Performance of OFDM based FSO Communication Systems using M-Ary PSK Modulation

M. Selvi
Associate Professor/ECE,
Saveetha Engineering College
Thandalam, Chennai, INDIA

K. Murugesan
Professor and Head / ECE
SreeSastha Institute of Engg.and Technology
Chembarambakkam, Chennai, INDIA

ABSTRACT
In this paper, the performance of Radio on Free Space Optics (RoFSO) a cost effective and efficient method of wireless transmission that supports high data rate of communication as compared to optical fiber, whose data rate is limited by dispersion and nonlinearity is studied. The performance primarily depends on atmospheric conditions which is the recent area of study. OFDM based FSO, is a hybrid technique that combines the two developed technology namely OFDM and FSO to enhance the performance of wireless optical communication system. The performance of OFDM based FSO is evaluated under weak turbulent condition using PSK baseband modulation. The performance analysis shows that 3 to 5 dB SNR improvement is obtained for such system compared with RF wireless OFDM system.

General Terms
Scintillation, PSK Modulation, Wireless Channel

Keywords
Free Space Optics, Log-normal Distribution, OFDM, Radio on FSO, Turbulence Modeling

1. INTRODUCTION
The concept of data transmission on light through free space started with the invention of LASER. But due to heavy attenuation experienced, optical fiber was invented and has tremendously improved the data rate of communication. The data rate over fiber is limited by its dispersion characteristics. In order to meet the demand for high speed communication through wireless medium,Free Space Optics (FSO) is more promising. FSO is more often suggested as an alternative solution to fiber network, when deployment becomes difficult and broadband connectivity is in scarce. It is now a day's becoming an easy solution for IP connectivity. Maintaining a clear Line Of Sight (LOS) between transmitter and receiver is essential for effective communication. But being free space, the atmospheric weather condition poses threat to this LOS. The LOS is affected by fog, rain, snow, dust cloud and temporary obstruction like crossing of birds. Under various atmospheric conditions, optical signals suffer from absorption, scattering etc. Fog being one of the major threat to FSO, it is extensively studied and various probabilistic models have been proposed for these conditions [1,2].

FSO terrestrial links are also affected by scintillations or optical turbulence, which is defined as the fluctuation of irradiance caused by the temperature and pressure variations along the path of the signal, that result in power variation of RF signal at the receiver. Optical signal attenuation and fluctuations are represented by various distributions like Wakeby, Log Normal, Weibull, Kumarasamy etc. [3]. In general the atmospheric turbulence is represented by Probability Density function since the phenomenon being random in nature. But atmospheric conditions like scattering, absorption and scintillation affect the performance of the link to a large extent. The link may sometimes become infeasible due to severe weather conditions. 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 technique that combines the radio frequency transmission and the optical fiber link takes the advantage of high transmission capacity and the enormous bandwidth available. This new emergence is enabled by the development in optoelectronic devices and ease of wireless deployment [5].

Orthogonal Frequency Division multiplexing 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 OFDM and FSO to become a good candidate for "last mile" solution for broad band connectivity [7].

In this paper we study the impact of PSK baseband modulation technique that is used for the OFDM signal at the transmitter. We evaluate the M-ary PSK modulation for different values of M, the number of symbols on a subcarrier. The performance of FSO- OFDM is compared with its performance in wireless environment. Bit Error Rate curve is plotted for various values of M. The remainder of the paper is arranged as follows: Section 2 describes system turbulencemodel and aperture averaging technique. FSO-OFDM system model is dealt in section 3. In section 4, the simulation proof for the choice of wavelength with Gaussian beam and the improvement in performance for M- aryPSK with the helpof BER analysis is discussed. Section 5 contains the concluding remarks

2. SYSTEM MODEL
2.1 Turbulence Modeling
The transmission in free space encounters challenges due to random changes in the local atmospheric state. Many factors contribute to this change, but more of serious consideration for free space link is fluctuation of refractive index. This turbulent condition is caused by the temperature and pressure

variation creating constructive and destructive interference called fading [8].

Laser can produce beam in the form of plane wave, spherical wave orGaussian wave. Laser beam is chosendepending upon the type of link. For example, plane and spherical beam are commonly used for optical link through free space i.e. both uplink and downlink whereas Gaussian beam is found suitable for terrestrial link applications [9].

At the transmitter, Gaussian beam along the direction of propagation is characterized by two main parameters viz., the beam spot radius W_o, which is defined as the distance between beam axis and the point where the intensity drops by $1/e^2$ of the maximum value and the radius of curvature of the phase front F_o, that defines beam forming. For any free space optical communication system, two types of parameters are defined- Input Plane parameter at the transmitter and Output Plane parameter at the receiver [9].

