Performance Analysis of OFDM-FSO System using BPSK, QPSK and 8-PSK Modulation Techniques

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ABSTRACT
This paper analytically investigates bit error rate (BER) performance of Free Space Optical (FSO) system. The FSO which is rapidly gaining popularity for its cost effectiveness and efficient means of transferring high data rates as well as optical fiber, whose data rate is limited by the atmospheric turbulence and scintillation conditions are studied. Orthogonal Frequency Division Multiplexing (OFDM) based Free Space Optical (FSO) communication is a technique which combines two developed technologies to enhance the performance of wireless optical communication system. The FSO channel modeled under atmospheric turbulence of Gamma-Gamma Distribution using BPSK, QPSK and 8-PSK modulation techniques. The performance analysis shows that the system performance improves with different PSK modulations applied to the OFDM-FSO system, the obtained results are the comparative study of Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR), can be useful designing, predicting and evaluating the FSO systems.

General Terms
Atmospheric Turbulence, Bit Error Rate, Optical fiber, Optical communication, Scintillation, Signal to Noise Ratio

Keywords
BPSK, FSO, Gamma-Gamma Distribution, OFDM, QPSK, 8-PSK

1. INTRODUCTION
Optical communication has played a significant although hidden role in our everyday life as the backbone of communication networks. This is a field that seems to appeal to those researchers and engineers with an interest in the physical aspects of optical communications. Thus, optical communication devices are often modelled and designed from physicist's point of view. An initial hurdle faced by early means of wireless communication was the enormousheat generated by pumped laser action. However, in the late 1960's, semiconductor laser was developed and ever since, the possibilities for laser communication have grown [1]. The Free Space Optical (FSO) Communication is developed to achieve the high data rates in wireless medium, which is often used as an efficient alternate of fiber cable network. When deployment becomes difficult and broadband connectivity is in scarce, FSO is becoming an easy solution to the IP connectivity. FSO communication which recently signifies its importance as in provides essential combination of qualities required to bring the traffic load to the fiber back bone. Virtually unlimited bandwidth, low cost, ease of deployment and excellent security are among of the most attractive features of FSO. It is becoming a good solution for a high speed point to point communication between fixed locations on lands and on moving platforms also [2].

But being free space, atmospheric conditions are threat to this LOS system (i.e. FSO link). The system gradually affected by rain, fog, snow, dust, cloud and temporary obstructions too. FSO terrestrial links are also affected by scintillations and atmospheric turbulence, which is defined as the fluctuations of irradiance caused by the temperature and pressure variance in the atmosphere that result in power variation of RF signal at the receiver, atmospheric conditions like scattering, absorption and scintillation affect the performance of the link to a large extent [3]. The development in semiconductor laser and photodetector fabricating technology is augmenting the popularity of FSO. Wireless access is facilitated by this use of radiofrequency over optical fiber popularly called RoF- Radio over Fiber. At the same time this facility can be used only if fiber network is installed already. Similar to above, researches are concentrating towards RF signal over FSO links which are referred as Radio over Free Space Optics (RoFSO) [4].This new approach which integrates the radio frequency transmission and optical fiber links takes the advantage of high transmission capacity and the enormous bandwidth availability. This new emergence is enabled by the development in optoelectronic devices and ease of wireless deployment [5].

Orthogonal Frequency Division multiplexing (OFDM) is a popular modulation/multiplexing technique for broadband wireless communication which is robust to multipath fading and frequency selective fading [6]. By this virtue, OFDM has become a modulation technique for IEEE 802.11a Wireless Local Area Network and IEEE 802.16 standards. Combining OFDM with FSO gives rise to OFDM based FSO which will exploit the advantages of both becomes a good candidate for "last mile" solution for broad band connectivity with high speed data rates [7].

