Comparison of OOK, BPSK, QPSK, 8-PSK and PAM-16 for Optical Wireless for Weak Atmospheric Turbulence

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***Abstract*— In free space optical communication, the effect of atmospheric turbulence, which causes fluctuations in received optical power, is inevitable. Based upon inhomogeneity in refractive index, the atmospheric turbulence can be classified into weak, moderate and strong turbulence. In this paper, analysis of FSO link for various modulation schemes such as OOK, BPSK, QPSK, 8-PSK and PAM-16 is carried out for Log-normal channel model (weak turbulence). BER is plotted with respect to SNR. Further, it is deduced that PAM-16 modulation scheme is better for overall range of SNR (-5 to 20 dB) considering log irradiance variance (σ_I^2) greater than 0.56**

***Keywords*— Free Space Optical (FSO) Communication, Log-Normal Channel Model, Bit Error Rate (BER), Atmospheric Turbulence, Log Irradiance Variance, Refractive Index Structure Parameter.**

1. INTRODUCTION

FSO (Free Space Optics) is a technology in which data is transmitted by propagation of light in free space allowing optical connectivity. Optical fiber cable is not required as medium for transmitting data. Working of FSO is similar to optical fiber cable networks but the only difference is that the optical beams are sent through free air instead of OFC cores which is glass fiber. FSO system consists of an optical transceiver at both ends to provide full duplex (bi-directional) capability. It is not a new technology. It has been in existence from 8th century but now is more evolved [1]. FSO is a LOS (line of sight) technology, where data, audio and video communication is achieved with maximum 10Gbps of data rate by full duplex connectivity. Problems with bandwidth efficiency have been known through some time in industries because of excessive use of bandwidth for signal transmission in FSO technology. This problem can be solved in evolved FSO technology due to its high bandwidth availability [7].

2. CHANNEL MODELS FOR FSO

According to the temperature and pressure gradients, there are irradiance fluctuations in the received signal which results in distortion and beam broadening of received spectrum [3]. As per the different levels of turbulent conditions such as weak (S.I. <1), moderate (S.I. =1) and strong (S.I. >1), where S.I. is Scintillation Index. Various statistical channel models for transmission in free space are developed which are Gamma-Gamma channel model, Log-Normal model, K–channel distribution, I-K channel model, Negative exponential model, etc. [4]. In this paper, we have discussed 2 types of channel models.

2.1 LOG-NORMAL Channel Model

Log normal model is widely accepted because of its simplicity in terms of mathematical calculations. The lognormal probability density function describes the scintillation and fading statistics of weak turbulence. Considering the log normal model, the probability density function of received optical signal is given by:

$$p(I) = \frac{1}{\sqrt{2\pi\sigma^2}}\frac{1}{I}exp\left\{-\frac{(\ln(I/I_0)-m_i)^2}{2\sigma^2}\right\}, I \geq 0 \quad (1)$$

Where, I_o is the normalized irradiance arrived at each receiver end; σ represents the log irradiance variance; m_i is mean log intensity.

Log-normal channel model is suitable only for short distance ranges to 100 meter because as distance increases it encounters with elements in the atmosphere causing fading and scattering. It is only valid for weak turbulence conditions because as the strength of turbulence increases, scattering effects are also taken into consideration due to which detection and fading probabilities are not accurately analysed. To quantify the amount of variation of refractive index in the medium, refractive index structure parameter (C_n^2) is used [1]. For a horizontally propagating field via turbulent medium, the refractive index structure parameter and log irradiance variance are related as [1]:

$$\sigma_l^2 = 1.23 C_n^2 k^{7/6} L_p^{11/6} \quad (2)$$

Where, wave number k = 2π/λ, L_p is horizontal distance of optical irradiance, C_n^2 is refractive index structure parameter and σ_l^2 is log irradiance variance. So, there is a direct relation between σ_l^2 and C_n^2.

2.2 NEGATIVE EXPONENTIAL Channel Model

For strong atmospheric turbulences where link length is in the range of several kilometers, number of scatter becomes large results in fading which is assumed to be a random process. In that case signal amplitude follows a Negative-exponential distribution for the signal intensity given as [2]:

$$p(I) = \frac{1}{I_0} exp\left[-\frac{I}{I_0}\right], \; I_0 > 0 \quad (3)$$

Where, E[I] =I_o is the mean received irradiance. During the saturation regime, the value of the scintillation index, S.I→1.

3. Modulation Schemes

We can modulate the carrier wave by its frequency, amplitude and phase. Amplitude modulation with direct detection is the simplest scheme commonly used to implement.

3.1 OOK Modulation

On Off Keying or more popularly known as Amplitude Shift Keying is a modulation scheme in which binary 1 is represented by the presence of carrier and binary 0 is represented by the absence of carrier. This is one of the most simple modulation techniques.

3.2 BPSK Modulation

Phase Shift Keying or Binary Phase Shift Keying is a modulation scheme in which binary 1 is represented with actual carrier and binary 0 is represented with 180-degree phase shift of the carrier.