For Gaussian beam, the input plane beam parameter includes curvature parameter $\Theta_o = 1 - (L/F_o)$ and the Fresnel Ratio $\Lambda_o = 2L/kW_o^2$ where L is the distance between transmitter and the receiver and $k = 2\pi/\lambda$ is the propagation constant. The output plane parameters are

$$\Theta = \Theta_o / (\Theta_o^2 + \Lambda_o^2) = 1 - (L/F) \quad (1)$$

$$\Lambda = \frac{\Lambda_o}{\Theta_o^2 + \Lambda_o^2} = \frac{2L}{kW^2} \quad (2)$$

where F is the radius of curvature at the receiver and W is the beam spot radius at the photo detector which is given as

$$W = W_o (\Theta_o^2 + \Lambda_o^2)^{1/2} \quad (3)$$

The irradiance of optical beam is the square of the amplitude of the optical field and it is a function of radial distance from the optical axis and the distance between transmitter and the receiver. It is defined by

$$I(r, L) = I_o \left[\frac{W_o}{W}\right]^2 \exp\left[-\frac{2\pi^2}{W^2}\right] \quad (4)$$

where $I_o = I(0,0)$ is the transmitter output irradiance at its center.

The relation between irradiance and power in the beam is given as

$$P_R(D, L) = I(0, L)\frac{\pi D^2}{4} \quad (5)$$

where$I(0, L)$ is the irradiance for the case r=0 and D is the receiver lens aperture diameter.

2.2 Aperture Averaging

The atmospheric turbulence causes both temporal and spatial fluctuations of irradiance which is referred asscintillation. Being random in nature, its normalized variance is called Scintillation Index given by

$$\sigma_I^2 = \frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2} \quad (6)$$

where the ensemble averages are considered for the Intensity of the optical signal and its squared value. The extent of turbulence is represented by Rytov variance given as

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

where $C_n^2 = (m^{-2/3})$ is refractive index structure parameter.

Scintillation levels are divided into three regimes based on Rytov variance: Weak regime $\sigma_R^2 < 0.3$, Moderate regime $0.3 \leq \sigma_R^2 \leq 5$ and Strong regime $\sigma_R^2 \geq 5$ [10-13].

Received signal power variance depends on the receiver aperture. This dependence is exploited to reduce the effect of power variation. Instead of using point receiver, lens with aperture of diameter larger than the large scale eddies are used. It averages the fluctuations over its aperture and hence reduces the scintillation induced fading relative to a point receiver. This fading reduction with the help of aperture average effect is termed as Aperture Averaging and is represented by [9]

$$A = \frac{\sigma_I^2(D)}{\sigma_I^2(0)} \quad (8)$$

where$\sigma_I^2(D)$and $\sigma_I^2(0)$ are the scintillation index for a receiver diameter D and a point receiver respectively.

For Gaussian beam wave model the scintillation index $\sigma_I^2(D)$ can be written as

$$\sigma_I^2(D) = \exp(\sigma_{\ln x}^2(D) + \sigma_{\ln y}^2(D)) - 1 \quad (9)$$

The large and small scale log irradiance are defined as

$$\sigma_{\ln x}^2(D) = 0.49\sigma_R^2\left(\frac{\Omega_G - \Lambda}{\Omega_G + \Lambda}\right)^2\left(1 + 0.56\sigma_B^{\frac{12}{5}}\right)^{-\frac{7}{6}} x\,(1 + 0.4\eta x(2-\Theta)/(\Omega G+\Lambda)-7/6 \quad (10)$$

$$\text{and}\,\sigma_{\ln y}^2(D) = \frac{0.51\sigma_B^2}{\left(1+0.69\sigma_B^{12/5}\right)} \times \frac{1}{1+1.2\left(\frac{\sigma_R^2}{\sigma_B^2}\right)^{6/5}\frac{\left(1+0.69\sigma_B^{12/5}\right)}{(\Omega_G+\Lambda)}} \quad (11)$$

where$\overline{\Theta} = 1 + \Theta$ is a complementary parameter, $\Omega_G = 16L / kD^2$ is a Fresnel ratio characterizing the spot radius of the receiver collecting lens, η_x is an artificial variable given by

$$\eta_x = \frac{\left(0.33 - 0.5\overline{\Theta} + 0.2\overline{\overline{\Theta}}^2\right)\left(\frac{\sigma_R^2}{\sigma_B^2}\right)^{6/7}}{(1+0.56\sigma_B^{12/5})} \quad (12)$$

andσ_B^2 corresponds to the Rytov variance for a Gaussian-beam wave given by

$$\sigma_B^2 = 3.86\,\sigma_R^2\left\{\frac{2}{5}[(1+2\theta)^2 + 4\Lambda^2]^{\frac{5}{12}} \times \cos\left[\frac{5}{6}\tan^{-1}\frac{(1+2\theta)}{2\Lambda}\right] - \frac{11}{6}\Lambda^{5/6}\right\} \quad (13)$$

