

Effects of weak atmospheric turbulence on FSO link Systems and its reducing technique

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Abstract: Weak atmospheric turbulence results in intensity scintillation which severely effects the FSO (Free Space Optics) system, which increases the need for improving the quality of this system. SNR (Signal to Noise Ratio) and BER(Bit Error Rate) are two Significant parameters which depicts the quality of FSO. In this paper, we analyze the effect of weak atmospheric turbulence on the SNR and BER and performance of BER on FSO link using transmit diversity is described for non-coherent modulation using OOK(On Off Keying) modulation and 4-PPM schemes. It is also analyzed that 4-PPM performs better than OOK and it deteriorates than OOK for few values.

Index terms: FSO communication, OOK, Q-PPM, weak atmospheric turbulence, SNR, BER, intensity scintillation, transmit diversity , non-coherent modulation.

I. INTRODUCTION

FSO communication systems have many advantages over free space radio frequency based system such as reduced size, narrow spatial width, light weight, high bandwidth. However light propagation in free space medium is not ideal and it suffers many effects like scattering and absorption which depends on atmospheric condition. Due to atmospheric turbulence which causes fluctuations in phase and intensity of received optical signals degrades the performance of the FSO communication system. The requisition for higher carrier frequency is due to the enhancement of communication system. In such situation laser communication seems an attractive option as it has various advantages over microwave system in terms of narrow spatial beam width, greater bandwidth and reduced antenna size. In homogeneities of pressure and temperature in atmosphere leads to fluctuations in phase and intensity of received optical signal which in turn causes random changes in refractive index of atmosphere. Further communication between ground to satellite beam attenuation occurs due to the presence of fog, rain, snow and clouds. Bit Error Rate (BER) performance and signal intensity at the receiver are deteriorated due to turbulence in atmosphere.

II. BACKGROUND OF THEORY ON EFFECTS OF ATMOSPHERIC TURBULENCE:

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Field of plane wave in random media as on the bases of Rytov theory is given as

$$E_{to}(\vec{r})=M_{to}(\vec{r})\exp(i\varphi_{to}(\vec{r})) \quad (1)$$

where $M_{to}(\vec{r})$ is amplitude of laser beam in atmosphere without turbulence, φ_{to} and $E_{to}(\vec{r})$ the phase and laser beam, respectively. Scintillation, Beam wander and Beam spreading are the three reasons due to which signal is degraded at the receiver. Tracking schemes can be used to cancel the effect of Beam wander on the signal. Strewing of average energy over a wider area is referred to as Beam spreading. Changes in the refraction index leads to fluctuations in intensity of beam. This significant effect is termed as Scintillation. The wave equation can be written as

$$E_t(\vec{r})=E_{to}(\vec{r})\exp(\varphi_e) \quad (2)$$

Where φ_e is the exponential factor due to turbulence given as

$$\varphi_e = x_t + ip \quad (3)$$

Where x_t represent fluctuations of log amplitude and p is the phase fluctuations. The affects of SNR and BER of the signal is due to fluctuations in intensity and phase which can be predicted using the above equation. For a plane wave, when turbulence is weak, the refractive index coefficient C_n^2 is symmetrical along beam. Rytov

propounded a variance for fluctuations of log intensity given as

$$\sigma_{\ln I_R}^2 = 1.23 C_n^2 k^{7/6} L_p^{11/6} \quad (4)$$

where $k=2\pi/\lambda$, L_p is propagation length. The subscript R shows the variance is Rytov regime. The log irradiance variance for practical FSO system is described by [1,2]

$$\chi_t^2 = 0.31 C_n^2 k^{1.166} L_p^{1.833} \quad (5)$$

In this paper only dominant noise is assumed, by dereliction of other noise sources, thus

$$x = \ln\left(\frac{M_{to}(r)+M_n(r)}{M_{to}(r)}\right) = \ln(1 + \epsilon_{no}) \quad (6)$$