3.3 QPSK Modulation

Quadrature Phase Shift Keying is a modulation scheme in which 2 bits as a bunch is transmitted. Using 2 bits there are 4 possible symbols. Change in the bit of a symbol causes a 90 degree phase shift with respect to the original symbol.

3.4 8-PSK Modulation

It is modulation scheme in which three bits as a symbol are transmitted. Using three bits there are 8 symbols possible. There are eight phases corresponding to eight symbols of the scheme.

3.5 PAM Modulation

Pulse amplitude modulation is a modulation scheme in which the carrier is pulsed in nature. In this scheme amplitude of the pulse i.e. carrier, is varied according to the message signal. In PAM-16, 4 bits as a bunch is transmitted. For 4 bits, we have 16 different possible symbols.

4. Simulation and Discussion

4.1 BER analysis of LN model with different modulation schemes ($\sigma_l^2 = 0.36$)

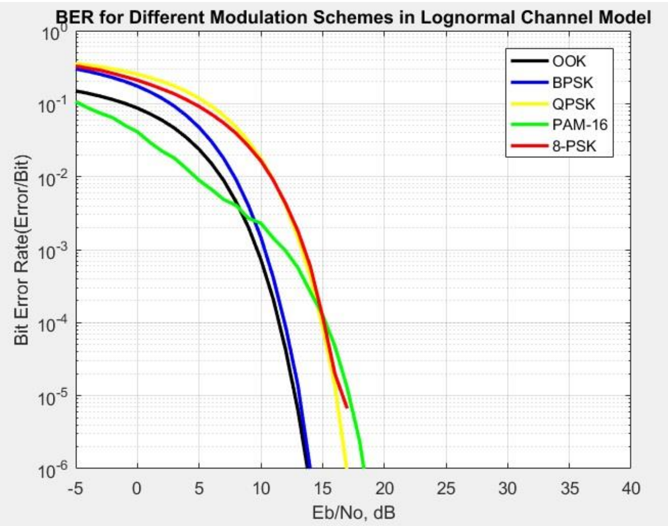

Fig. 1 Variation of BER with respect to SNR comparing OOK, BPSK, QPSK, 8-PSK and PAM-16 using Log-Normal Channel Model for log irradiance variance σ_l^2=0.36

In fig. 1, the standard deviation parameter (σ_l) was taken to be 0.6, hence log irradiance variance (σ_l^2) is 0.36. This low value of σ_l^2 implies lesser atmospheric turbulence and hence value of BER is expected to be low for a particular SNR for each of the modulation technique.

The plot in fig. 1 shows comparison between different modulation schemes for weak atmospheric turbulence using Log-Normal Model. For fig. 1, log irradiance variance is taken as 0.36 and BER is observed least for PAM-16 modulation at lower SNR values and for OOK at higher SNR values. Hence, for lower SNR values (< 8dB) PAM-16 is preferred and for higher SNR value (8-20dB) simpler modulation techniques like OOK, BPSK would work fine by providing least Bit Error.

TABLE I
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 5dB AND $\boldsymbol{\sigma_l^2}$ = 0.36 USING LOG-NORMAL CHANNEL MODEL

Modulation	BER Values (× 10^{-3})
PAM-16	8.92
OOK	23.69
BPSK	47.24
8-PSK	91.47
QPSK	118.50

TABLE II
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 13dB AND $\boldsymbol{\sigma_l^2}$ = 0.36 USING LOG-NORMAL CHANNEL MODEL

Modulation	BER Values (× 10^{-3})
OOK	0.0064
BPSK	0.0140
PAM-16	0.5682
8-PSK	1.8130
QPSK	1.8150

4.2 BER analysis of LN model with different modulation schemes ($\sigma_l^2 = 0.56$)

In this case, the value of log irradiance variance (σ_l^2) is increased to 0.56 and as a result the Bit Error rate is also increased for all the modulation schemes. This increase in BER is because σ_l^2 is directly proportional to C_n^2 which is evident from equation (2). C_n^2 (refractive index structure parameter) is parameter which describes the amount of unevenness in the channel's refractive index, which is responsible for degradation of link.

The second plot, from fig. 2, log irradiance variance is taken as 0.56, which indicates more atmospheric turbulence strength than the previous case. In this scenario, the BER values for PAM-16 are least for the whole range of values as tabulated in table III and IV.

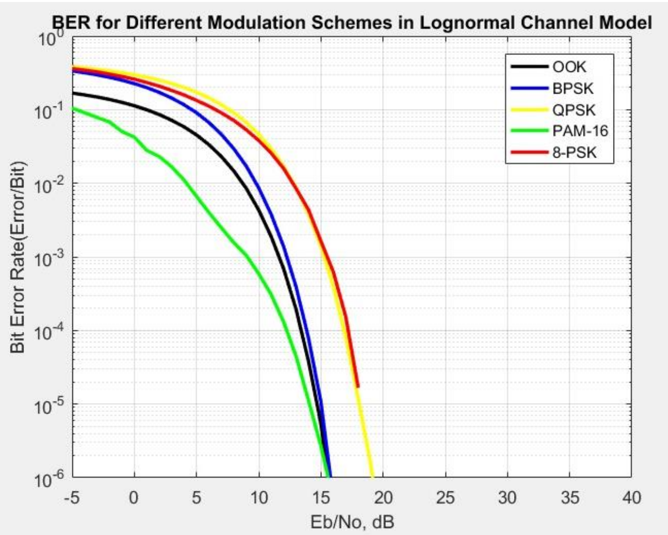

Fig. 2 Variation of BER with respect to SNR comparing OOK, BPSK, QPSK, 8-PSK and PAM-16 using Log-Normal Channel Model for log irradiance variance $\boldsymbol{\sigma_l^2}$=0.56