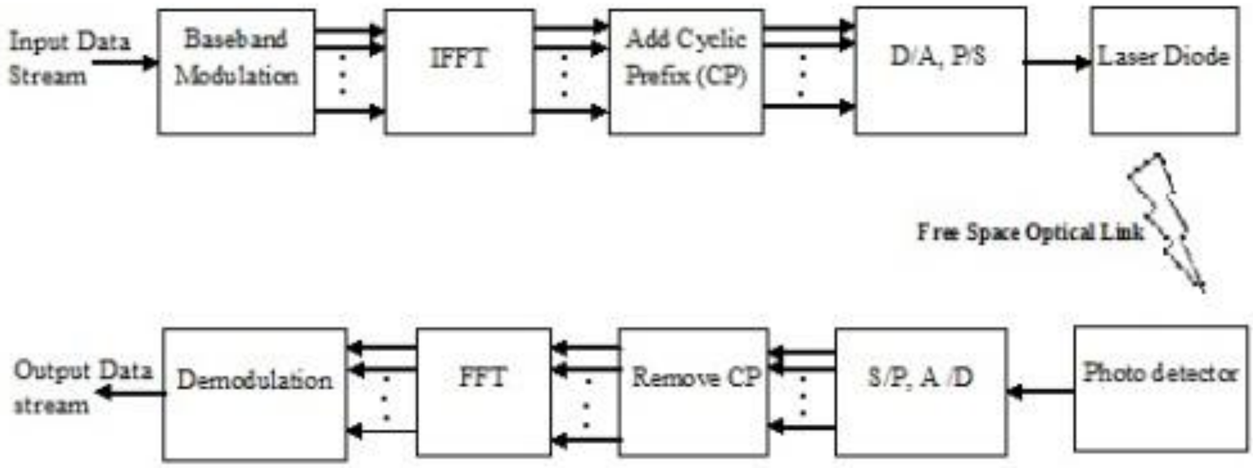

Fig. 1 Block Diagram of FSO-OFDM System

When aperture averaging is employed, the irradiance fluctuations are represented by the log-normal distribution. The PDF of such distribution is given by

$$p(I) = \frac{1}{\sqrt{2\pi\sigma_I(D)}}\frac{1}{I}\exp\left\{-\frac{(\ln(I/\langle I\rangle)+\sigma_I^2(D))^2}{2\sigma_I^2(D)}\right\},\ \text{for } I \geq 0 \quad (14)$$

and it is used in the performance analysis of FSO-OFDM in the next section.

3. FSO-OFDM SYSTEM MODEL

OFDM is a multicarrier modulation that divides the high data rate signal into number of lower data rate signals and transmit them in parallel form. The subcarriers are baseband modulated using any of constant envelope modulations like PSK, QAM, QPSK, etc. In OFDM, subcarrier spacing is selected in such a way that each subcarrier is orthogonal to each other. Such subcarriers are generated using Inverse Fast Fourier Transform (IFFT) at the transmitter and Fast Fourier Transform (FFT) is employed at the receiver to get back the data. This makes the receiver design simple, since one or two tap equalizer alone is required [6].

The block diagram of FSO- OFDM system is shown in fig.1. At the transmitter, 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. This OFDM signal modulates the laser diode and is then transmitted through free space. 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.

The complex OFDM signal is represented as:

$$s(t) = \frac{1}{\sqrt{T}}\sum_0^{K-1} a_k e^{\frac{j2\pi kt}{T}}\, w(nT) \quad (15)$$

where T is the symbol duration,a_k is the data bits, and w (.) is the rectangular window function.

$$P(t) = P_t \sum_{n=0}^{N-1} m_n s_n(t) \quad (16)$$

whereP_t is the average transmitted optical power, $m_n$is the Optical Modulation Index (OMI) for each subcarrier and the total OMI is given as

$$m_{total} = \frac{1}{N}\sqrt{\sum_{n=0}^{N-1} m_n^2} \quad (17)$$

For an FSO link, the field at any point can be written as product of free space attenuation and stochastic amplitude to describe the field variation.

