Investigating the Performance of Free Space Optical Communication Link using OOK and DPSK Modulation Techniques under Atmospheric Turbulence

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Abstract- **Free Space Optics involves the transmission of data using optical beam through free space. The most commonly used modulation technique for FSO is OOK. This is primarily because of the simplicity of its design and implementation. However in this paper , we have investigated the performance of FSO system under Differential Phase Shift Keying modulation technique. The Bit Error Rate performance of Free Space Optical Link using DPSK modulation technique has been analyzed under atmospheric turbulence. The BER performance of DPSK has also been compared with OOK. Further, the BER performance of DPSK modulation technique has been investigated for different wavelengths and link ranges.**

Index Terms- **FSO, Atmospheric Turbulence, OOK, DPSK, BER.**

I. INTRODUCTION

In basic terms, FSO involves the data transmission between two points through free space. It requires the line of sight connection between transmitter and receiver [1].FSO communication technology became popular due to its large bandwidth potential, unlicensed spectrum, excellent security and quick and inexpensive set-up.

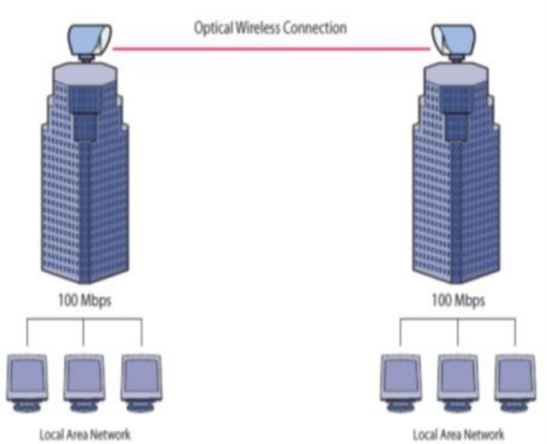

Fig. 1 Schematic of FSO [1]

However, the optical beam travelling through atmosphere experiences scintillation. Scintillation results from thermal gradients and turbulence within the optical path caused by the variation in air temperature and density. Zones of different densities act as lenses, scattering light away from its intended path [2].These paths can cause scattered laser beam to travel along different paths and then recombine. Compared with the RF system, FSO is less affected by snow and rain, but can be severely affected by atmospheric turbulence and fog. The attenuation coefficient ranges from a few dB/km to 270 dB/km [3].Another factor that accounts for the FSO performance degradation is the irradiance fluctuation and the phase fluctuation which results from random index of refractive variations along the propagation path due to atmospheric turbulence [4].The performance of the FSO link can also be improved by employing an appropriate modulation technique that makes a good compromise between complexity and performance.

The paper is organised as follows: The gamma gamma turbulent model has been described in section 2.In section 3,the theoritical analysis of OOK and PPM has been done. In section 4,the results and simulations have been discussed. This is followed by main conclusion in section 5.

II.GAMMA GAMMA DISTRIBUTED CHANNEL MODEL

In the gamma-gamma distributed channel model, the normalized light intensity I can be partitioned into large-scale and small-scale intensity effects [5].Both the large-scale and small-scale intensity fluctuations follow gamma-gamma distribution. Hence, the probability density function of light intensity I is given by:

$P(I)=\frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{\alpha+\beta-2}{2}} K_{\alpha-\beta}(2\sqrt{\alpha\beta I}),\ I>0$ (1)

Where Γ(.) is the Gamma Function, $K_{\alpha-\beta}$ is the Bessel Function of the second kind of order n, α and β are the effective number of small scale and large scale eddies of the scattering environment which are given as :

α={exp[0.49$\sigma^2/(1+1.11\sigma^{12/5})^{7/6}$]-1}$^{-1}$ (2)

β={exp[0.51$\sigma^2/(1+1.11\sigma^{12/5})^{5/6}$]-1}$^{-1}$ (3)

where σ^2=1.23〚C_n〛^2 k^(7/6) L^(11/6) is the Rytov Variance representing the variance of log-intensity fluctuation in which 〚C_n〛^2 is the refracrtive-index structure parameter, k is the wave number and L is the distance between transmitter and receiver [6].