This paper presents a comparative study of impact of the different modulation techniques over the OFDM based FSO system. Also this approach evaluates that which modulation scheme is better for the OFDM-FSO system. The performance of the modulated FSO relates with the data rate of the system shows the variations with different modulation schemes, variations in both type of system has been plotted as the curve of BER vs. SNR for various values.

2. OFDM-FSO SYSTEM
OFDM-FSO system support high data rates by splitting a high-rate data-stream into a number of low-rate data-streams andtransmitting these over a number of narrowband subcarriers. The narrowband subcarrier data-streams experience smaller distortions than high-speed ones and

require no equalization. Moreover, most of the required signal processing is performed in the free space domain. This is advantageous because microwave devices are much more mature than their optical counterparts and because the frequency selectivity of microwave filters and the frequency stability of microwave oscillators are significantly better than that of corresponding optical devices. The subcarriers are themselves modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM) and are then carried on a high frequency carrier [8]. The OFDM signal for N subcarriers, after up-conversion to the wireless service carrier frequency f_c, can be written as:

$$S_{OFDM}(t) = \sum_{n=0}^{N-1} s_n(t)$$

The first raw data is mapped according to different types of modulation techniques (BPSK, QPSK, 8-PSK, 16QAM, 64QAM), depending upon data rate. Representing the equation (1) in complex data symbol,

$$S_{OFDM}(t) = \sum_{n=0}^{N-1} X_n \exp(j(\omega_n + 2\pi f_c)t), \qquad 0 < t < Ts$$

The above equation represents each symbol X_n is amplitude modulated on orthogonal subcarriers. This process is performed using the IFFT which guarantees that all the subcarriers are orthogonal to each other over the symbol interval. Here, we set the guard interval to zero and thus the OFDM symbol duration Ts equals to the Fourier analysis window. The $s_{OFDM}(t)$ is real by enforcing the conjugate-symmetry (Hermitian symmetry) of the IFFT input vector, The first input X_0, corresponding to the zero frequency, needs to be real-valued and is generally left unmodulated. This approach with real-valued IFFT output is used in digital subscriber line (DSL) systems and is known as Discrete Multitone (DMT). Due to frequency selectivity, the subcarriers experience in general different channel gains which can be mitigated through the use of many narrow subcarriers. The signal $s_{OFDM}(t)$ is then used to modulate the optical intensity of laser diode (LD) to be transmitted through fiber optics [9].

OFDM can be simply defined as a form of multicarrier modulation where its carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers and can be separated at the receiver by correlation techniques, hence, inter symbol interference among channels can be eliminated. The set of orthogonal carriers is realized by using the inverse fast Fourier transform (IFFT) at the transmitter. In addition, the channel estimation based on block type pilot arrangement is performed by sending pilots at every sub-channel and using this estimation for a specific number of following symbols [10]. The input signal is taken as series of bits/symbols which are base band modulated also called mapping. This converts the signal into complex form. The mapped signal is converted from serial to parallel form and IFFT is computed to obtain the OFDM symbol. To the generated OFDM symbol, cyclic prefix (CP) bits/guard bands are added for improved system performance followed by parallel to serial conversion and digital to analog conversion. At the receiver, the reverse process is carried out after being detected by the photo diode and FFT is taken to convert the OFDM symbol back into complex bit sequences. De-mapping converts the complex signal into original bit sequences.

3. ATMOSPHERIC TURBULENCE CHANNEL MODEL

In FSO channel, the atmospheric turbulence causes irradiance fluctuations, known as scintillation, on the received signals propagating along a horizontal path near ground. Scintillation is mainly caused by small temperature variations in the atmosphere, resulting in refraction-index random variations. Different statistical models have been proposed over the years to describe the atmospheric turbulence channels for varying degrees of strength. The atmospheric turbulence optical channel has been intensively studied and various models have been proposed to describe turbulence induced performance degradation and intensity fluctuations, in this paper Gamma-Gamma modelling is used[11]

