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

Swadha Agarwal[#1], Priyanka Bhardwaj[*2]

[#1] Department of Electronics and Communication Engineering, Bharati Vidyapeeth College of Engineering, A-4 Paschim Vihar, Delhi-110063, India

[*2]Faculty, Department of Electronics and Communication Engineering, Bharati Vidyapeeth College of Engineering

A-4 Paschim Vihar, Delhi-110063, India

Abstract— *Free Space Optical (FSO) communication has become an important area for research with its numerous advantages over conventional communication systems. But with the set of advantages, there are some limitations which need to be addressed. Atmospheric conditions prominently affect the performance of FSO system making them highly susceptible to degrading effects of atmospheric turbulence and pointing errors. In this research paper, simulation of Quadrature Phase Shift Keying (QPSK) modulated FSO signal is done for various turbulence conditions with and without pointing error to analyze the effect of turbulence on the transmitted signal. Parameters like Bit Error Rate (BER) and Signal to Noise Ratio (SNR) are considered for simulation.*

Keywords - *FSO, Pointing Error, Atmospheric turbulence, Quadrature Phase Shift Keying (QPSK)*

I. INTRODUCTION

(Free Space Optics (FSO) is an optical wireless Line Of Sight (LOS) communication technology that uses light for the transmission of information through air or vacuum. In FSO, data is transmitted by propagation of light in free space allowing fiber optical connectivity. Free Space Optics is having the same capabilities as that of fiber optics, but at a lower cost and very high speed. Free Space Optics works on the principle of laser source driven technology which uses light sources at transmitter end and detector at receiver end to transmit and receive information, through the atmosphere [1]. FSO links have some distinct advantages over conventional microwave, radio frequency and optical fiber communication system by virtue of their very high carrier frequencies that permit large capacity, enhanced high security, high data rate and so on. [2]

In examining FSO performance, it is important to take several system parameters into consideration. Although there are many advantages of FSO, there is a lot of scope for improvement by choosing the correct modulation scheme which is least susceptible to the degrading effects of atmospheric channel. Thus, this paper focuses on the two main challenges faced by the transmitted signal which are atmospheric turbulence and pointing error. These topics along with the modulation scheme will be studied in detail in the subsequent topics. For this paper, focus will be on Quadrature Phase Shift keying (QPSK) and after simulations will be done for the same. The next two sections explain what QPSK modulation technique refers to and the QPSK modulator system.

II. QPSK MODULATION

This type is one of the variants of PSK modulation which uses four different points on the constellation diagram, equally spaced around a circle to represent the data bits. These four phases help the QPSK to encode two bits per symbol while representing the data [3].

The QPSK constellation diagram is shown in Figure 1. It is just a geometric representation of the signal.

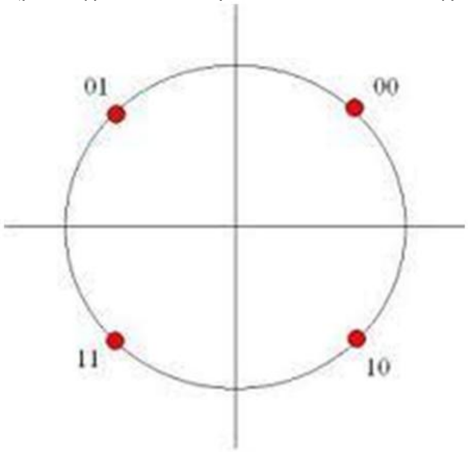

Figure 1: QPSK Constellation Diagram

The QPSK can be used to double the data rate compared with a BPSK system while it maintains the same bandwidth of the signal. The QPSK can also work in a manner, in which it maintains the data-rate of BPSK but make the bandwidth requirement half as compared to BPSK [4]. The BER equation of QPSK modulation is simplified as [5]:

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

III. BLOCK DIAGRAM FOR FSO COMMUNICATION

Figure 2 shows the modulator of Quadrature Phase Shift Keying. At the input of the modulator, the digital data's even bits (i.e., bits 0,2,4 and so on) are stripped from the data stream by a "bit-splitter" and are multiplied with a carrier to generate a BPSK signal. At the same time, the data's odd bits (i.e., bits 1,3,5 and so on) are stripped from the data stream and are multiplied with the same carrier to generate a second BPSK signal. However, the second signal's carrier is phase shifted by 90^o before being modulated.