III.PERFORMANCE ANALYSIS

A. BER Analysis using OOK Modulation Technique

OOK is the most reported modulation technique used for FSO. This is apparently due to its simplicity. Logic 1 is simply represented by an optical pulse that occupies the entire or part of the bit duration while a logic 0 is represented by the absence of an optical pulse. Both return-to-zero (RZ) and non-return-to-zero (NRZ) schemes can be applied. The normalized transmit pulse shape for OOK is given by [7]:

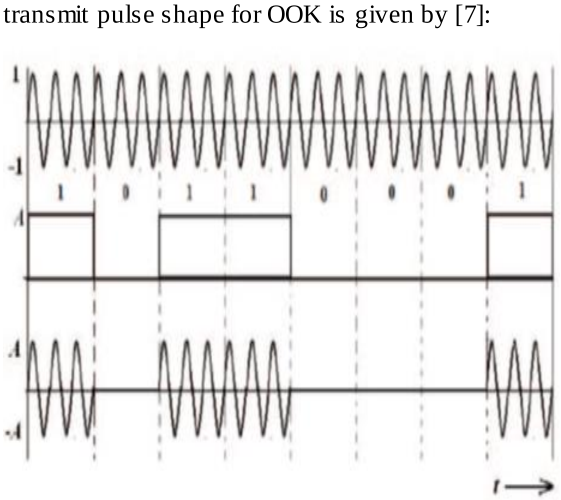

Fig.2 OOK modulation with NRZ Pulses [3]

In the NRZ scheme, a pulse with duration equal to the bit duration is transmitted to represent logic 1 while in the RZ scheme, the pulse occupies only the partial duration of bit. The bit error rate probability for OOK is given by [8]:

$P_{OOK}=\frac{1}{2}erfc(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}})$ (4)

Where

erfc(x)=$(2\pi)^{-\frac{1}{2}}\int_0^{\infty}\exp(-t^2)dt$, $\sqrt{\frac{S}{N}}=\frac{i_S^2}{2q\, i_S\, \Delta f+4kT\Delta f/R}$

R is the resistance, q is the electronic charge, k is the Boltzmann's constant and T is the absolute temperature, Δf is the filter bandwidth, i_s is the average photocurrent which is given by[9]:

$i_{s=\Re P_R}$ (5)

Where P_R is the power received and $\Re$ is the responsively of photo detector.

B. BER Analysis using DPSK Modulation Technique

In Differential Phase shift keying (DPSK), the change in the phase of the received signal is determined by the demodulator rather than the phase itself. As this technique depends on the difference in phase between the successive phases, hence it is named as DPSK. This modulation scheme is the most suitable when the absolute phase estimation needed for the subcarrier coherent demodulation is not feasible or too complex to realise. The DPSK pre-modulated SIM-FSO is demodulated by comparing the phase of the received signal in any signalling interval with the phase of the signal received .

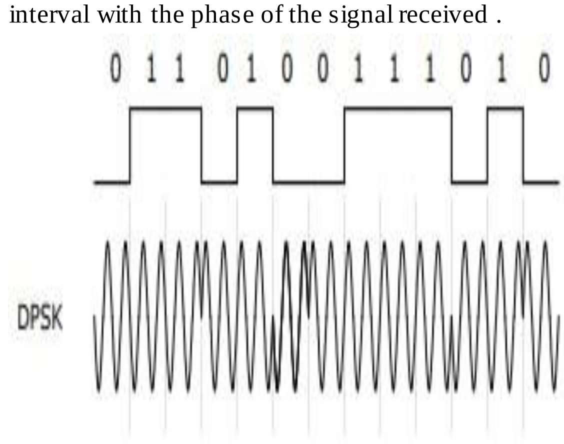

Fig.3 DPSK modulation [9]

Accurate demodulation of the present data symbol thus depends on whether the preceding symbol has been correctly demodulated or not. The demodulation of DPSK based SIM-FSO is feasible during atmospheric turbulence because the turbulence coherence time, which is in the order of milliseconds, is far greater than the typical duration of two consecutive data symbols.