TABLE III
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 5dB AND $\boldsymbol{\sigma_l^2}$ = 0.56 USING LOG-NORMAL CHANNEL MODEL

Modulation	BER Values (× 10^{-3})
PAM-16	6.63
OOK	45.41
BPSK	90.70
8-PSK	133.40
QPSK	172.10

TABLE IV
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 13dB AND $\boldsymbol{\sigma_l^2}$ = 0.56 USING LOG-NORMAL CHANNEL MODEL

Modulation	BER Values (× 10^{-3})
PAM-16	0.0449

OOK	0.1950
BPSK	0.3947
8-PSK	8.4870
QPSK	8.7580

4.3 BER analysis of LN model with different modulation schemes ($\sigma_l^2 = 0.72$)

From fig. 3, it can be visually deduced that PAM-16 has far low BER for overall range of SNR (-5 to 20 dB) if log irradiance variance (σ_l^2) is further to 0.72. The resultant BER values for variance as 0.72, is tabulated in table V and VI at SNR 5 dB and 13 dB respectively.

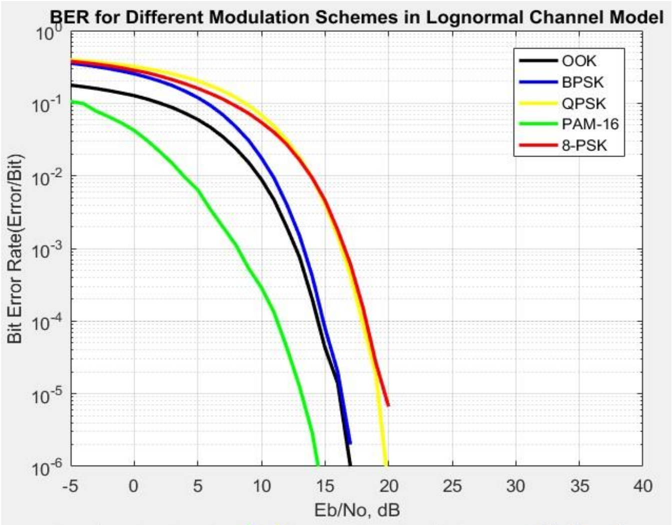

Fig. 3 Variation of BER with respect to SNR comparing OOK, BPSK, QPSK, 8-PSK and PAM-16 using Log-Normal Channel Model for log irradiance variance σ_l^2=0.72

TABLE V
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 5dB AND σ_l^2 = 0.72 USING LOG-NORMAL CHANNEL MODEL

Modulation	**BER Values (× 10^{-3})**
PAM-16	6.41
OOK	59.49
BPSK	119.40
8-PSK	159.80
QPSK	202.40

TABLE VI
COMPARISON OF OOK, BPSK, QPSK, 8-PSK AND PAM-16 FOR SNR = 13dB AND σ_l^2 = 0.72 USING LOG-NORMAL CHANNEL MODEL

Modulation	**BER Values (× 10^{-3})**
PAM-16	0.013
OOK	0.760
BPSK	1.498
8-PSK	16.550
QPSK	17.970

5. RESULT AND CONCLUSION

The FSO link proposed in this paper is analyzed considering weak turbulent condition and channel length to be in range of 100 meter; hence it is modeled by Log-Normal channel model. Five modulation schemes were implemented in the proposed FSO link, namely OOK, BPSK, QPSK, 8-PSK and PAM-16. The parameter used to distinguish the amount of turbulence is log irradiance variance (σ_l^2). The mentioned model, with all essential parameters was simulated on the MATLAB software.

The results of the simulation suggested that for weak turbulences i.e. for Log-Normal channel with log irradiance variance as 0.36 for smaller values of SNR, it was observed that PAM-16 has the best performance. On gradually increasing the value of SNR, OOK overtook to be the best performer. On further increasing value of log irradiance variance (σ_l^2), it was observed that PAM-16 has the best performance over entire range of SNR for values of σ_l^2 greater than 0. To conclude with, as value of log irradiance variance (σ_l^2) increases, indicating more atmospheric turbulence, the Bit Error Rate in received signal also increased for OOK, BPSK, QPSK and 8-PSK. But, on the other hand PAM-16 modulated signal has lesser BER at receiver as σ_l^2 was increased. If complexity and power are constraints then OOK is favorable otherwise PAM-16 is best suitable option. Therefore, PAM-16 has shown best results for $\sigma_l^2 \geq 0.56$ in free space optical channel considering weak turbulence in medium.

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