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Performance Analysis of Optical Wireless System with Aperture Averaging

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Abstract—***The performance of FSO communication is degraded due to the turbulent atmospheric channel, causing variations in intensity of the received signal at the receiver. In this paper the effect of aperture averaging is investigated on the BER performance in a weak turbulent regime for coherent detection modulation schemes, namely ASK, FSK and PSK using lens of different aperture diameters.***

I. Introduction

Wireless optical communication has become the most promising technology for the next generation's both indoor and outdoor wireless broadband applications. Its applications have a wide range. They range from short range wireless communication links providing network access to portable computer systems, to last mile links bridging the gaps between end users and existing fiber optical communication backbones, and even laser communications in outer space links. Wireless outdoor communication is known as free space optical (FSO) communication .

Free space optical communication requires line of sight (LOS) and point to point laser links from the transmitter and the receiver. FSO communication provides the potential of broadband communication capacity utilizing unlicensed optical wavelengths. Though refractive index variations are caused in the transmission path due to in-homogeneities in the temperature and pressure of the atmosphere. These variations in the refractive index lead to temporal and spatial variations in the intensity which is incident on the receiver which in turn causes fading. Fading causes degradation in performance by increasing the bit error rate (BER) and also induces a delay in transmission[4].

Numerous techniques are used to reduce the fading of a FSO system [5]: i) Adaptive optics before transmission, ii) Spatial and temporal diversity techniques, iii) Aperture averaging and iv) Forward error correction technique. In this paper we have used the aperture averaging technique to analyze its effect on the BER. In aperture averaging the diameter of the receiver lens is increase and hence increasing the amount of measured radiations. As a result the fluctuations in the intensity across the receiver lens are averaged by the large size of the collecting lens. A lens with a larger aperture will average the intensity fluctuations and hence reduce the bit error rate (BER) [9].

The rest of the paper is organized as follows: Section II describes the system model, section III gives the BER analysis, section IV describes that what is aperture averaging, section V gives the BER analysis considering aperture averaging, section VI is about simulation and result analysis. The comparative analysis and conclusion has been presented in section VII and VIII respectively.

II. System Model

The various parts of a FSO link are a transmitter, an atmospheric channel and a receiver .The system model taken under consideration in this paper consists of a single transmitter on the transmission side and a single receiver on the receiving side of the FSO system. The received signal, y is represented by the equation below:

$$y = h\,x + n \qquad (1)$$

Where h is the channel parameter for a weak turbulent channel statistically modeled by log normal pdf and n is the background noise. The log normal pdf is given by:

$$\rho(x) = \frac{1}{\sqrt{2\pi\sigma_\chi^2}}\exp\left\{-\frac{\left(\chi - E[\chi]^2\right)}{2\sigma_\chi^2}\right\} \qquad (2)$$

Where, $E[x]$ denotes the expectation of x and σ^2_x is the log-amplitude variance.

The three modulation schemes that have been taken into consideration are amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK).

III. BER Analysis

In a turbulent atmosphere the BER becomes a vital parameter to gauge the effectiveness of a FSO system. The BER calculated for a weak turbulent regime using log normal distribution for ASK modulation scheme is [1] [3]:

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$$P=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\left(\sqrt{\frac{\eta}{2RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i-\frac{\sigma_I^2}{2}\right)\right) \qquad (3)$$

Where, h is Plank's constant, f is Frequency of Incident photons, R is responsivity, η is the Quantum Efficiency, B_{IF} is the Operating Bandwidth, σ^2_I is variance (0.01). Result obtained for PSK scheme is [1] [3]:

$$P=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\left(\sqrt{\frac{2\eta}{RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i-\frac{\sigma_I^2}{2}\right)\right) \qquad (4)$$

And for FSK is:

$$P=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\left(\sqrt{\frac{\eta}{RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i-\frac{\sigma_I^2}{2}\right)\right) \qquad (5)$$