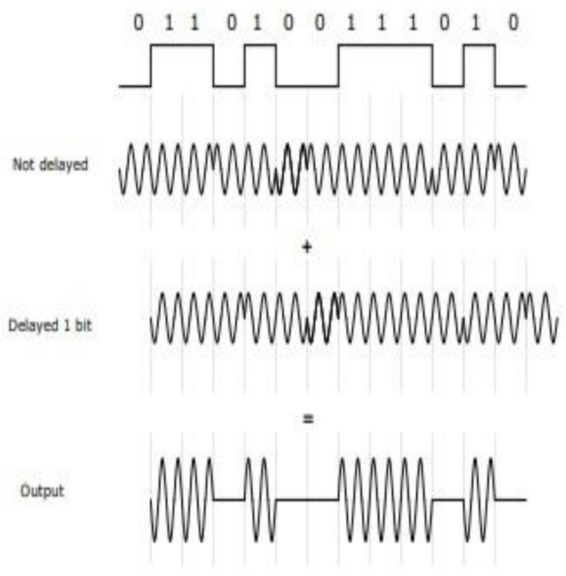

Fig.4 DPSK Demodulation [10]

This implies that the channel properties are fixed during a minimum of two symbol durations – a pre-requisite for non-coherent demodulation of DPSK subcarrier signal It is not mandatory for the demodulator to have a copy of the reference signal in order to determine the exact phase of the received signal, so this technique is simpler than ordinary PSK. So this technique finds application in the cases when the estimation of phase is not possible for the carrier demodulation. In FSO systems, the irradiance of an optical carrier is modulated by RF carrier signal. After travelling through the turbulent atmospheric channel, the photo detector receives the irradiance and photocurrent is generated accordingly which is given by [11]:

$I(t)=RI(1+\beta m(t)) + n(t)$ (6)

Where $I=I_{max}/2$,I_{max} is the maximum received irradiance, R is the responsively of the photo detector, β is the modulation index, $m(t)=A(t)\cos(\omega_c t + \theta)$, n(t) is the additive noise. As the the subcarrier has been pre-modulated using DPSK and the amplitude is also non-varying and β has been normalized to unity. So the peak amplitude is $A(t)=A\leq 1$.

We have considered background noise and thermal noise as the noise sources in this work. The background noise is mainly because of the radiations from both sky and sun . Their radiances are given as [12]:

$I_{sky}=N(\lambda)\ \Delta\lambda\pi\Omega^2/4$ (7)

$I_{sun}=W(\lambda)\ \Delta\lambda$ (8)

where N(λ) and W(λ) are the spectral radiance of the sky and spectral radiant emittance of the sun respectively, Δλ is the bandwidth of the optical band pass filter at the receiver, and Ω is the receiver field of view angle (FOV) in radian, We can the reduce the impact of background noise greatly by choosing narrow FOV and Δλ for the receiver. We can get the empirical values of N(λ) and W(λ) under different observation conditions in the literature. The background noise is a shot noise with a variance given by [13] :

$\sigma_{Bg}^2 = 2qBR\ (I_{sky} + I_{sun})$ (9)

where B is the electrical bandwidth of system.

Thermal noise is caused due to thermal fluctuations of electrons in the receiver circuit having equivalent resistance R_L and temperature T_e . The variance is given by:

$\sigma_{Th}^2 = = 4\ kT_e BR_L^{-1}$ (10)

Noise due to the quantum nature of light, the dark current and the relative intensity noise has been assumed negligible. Hence, the total noise variance is given

$\sigma^2=\sigma_{Bg}^2 + \sigma_{Th}^2$ (11)

The electrical SNR per bit is given by :

$SNR=A^2\ R^2\ I^2/2\sigma^2$ (12)

The conditional BER for the DPSK technique is given by :

$P_{ec}=0.5exp(-0.5\ SNR)$ (13)

In the presence of atmospheric turbulence, the unconditional BER is given by:

$P_e=\frac{(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)}\int_0^\infty x^{\frac{\alpha+\beta}{2}-1}\ K_{\alpha-\beta}(2\sqrt{\alpha\beta I})\times(0.5\exp(-0.5SNR))\ dx$ (14)

IV. RESULTS

The system described above is simulated using matlab.

Parameters	Value
Wavelengths	10 μm, 1.55 μm and 0.85 μm
Bit Rate(R_b)	155 Mbps
Link Range	1 Km
Responsivity	1
Modulation Index	1
Temperature	300 K
Optical Filter Bandwidth	1e-3 μm
Receiver Field of view	0.6 radian

Refractive Index Structure Parameter, C_n^2	0.75e-14 $m^{-2/3}$
Load Resistance	50 Ω
Boltzman's Constant	1.38e-23 J/K
Electronic Charge	1.602e-19 C

