For the next plot of BER vs SNR in Figure 5 also shown in Table 4, two plots are simulated showing the value of BER with and without pointing error at a slightly higher value of sigma equal to 0.6. Here it was observed that BER is increases on introducing pointing error. And the BER at a particular SNR for sigma=0.6 is higher than sigma = 0.05 as well as sigma = 0.2.

Thus we conclude Bit Error Rate is affected by both atmospheric turbulence and pointing error. These two factors degrade the FSO transmitted signal. Choice of modulation scheme plays a large role in determining the extent to which these factors affect the transmission. As the turbulence coefficient increases, bit error rate increases. OOK scheme is the simplest scheme and is proved as an optimal modulation scheme in cases where there is power or cost restrain. Further, OOK with similar atmospheric turbulences shows a very little increase in bit error rate when pointing errors are incorporated.

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