$$p_x(x) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} X^{\frac{\alpha+\beta}{2}} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta x}\right), \qquad x > 0$$

where Γ(·) is the Gamma function, K(·) is the modified Bessel function of the second kind of order n, α and β are the effective numbers of small scale and large scale eddies of the scattering environment and defined for spherical wave with aperture-averaged scintillation as [12]

$$\alpha = [\exp\left\{\frac{0.49\sigma^2}{(1 + 0.18d^2 + 0.56\sigma^{12/5})^{7/6}}\right\} - 1]^{-1}$$

$$\beta = [\exp\left\{\frac{0.51\sigma^2 + (1 + 0.69\sigma^{12/5})^{-5/6}}{(1 + 0.9d^2 + 0.62d^2\sigma^{12/5})}\right\} - 1]^{-1}$$

where$\sigma^2 = 0.5C_n^2 k^{7/6} L^{11/6}$and d=$\sqrt{(\pi D^{2/} 2\lambda L)}$, D(m) is the diameter of the receiver collecting lens aperture, λ(m) is the wavelength, L(m) is the link distance, and $C^2_n(m^{-2/3})$ is the refractive index structure parameter. The scintillation index S.I. can be expressed in term of α and β as follows:

$$S.I. = \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\alpha\beta}$$

The gamma–gamma distribution is more general model, which includes the results of the K-distribution model (i.e. whenβ=1). For weak turbulence regime, the probability density function (PDF) of the intensity fluctuation is modelled as lognormaldistribution, whereas for moderate to strong regimes, the gamma–gamma distribution is used [13]. The gamma–gamma model describes both small-scale and large-scale atmospheric fluctuations and factorizes the irradiance as the product of two independent random processes, each having a gamma PDF.

4. DETECTION OF FREE SPACE SNR

The performance of a receiver is often based on the notion of signal-to-noise ratio SNR, i.e., the rms signal power over the rms noise power. For photon-noise limited performance, the mean SNR fora direct detection system is [14],

$$SNR = \frac{SNR_O}{\sqrt{\left(\frac{P_{s_o}}{P_s}\right) + \sigma^2(D)SNR_O}}$$

whereP_{So} is the signal power in free space, P_S is themean signal power, $\sigma^2(D)$ is the irradiance flux variancefor an aperture of diameter D, and SNR_O is the free-spaceSNR defined by,

$$SNR_O = \sqrt{\frac{\eta P_{S_O}}{2h\nu B}}$$

System performances for continuous wave (CW) or singlepulse optical systems are based on SNR and fade probability. For digital transmission of information, the performance measure is based on the probability of error, also called the bit error rate BER. The OFDM-FSO system link parameters and their numerical values used for simulations are given in the table1:

Table 1: OFDM-FSO Link Parameters

SYMBOL	PARAMETERS	VALUE
h	Plank's constant	6.63 x 10^{-34} J-sec
η	Detector quantum efficiency	0.6 electrons/photon
L	Distance between transmitter and receiver	10000 m
e	Electric charge	1.6 x 10^{-19} C
B	Bandwidth	1.93 x 10^{13} Hz
P_{So}	Transmitted power	50 mW
ν	Optical frequency	2.5 x 10^{11} Hz
k	Boltzmann's constant	1.374 x 10^{-23} JK^{-1}
T	Temperature	300K
T_S	Symbol duration	4 μs
N	Number of subcarriers	52
R_L	Load resistance	50 Ω
R	Photo detector responsivity	0.8 A/W

5. RESULTS & DISCUSSION

In this section, there aresimulation results presented using MATLAB™by implementing the various baseband modulation techniques i.e. BPSK, QPSK and 8-PSK modulation techniques over the OFDM-FSO system link, these techniques are used as the modulation schemes over the FSO link. The paper shows the analytical study of BER vs. SNR for the OFDM-FSO system implementation for various modulation techniques. The free space SNR has been defined by the above equation, the value of SNR_O is inversely proportional to the scintillation index (S.I.), if the scintillation index is increased the value of SNR_O is decreased. TheSNR_O is derived by the equation and values for the evaluation is given in table 1 for the ease of simulation. The above given formulation and value of SNR_O is used for the system implemented with OFDM. The comparison among the modulation techniques based on the variation of BER values over the same power of FSO system. The comparison of these techniques has been explained in following sub-sections.