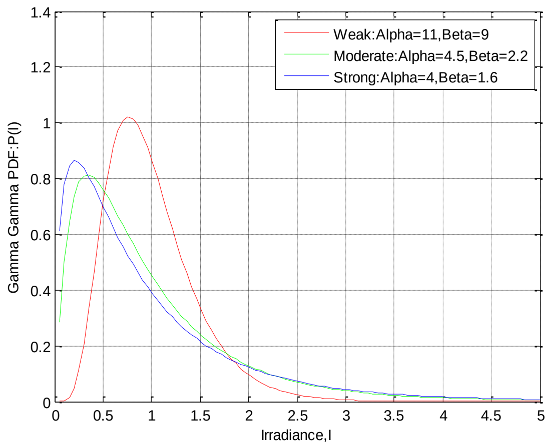

Fig 5: Gamma Gamma probability Density Function for three different turbulent regions, namely Weak, Moderate and Strong

The plot of the probability density function for gamma-gamma distribution model is shown in Fig. 5 with typical values of turbulence strength. In particular, notice the gamma-gamma model has a much higher density in the high amplitude region, leading to a more severe impact on the system performance. The values of α and β indicate the nature of atmospheric turbulence i.e. whether it is strong, moderate or weak. In Fig. 6 the scintillation index has been plotted as a function of rytov parameter. Scintillation Index measures the normalised intensity variance caused by atmospheric turbulence.

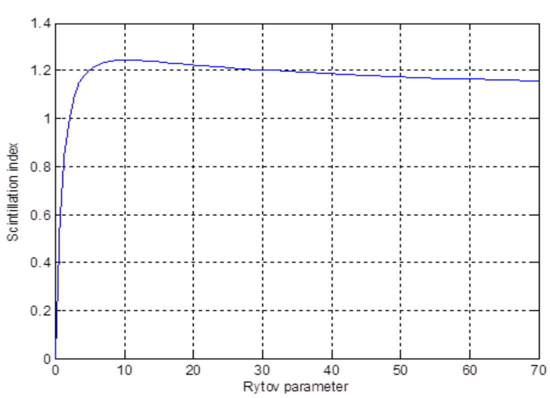

Fig 6: Scintillation Index as a function of Rytov Parameter

The OOK modulation technique is the basic technique used for FSO because of its simplicity and easy implementation. The BER of OOK and DPSK modulation technique has been compared and it is clear from the Fig. 7 that DPSK gives better BER performance than OOK in the presence of atmospheric turbulence.

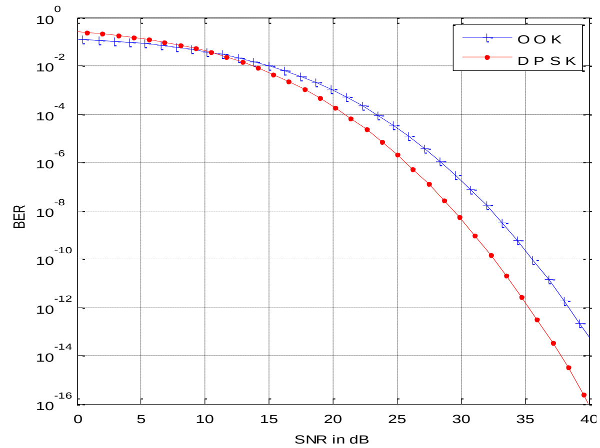

Fig. 7: Comparison of BER performance of OOK and DPSK Modulation Techniques

The BER performance of DPSK has been analysed for different wavelengths which are 850 nm, 1350 nm and 1550 nm. From Fig. 8 it is clear that BER performance of DPSK is better for higher wavelengths as compared to smaller wavelengths. The BER performance of link using 1550 nm wavelength is better than that for 850 nm wavelength.

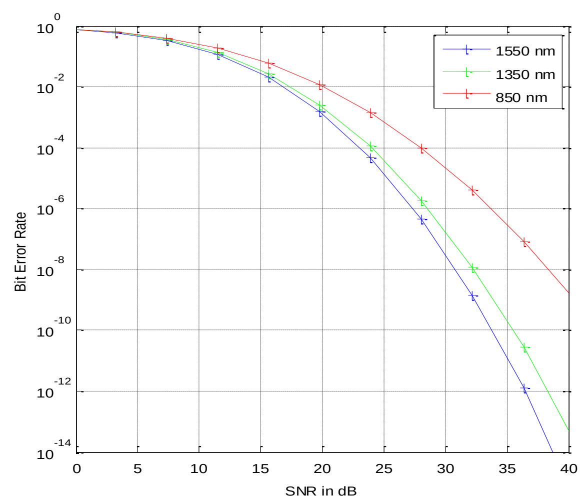

Fig 8: Bit error rate performance of DPSK Modulation Technique for different wavelengths

The BER performance of DPSK has been analyzed for different link ranges which are 1 km, 1.5 km and 2 km. As it can be observed from Fig. 9 that BER performance of DPSK is better for shorter link ranges as compared to larger link ranges .