The two BPSK signals are then simply added together for transmission and, as they have the same carrier frequency, they occupy the same portion of the radio frequency spectrum. While this suggests that the two sets of signals would be irretrievably mixed, the required 90^o of phase separation between the carriers allows the sidebands to be separated by the receiver using phase discrimination [3].

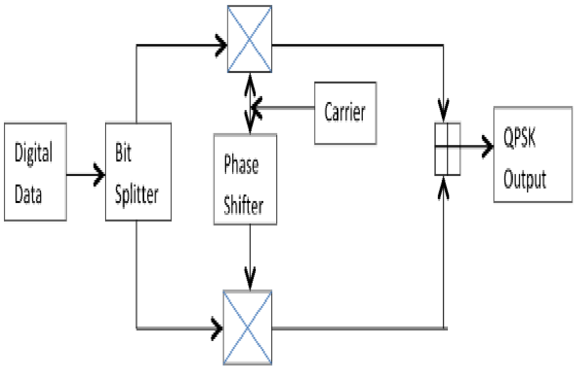

Figure 2: Block diagram of QPSK modulator

In this paper, QPSK technique of modulation is used to simulate the FSO transmitted signal.

IV. POINTING ERRORS AND SYSTEM MODEL

In optical wireless systems, a major performance limiting factor is the turbulence induced fading, that is, rapid fluctuations of the irradiance of the propagated optical signals caused by atmospheric turbulence, which can be accurately modeled using different channel models. [6]

The atmospheric turbulence is caused by both temporary and special random fluctuations of the refractive index along the optical propagation path. Clear air turbulence impairs the performance of the FSO due to the fluctuation in the intensity of the laser beam. [7]

Another effect which mitigates significantly the performance of the FSO systems is the pointing errors of the optical beam at the alignment between the transmitter and the receiver, which inserts additional irradiance fluctuations. The FSO receivers are usually installed on tall buildings or towers. In spite of the fact that they are mounted stiffly, small movements of the transmitter are inevitable due to wind loads, building sway, small earthquakes, etc., provoking proportional sways of the optical beam on the receiver's plane. The effect of pointing error consists of three essential parameters: beam width, jitter and boresight displacement [11]. 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. It should, however, be noted that there are two kinds of boresight displacements: the inherent boresight 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 boresight error that is due to the thermal expansion of the building. 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 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 α from the origin of the detector can be approximated as [13]:

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

Where,

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

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

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

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

$$Y = S*H_a*H_p + N \tag{6}$$

where S is transmitted signal and N is noise.

Pointing error has significant impact on BER performance of FSO system. By referring to the two criteria, namely bit error rate (BER) and signal to noise ratio (SNR), this work includes analysis of the effect of atmospheric turbulence on FSO systems in Log normal channel model.

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].

V.SIMULATIONS AND RESULTS

The performance of QPSK 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 R2015a.

TABLE 1:

Parameter	Value
Carrier frequency	8 GHz
Sampling frequency	20 MHz
Standard deviation (turbulence)	0<sigma<0.75
Distance between Tx and Rx	1 km
Receiver diameter (2a)	40 cm
Beam radius (w_z)	2.5 m

Table 1 shows the different parameters used for simulations with their values. For each value of turbulence factor (σ), the graph for QPSK is plotted with and without pointing error.

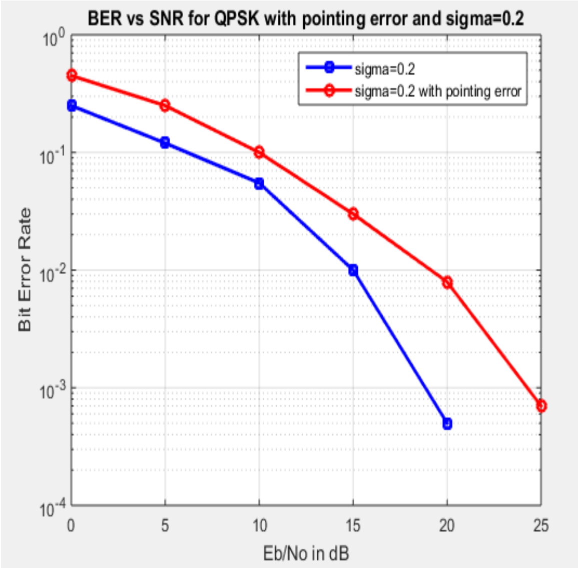

Figure 3: BER vs SNR for QPSK with and without Pointing Error with σ = 0.2

In figure 3, the plot for BER vs SNR is shown for QPSK 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.