5.1 Analysis of OFDM-FSO System with BPSK Modulation

In this approach the FSO system is been modulated by the BPSK modulation technique, over this link OFDM system is applied. The resultant curve is between BER and SNR, which shows the BER is increased over the same SNR after implementing OFDM. At 7.6dB of SNR the BER of the system with OFDM 10^{-4}. Fig. 1 represents the BER vs. SNR curve indicates that data rate increases as per as the BER increases over the same SNR value, also analyses that OFDM technique is efficiently used with the FSO system, with BPSK modulation.

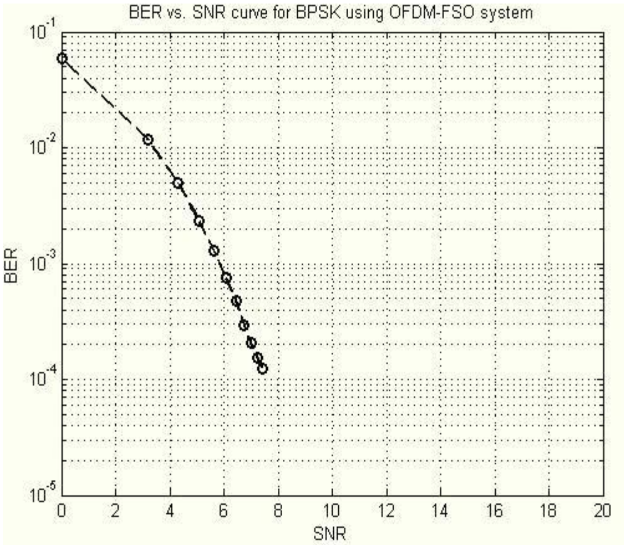

Fig. 1 BER vs. SNR curve for OFDM-FSO system with BPSK Modulation

5.2 Analysis of OFDM-FSO System with QPSK Modulation

Furthermore, another case is of QPSK modulation applied over the FSO link with OFDM. As in BPSK--FSO modulation vice-versa is done with the QPSK-FSO system. With OFDM QPSK-FSO modulation the BER is approximate 10^{-3} at SNR of 9 dB.so, that data rate is increased as the result of bit error rate is analyzed. Fig. 2 shows the results of BER vs. SNR for QPSK modulated system.

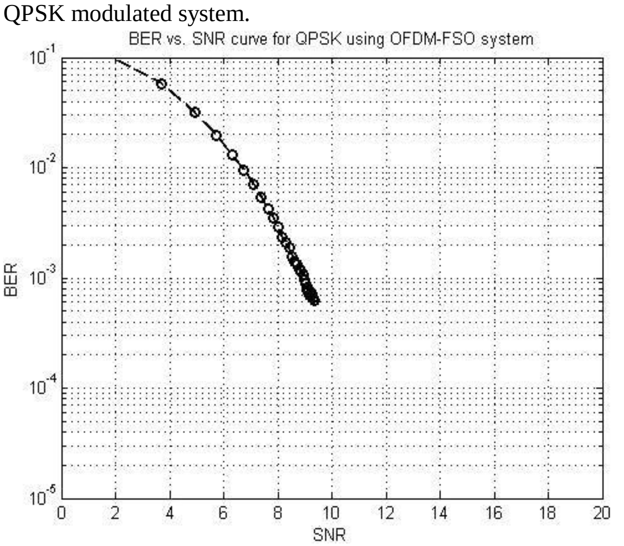

Fig. 2 BER vs. SNR curve for OFDM-FSO system with QPSK Modulation

5.3 Analysis of OFDM-FSO System with 8-PSK Modulation

Another modulation technique is used is 8-PSK modulation over FSO system. The resultant curve of BER vs. SNR in case of 8-PSK modulation with OFDM system is given by Fig.3 which shows that improvement in BER at SNR of 9.5dB.Results of all figures shows that OFDM system gives a improved performance if applied with FSO system link.