IV. APPERTURE AVERAGING

Aperture averaging is a mitigation technique used to combat the BER by reducing its value relatively. When a wave propagates through a turbulent channel spatially and temporally random irradiance patterns are formed. The receiver lens averages out the fluctuations unless the aperture of the lens is lesser than the spatial scale of fluctuations .This phenomenon is called aperture averaging. The aperture averaging factor is the ratio of fluctuations seen at a receiver lens with diameter, D to that observed by a point receiver. By increasing the size of the receiver aperture, the power variance is reduced which in turn gives a decreased value of BER and hence a better performance. Aperture averaging is the simplest form of spatial diversity wherein the receiver lens aperture is greater than the fading correlation length. Aperture averaging factor 'A' is defined as the ratio of the normalized intensity variance of the signal at a receiver with diameter D to that of a point receiver [2] [7].

$$A=\frac{\sigma^2(D)}{\sigma^2(0)} \qquad (6)$$

Where $\sigma^2(D)$ and σ^2 (0) denote the scintillation index for a receiver lens of diameter D and a 'point receiver' (D ≈ 0), respectively.

In this paper we have studied aperture averaging for a plane wave for which the aperture averaging factor is given as follows [4] [6]:

$$A=\left[1+1.07\left(\frac{D^2k}{4L}\right)^{\frac{7}{6}}\right]^{-1} \qquad (7)$$

Where, D is the lens diameter k is the wave number and L is the link distance.

V. BER USING APPERTURE AVERAGING

In this paper, analysis has been carried out for four different values of receiver diameter apart from a point receiver (D=0), that is for 5cm, 10cm, 15cm and the maximum practically possible, 20cm. The general expression derived for a diameter D in ASK modulation scheme is given as follows [1] [3]:

$$BER=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\sqrt{\frac{\eta}{2RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i \sqrt{A}-\left(\sigma_I^2\frac{[A]^{-1}}{2}\right)\right) \qquad (8)$$

For PSK scheme,

$$BER=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\sqrt{\frac{2\eta}{RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i \sqrt{A}-\left(\sigma_I^2\frac{[A]^{-1}}{2}\right)\right) \qquad (9)$$

Finally, for FSK scheme,

$$BER=\frac{1}{\sqrt{\pi}}\sum_{i=1}^{n} w_i Q\sqrt{\frac{\eta}{RhfB_{IF}}}\, I_0 \exp\left(\sqrt{2}\sigma_I x_i \sqrt{A}-\left(\sigma_I^2\frac{[A]^{-1}}{2}\right)\right) \qquad (10)$$

VI. SIMULATION AND RESULTS

The equations mentioned in section V were plotted in MATLAB and the graphs obtained were analyzed [1].

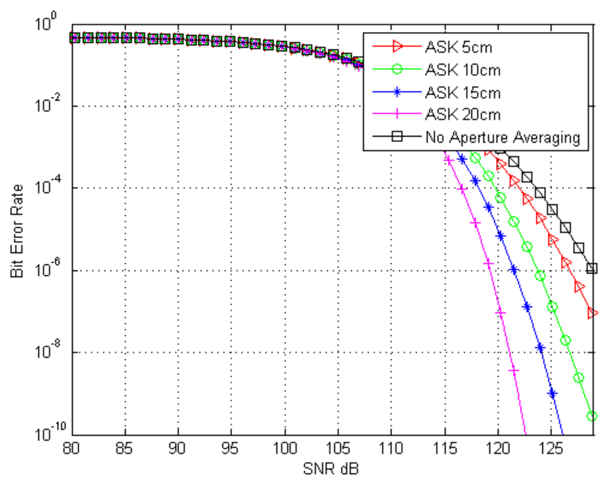

Fig. 1: BER vs. SNR (dB) with varying apertures for ASK

Fig. 1 is a plot between BER and SNR in a weak turbulent regime for ASK scheme for different receiver sizes .From the graph we observe that BER performance for 20 cm lens is the best and it is the worst for a point sized receiver, clearly depicting that how aperture averaging technique helps to mitigate the effects of a turbulent atmospheric regime.