At the receiver, the input to the photodiode is given as

$$P_{rx}(t) = P(t)L_{attn}\, L_{Scint}\, X + n_{FSO}(t) \quad (18)$$

where P(t) is power output from Laser.L_{attn} is loss due to atmosphere that includes rain and attenuation loss.L_{scint} is loss due to atmospheric turbulence and X is the signal fading due to atmospheric turbulence effects whose PDF is given in equation 14 and n_{FSO}(t) is the AWG Noise.

In the analysis, we use the averaged Carrier to Noise power ratio (CNR) with atmospheric effects. The Bit Error Rate is calculated as

$$BER = \frac{1}{2}\int_0^{\infty} P_{rx}(s)\,\text{erfc}\left(\frac{\sqrt{\langle CNR\rangle}.s}{P_{RX}}\right) ds \quad (19)$$

where s is the random signal.

4. SIMULATION RESULTS AND DISCUSSION

The FSO-OFDM system link parameters and their numerical values used for simulation are given in the table1:

Table 1 FSO- OFDM Link parameters

Symbol	**Parameters**	**Value**
L	Distance between the transmitter and the receiver	2000m
R	PhotodetectorResponsivity	0.8 A/W
Q	Electron Charge	1.6×10^{-19} C
K	Boltzman's Constant	1.374×10^{-23}
T	Temperature	300K
R_L	Load Resistance	50 Ω
RIN	Relative Intensity Noise	-150dB
B	Filter Bandwidth	6 MHz
W_o	Input Beam Spot Radius	20 mm
F_o	Input Radius of Curvature	-16 m
N	Number of Subcarriers	52
T	Symbol Duration	4 µs

The stream of data is superimposed on the subcarriers to generate the required OFDM symbol. Cyclic prefix is added and all symbols are made serial to form a train of OFDM symbols. Assuming that the RF conversion to be perfectly done and this block to be linear, the baseband OFDM signal is used to optically modulate the laser diode(LD). The light from LD is transmitted in free space which is assumed to be Log-Normally distributed. At the receiver, the received signal is subjected to the reverse processes.

Aperture averaging is performed and observed the variation in the scintillation index for a range of distance between transmitter and receiver and also the effect of changing the wavelength has been evaluated. Distance is varied over a range of 0 to 2 Km and four different wavelengthsviz, 780nm, 980 nm, 1330nm and 1550 nm areused. It is observed that irrespective of wavelength, for short distance over 500 m to 800 m scintillation index fluctuates from 0.5 to 0.9. As wavelength is increased from 780 nm to 1550 nm the curve shifts bothto the rightand upward.

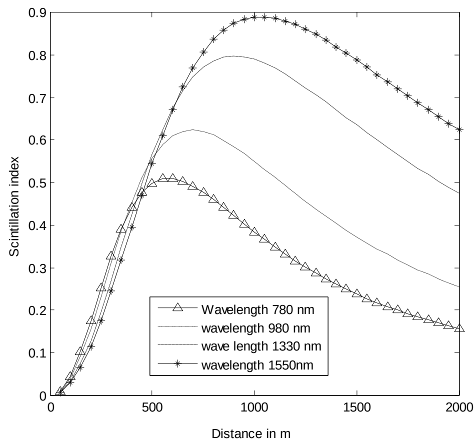

Fig.2 Scintillation Index Vs Distance forGaussian Beam

This shows that for longer wavelength, the fluctuation is more compared to shorter wavelength. Thus it is preferred to use shorter wavelength for free space communication over longer wavelength. Hence for terrestrial applications laser diode with Gaussian beam is used with shorter wavelength like780 nm.

At the transmitter, for the generation of OFDM signal, input data stream needs to be baseband modulated. At this stage we analyze the performance of M-ary PSK modulation in the RF wireless environment and FSO environment. The value of received signal power is obtained as per the algorithm given by BernardEpple [14].