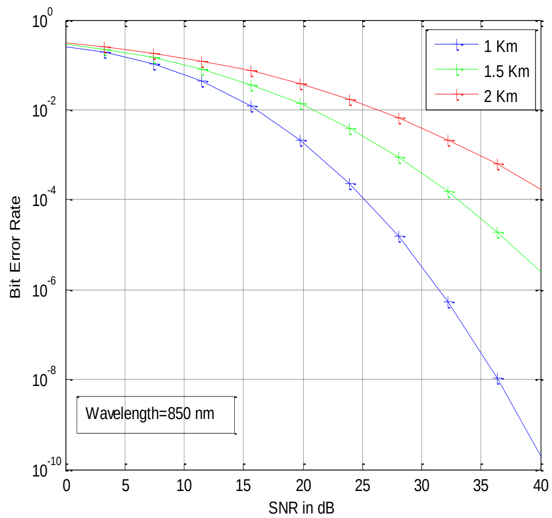

Fig. 9 Bit error rate performance of DPSK Modulation Technique for different link ranges.

V. CONCLUSIONS

The BER for FSO communications system employing OOK and DSPK modulation techniques has been analysed in this paper. It has been observed that in the presence of atmospheric turbulence, the BER performance of DPSK is better than OOK. DPSK modulation technique is giving better BER performance with the increase in value of wavelength. Further, the BER of DSPK modulation techniques has been investigated by considering different link ranges and it has been observed that as the link range increases, the BER performance is getting degraded

REFERENCES

[1] D.Killinger, "Free space optics for laser communication through the air",Optics & Photonics News,vol. 12,pp.36-42,Oct.2002.

[2] F.E Goodwin, "A review of operational laser communication systems",Proceedings of IEEE,vol.Series 3,pp.305-324,Oct.1970.

[3] A.C. Boucouvalas,"Challenges in Optical Wireless Communications",Optics & Photonics News, Vol. 16, No. 5, 36-39 (2005).

[4] Keang Po Ho, "Error Probability of DPSK Signals with Cross Phase Modulation Induced Nonlinear Phase Noise", IEEE Journal of Selected Topics in Quantum Electronics, Vol. 10, No. 2, pp. 421-427, 2004.

[5] L.C Andrews,R.L. Phillips,and C.Y.Hopen,Laser beam scintillation with applications,(Bellingham:SPIE,2001).

[6] H.Willebrand and B.S Ghuman,Free Space Optics:Enabling optical connectivity in today's network(Indiapolis,IN:SAMS publishing,2002).

[7] M.A A1-Habash,L.C Andrews,and R.L Philips,"Mathematical model for the irradiance probability density function of a laser beam propagating through turbulent media",Opt. Eng.,vol. 40,pp.1554-1562,2001.

[8] S.F. Clifford,"The classical theory of wave propagation in a turbulent medium",J.W. Strobehn,Ed.:Springer-Verlag,1978.

[9] Jinlong Zhang,"Modulation Analysis for Outdoor Applications of Optical Wireless Communications",0-7803-6394-9/00/c10.0002000 IEEE.

[10] R.K Tyson, "Bit-error rate for free space adaptive optics laser communications",Journal of the Optical Society of America A 19(4),2002,pp.753-758.

[11] D Zwillinger,"Differential PPM has a higher throughput than PPM for the band-limited and average-power-limited optical channel",IEEE tranactions on Information Theory 36 on Information Theory,34,1269-1273,1988.

[12] K kiasaleh, "Performance of APD-based,PPM free-space optical communication systems in atmospheric turbulence",IEEE Transactions on Communications,53,1455-1461,2005.

[13] S Sheikh Muhammad,W Gappmair and E Leitgeb, "PPM channel capacity evaluation for terrestrial FSO links",International Workshop on Satellite and Space Communications,University Carlos III de Madrid,Leganes,Spain,September 2006,pp 222-226.