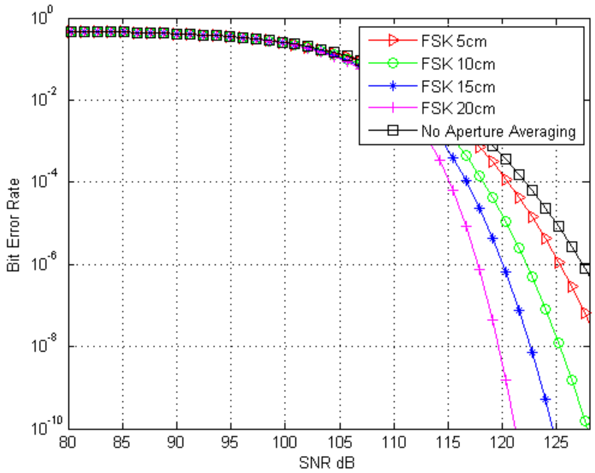

Fig. 2: BER vs. SNR (dB) with varying apertures for FSK

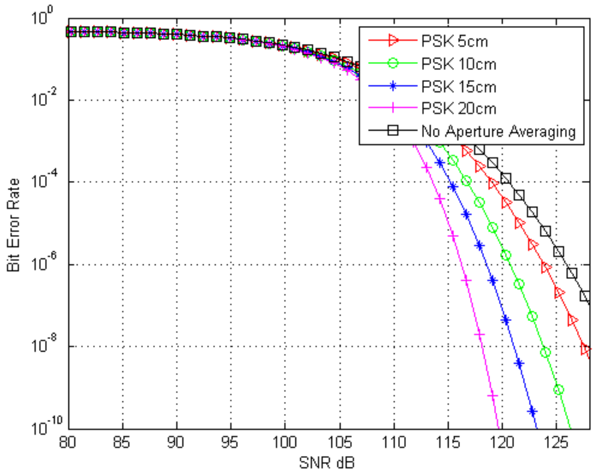

Fig. 3: BER vs. SNR (dB) with varying apertures for PSK

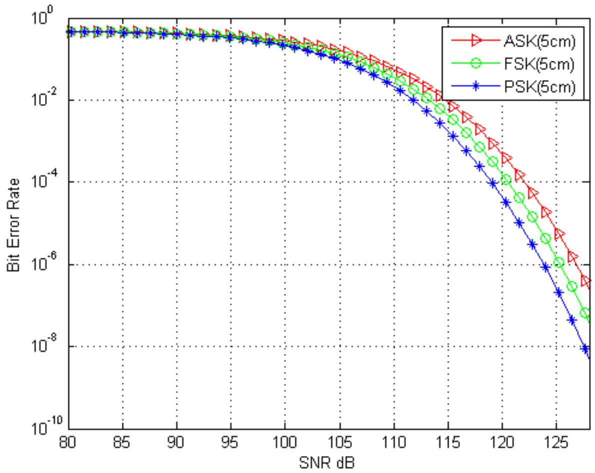

Fig. 4: BER vs. SNR (dB) for 5cm aperture diameter for ASK, FSK and PSK schemes

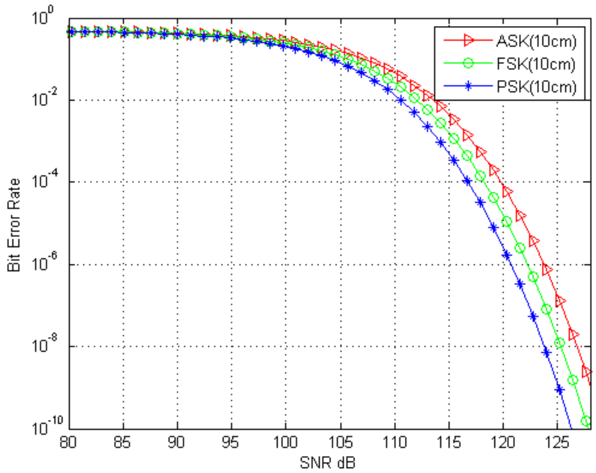

Fig. 5: BER vs. SNR (dB) for 10cm aperture diameter for ASK, FSK and PSK schemes

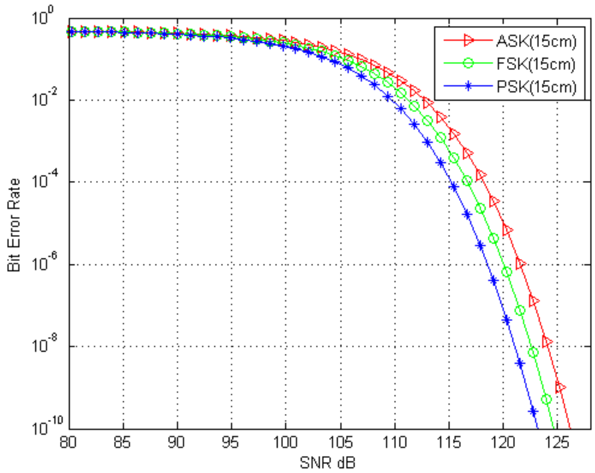

Fig. 6: BER vs. SNR (dB) for 15cm aperture diameter for ASK, FSK and PSK schemes

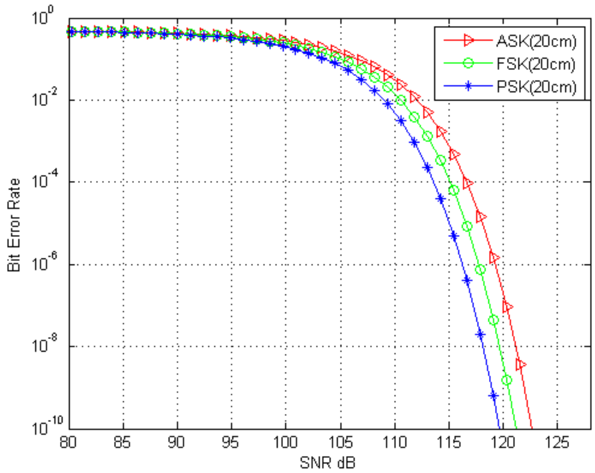

Fig. 7: BER vs. SNR (dB) for 20cm aperture diameter for ASK, FSK and PSK schemes

Similarly analyzing figures 5, 6 and 7, we deduce that PSK modulation scheme gives the best result in terms of BER performance for any diameter of the receiver lens.

VII. Comparative Discussions Analysing

Analyzing the various MATLAB plots obtained in section VI, a comparative table was plotted comprising of the values of SNR (dB) corresponding to a BER value of 10^{-6}.

Table 1 SNR Values for attaining Bit Error Rate of 10^{-6}

	SNR (dB)	SNR with Aperture Averaging(dB)			
		5cm	**10cm**	**15cm**	**20cm**
ASK	128.8	126.8	123.9	121.5	119.8
FSK	127.6	125.1	122.1	120.3	117.9
PSK	126.1	123.9	120.9	118.7	116.2