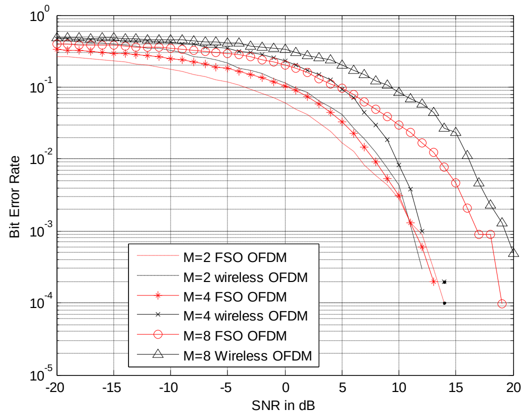

Fig. 3 BER Vs SNR with M-ary PSK Modulation

The Fig 3 shows that, at low SNR the performance of FSO-OFDM system as well as wireless OFDM system is almost the same. The deviation in the performance starts from 0dB SNR value, wherein the performance of the FSO - OFDM is observed to be better than that of the wireless OFDM. There is an improvement of 2 dB to 4dB for M =2 to M=8. But at the same time as the number of symbol on the carrier increases the BER also increases. As more symbols are packed onto same carrier, the probability of making error increases even at positive values of the SNR. In order to achieve low BER we would like to select BPSK as compared to M-ary Modulation where m= 4 or 8.

5. CONCLUSION

The simulation of the OFDM based Free Space Optical environment using log-normal distribution shows that OFDM performance is improved in free space optics as compared to the RF wireless system. Of the four wavelengths that are used in optical communication, we can select the short wavelength 780nm. The preferred baseband modulation for the generation of OFDM signal with M-ary PSKis lower order M= 2 or BPSK modulation is more suitable.

6. REFERENCES

[1] Mohammad SaleemAwan, LaszaloCsurgaiHorwarth, Sajid Sheikh Mohammad, Erich Leitgeh , FarukhNadeem and M.S Khan, 2009, Characterization of Fog and Snow Attenuations for Free Space optical Propagation, Journal of communications, Vol. 4, No.8, pp 533 - 545.

[2] Mohammad Saleem , Erich Leitgeh , M.SKhan and C.Capsoni,2009, A New method of Predicting Continental Fog Attenuation for Terrestrial Optical wireless Link, 3rd International Conference on Next Generation Mobile Application, Services and Technologies, pp 245- 250.

[3] M.S.Khan, M.S Awan, S.S. Muhammad, M. Faizal, marzuki, F. Nadeem and E. Lettgeb, 2010, Probabilistic Model for Free Space Optical Links Under Continental

Fog Conditions, Radio Engineering Vol. 19, No.3, pp 460- 465.

[4] H. Al-Raweshidy and S. Komaki Edtios,2002, Radio Over Fiber Technologies for Mobile Communications Networks, 1st ed. Norwell, MA: Artech House,

[5] K. Kazaura, K. Wakamori, M. Matsumoto, T. Higashino, K. Tsukamoto, and S.Komaki, B, 2010,RoFSO: A universal platform for convergence of fiber and free-space optical communication networks, IEEE Commun. Mag., Vol. 48, No. 2, pp. 130–137.

[6] R. V. Nee and R. Prasad, 2000, OFDM for Wireless Multimedia Communications. Norwell, MA: Artech House.

[7] AbdelmoulaBekkali ,Chedlia Ben Naila, KamugishaKazaura, Kazuhiko Wakamori, and Mitsuji Matsumoto,2010, Transmission Analysis of OFDM-Based Wireless Services Over Turbulent Radio-on-FSO Links Modeled by Gamma–Gamma Distribution,IEEE Photonic Journal ,Volume 2, Number 3, pp 510-520.

[8] L. C. Andrews, R. L. Philips and C. Y. Hopen, 2001, Laser Beam Scintillation with Applications, SPIE, Bellingham, WA.

[9] L. C. Andrews and R. L. Phillips, 2005, Laser beam propagation through random media, SPIE, Bellingham, Washington, USA,.

[10] Ales Prokes, 2009, Modeling of Atmospheric Turbulence Effect on Terrestrial FSO Link, Radio Engineering, Vol 18, No.1,pp 42-47.

[11] Jin Li, John Q.Liu and Desmond P.Taylor,2007, Optical Communication Using Subcarrier PSK Modulation Through Atmospheric Turbulence Channels, IEEE Transaction on Communications,Vol 55, No.8,pp 1598-1606.

[12] Wasio.O.Papoola and ZabihGhassemlooy,2009, BPSK Subcarrier Intensity Modulated Free Space Optical Communications in Atmospheric Turbulence, Journal of Lightwave Technology,Vol 27, No.8, pp.967-973.

[13] M.A.Khalighi, N.Aitamer, N.Schhwartz and S. Bourennane, 2010, Turbulence Mitigation by Aperture Averaging in Wireless Optical Systems, Proceedings of 10th International Conference on Telecommunications, ConTEL, Zagrab, Croatia., pp 59 -66.

[14] Bernard Epple,2010, Simplified Channel Model for Simulation of Free- Sapce Optical Communications, Journal of Optical Communication Network, Vol.2, No.5,pp293-305.