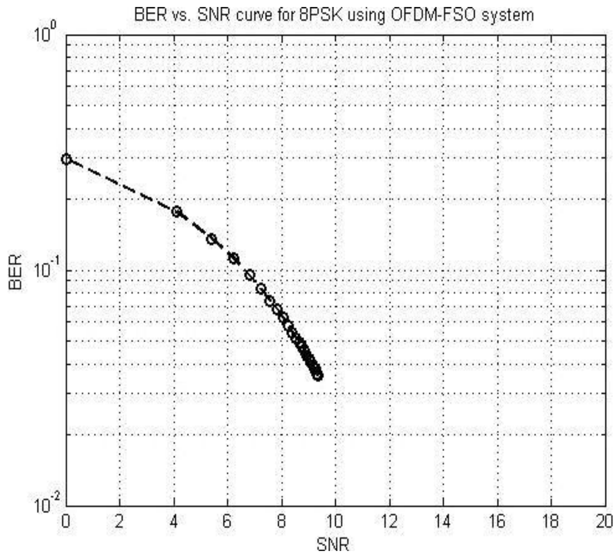

Fig. 3 BER vs. SNR curve for OFDM-FSO system with 8-PSK Modulation

5.4 Comparative Study of BPSK, QPSK and 8-PSK Schemes

The modulation techniques used in this paper is to be compared for their performance with OFDM-FSO system. Fig. 1, Fig.2 and Fig. 3 shows the results that as per the modulation levels increased, the data rate is also increased. The relative study of the effect of OFDM implementation over the FSO links demonstrates that OFDM is highly impactful over the FSO. So, that it can be categorized in different cases to make the clear comparison:

Case 1.BPSK-FSO System vs. QPSK-FSO System

Fig. 1 shows that bit error rate for BPSK modulated OFDM-FSO system is approximate 10^{-4}, compares to QPSK modulated system achieved bit error rate is 10^{-3} which is shown in Fig.2, this result represents that in same power adapted systemif modulation levels are increased the bit error rate also increases. In this case the BPSK modulated system gives better performance compares to QPSK system

Case 2.BPSK-FSO System vs. 8-PSK-FSO System

The analysis for BPSK and 8-PSK system is done by Fig. 1 and Fig. 3 shows that 8-PSK modulated OFDM-FSO system link achieves 10^{-2} bit error rate as BPSK modulated system has 10^{-4} bit error rate. It shows that the BPSK modulation technique with OFDM-FSO system gives better performance than 8-PSK modulated OFDM-FSO system.

Case 3. QPSK-FSO System vs. 8-PSK-FSO System

The case for QPSK and 8-PSK modulations, Fig. 2 and Fig.3 indicates that the resultant of 8-PSK modulation scheme bit error rate is approximate 10^{-2} than QPSK modulated system which results 10^{-3} of bit error rate for thesame system. Both the techniques are applied over OFDM-FSO link which results that the QPSK system is more appropriate to be used with the OFDM-FSO system link than 8-PSK scheme.

6. CONCLUSION

This paper has analysed several modulation techniques with OFDM over a FSO link. From equation (8) the free space SNR is evaluated, it shows that the free space SNR is increased as the scintillation index decreases. The values has been given in table 1, which is been used in this paper for the simulation and analysis of OFDM-FSO system link. Also the results shows that increasing the levels of modulation increases the bit error rate, which indicated to the better modulation scheme for the OFDM-FSO system is BPSK modulation

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