Referring to *Table 1*, we observe that for a BER of 10^{-6} the corresponding value of SNR for ASK scheme is minimum (119.8 dB) for a lens of 20 cm diameter and maximum without aperture averaging (128.8dB). Likewise for FSK, BER is minimum for a lens of 20 cm diameter (117.9dB) and maximum for a point receiver (127.6dB). Finally for PSK modulation scheme, the maximum BER (116.2 dB) is attained for no aperture averaging case and minimum (126.1dB) for 20cm diameter.

Next we deduce that for a 5cm diameter, the BER for PSK scheme is the least (123.9 dB) and it's the maximum for ASK scheme (126.8dB). Similar results were obtained for lens of diameters 10cm, 15cm and 20 cm. Hence the best case scenario is deploying a lens with diameter 20 cm and using PSK modulation scheme and the worst case is for ASK scheme without using aperture averaging technique.

VIII. Conclusion

From the results and their deduction, we observe how aperture averaging is one of the simplest forms of spatial diversity which helps to mitigate the effects of scintillation. We observe how PSK is the most effective modulation technique (lowest BER). For all modulation technique the BER with aperture averaging reduces in comparison to the case without using the mitigation technique. Therefore, it is concluded that as the diameter of the receiver lens is increased from 5cm to 10cm, 15cm and finally 20cm, the BER reduces. Lastly it is observed that how for a given lens diameter, PSK is the best modulation scheme (lowest BER).

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