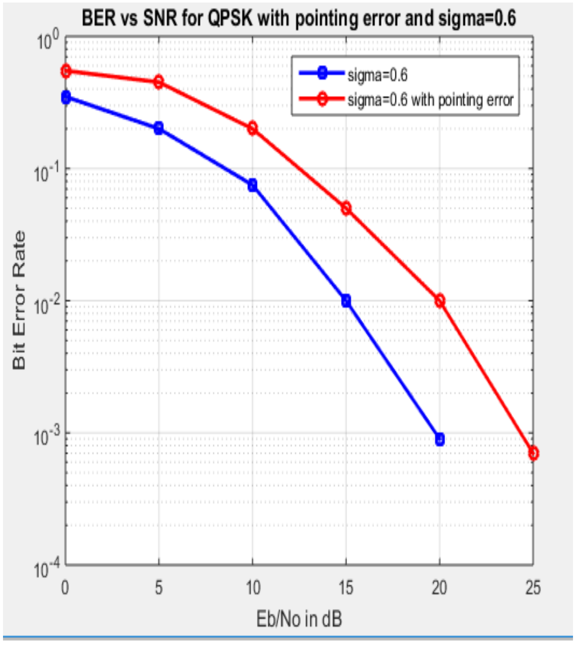

Figure 4: BER vs SNR for QPSK with and without pointing error with σ = 0.6

In figure 4, the plot for BER vs SNR is shown for QPSK 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.

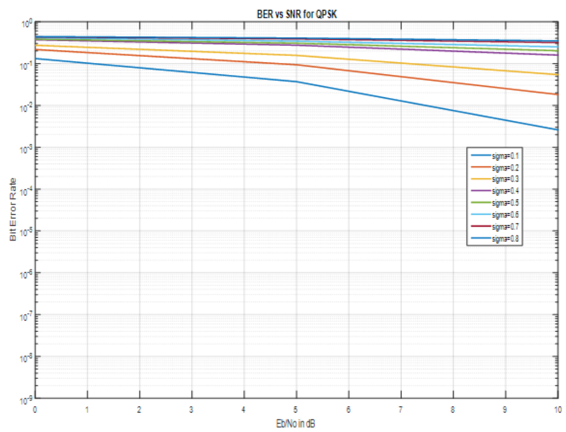

Figure 5: BER vs SNR for varying Atmospheric Turbulence

Figure 5 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 results simulated above are also shown in tabular form. Increase in Bit Error Rate on introducing pointing errors can be clearly seen in the following two tables.

TABLE 2:

SNR (dB)	BER without Pointing Error	BER with Pointing Error
5	0.125	0.250
10	0.055	0.100
15	0.010	0.030

Table 2 shows the values of BER for corresponding SNR from the Figure 3 with the value of atmospheric turbulence factor, σ=0.2

TABLE 3:

SNR (dB)	BER without Pointing Error	BER with Pointing Error
5	0.200	0.450
10	0.085	0.200
15	0.010	0.050

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

VII. CONCLUSION

This research paper provides a comprehensive analysis of Bit Error Rate versus Signal to Noise Ratio for Free Space Optical signal. QPSK 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 5 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 QPSK modulation scheme with and without pointing error for sigma value equal to 0.2. It was observed that the BER in the presence of pointing error becomes almost double 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 0.6. 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 = 0.2.

Thus we conclude Bit Error Rate is affected by many conditions like choice of modulation scheme, atmospheric turbulences, pointing errors etc. As the turbulence coefficient increases, bit error rate increases. Further, QPSK with similar atmospheric turbulences also shows increased bit error rate when pointing errors are incorporated. For a specific value of E_b/N_o, bit error rate has been observed. On comparing the results of QPSK with other modulation schemes, it is found that QPSK offers greater immunity to the degrading effects of the atmospheric turbulences and pointing error [18].

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