where $M_n(r)$ is amplitude of noise and $\epsilon = \frac{M_n(r)}{M_{to}(r)}$. Both SNR and BER are used to evaluate the quality of communicating system. The average received power, receiver noise and scintillation strength restricts the performance of BER. Not only increased received optical power but also reduced effect of scintillation can be obtained by suitable design of aperture. SNR in terms of mean signal and noise amplitudes can be expressed as follows:

$$SNR_{NI} = \frac{M_{to}^2(r)}{M_n^2(r)} = [\epsilon_{no}^2]^{-1} \quad (7)$$

For weak turbulence model, ϵ_{no} is very small and can be approximated as :

$$\chi_t = \ln(1 + \epsilon_{no}) \approx \epsilon_{no} \quad (8)$$

Therefore,

$$SNR_{NI} = [0.31 C_n^2 k^{1.166} L_p^{1.833}]^{-1} \quad (9)$$

With on-off keying (OKK) modulation scheme BER can be written as

$$BER = \frac{\exp(-SNR_{NI}/2)}{(2\pi SNR_{NI})} \quad (10)$$

For weak turbulence ($C_n^2 \leq 10^{-14}$), from equations (9) and (10) SNR and BER can be evaluated.

III. ANALYSIS FOR REDUCING THE EFFECTS OF ATMOSPHERIC TURBULENCE ON LASER BEAM

Multiple transmit antennae at ground station and single receiver placed on distinct space borne satellite have been

assumed in this paper. the signal arriving at the detector is given by

$$I_R = \frac{1}{N} \sum_{n=1}^N I_n \quad (11)$$

Where, I is the irradiance of the received signal and N is the number of the independent beams. Total uplink power is assumed to remain constant and thus, each beam has $1/N^{\text{th}}$ of the total power. To have same optical intensity with that of received optical power, the receiver area is normalized to unity. The generated photocurrent by the photo detector of responsivity R is given as

$$i_r = RI_R + n(t) \quad (12)$$

Where $n(t) \sim N(0, \sigma_n^2)$ is additive Gaussian noise. Assuming the log irradiance I of laser light travelling through the turbulence atmosphere is normally distributed under the weak atmospheric turbulence, its PDF is given as

$$f(I_R) = \frac{1}{I_R \sqrt{2\pi\sigma^2}} \exp\left\{-\frac{(\ln(\frac{I_R}{I_0}) + \sigma^2/2)^2}{2\sigma^2}\right\} \quad (13)$$

SISO (Single Input and Single Output) system is used to analyze error probability for non-coherent modulation schemes. BER without turbulence is expressed as

$$P_{er} = Q(\sqrt{SNR}) \quad (14)$$

Where $Q(x)$ is the Gaussian function defined as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-y^2/2} dy \quad (15)$$

Averaging in fading environment is carried out and above BER expression will get modified as given below

$$P_{er} = Q(\sqrt{SNR(I_R)}) \quad (16)$$

Where the parameter I is defined earlier is received irradiance. Since I is a random variable, average BER will be expressed as

$$P_{er} = \int_0^\infty f(I_R) Q(\sqrt{SNR(I_R)}) dI \quad (17)$$

Substitution of $f(I_R)$ from above equation gives

$$P_{er} = \int_0^\infty \frac{1}{I_R \sqrt{2\pi\sigma^2}} \exp\left\{-\frac{(\ln(\frac{I_R}{I_0}) + \sigma^2/2)^2}{2\sigma^2}\right\} Q(\sqrt{SNR(I_R)}) dI \quad (18)$$

The above expression cannot be evaluated since it is in a closed form, therefore it is approximated Gauss Hermite Quadrature integration and expressed as below

$$P_{er} = \int_{-\infty}^\infty \frac{1}{\sqrt{\pi}} \exp(-x^2) Q\left(\frac{RAI_0 \exp(\sqrt{2}\sigma_x - \frac{\sigma^2}{2})}{\sqrt{2}\sigma_n}\right) dx \quad (19)$$

Where $x = \left\{ \frac{\ln\left(\frac{J_R}{J_T} + \frac{\sigma^2}{s}\right)}{\sqrt{2}\sigma} \right\}$.

The reduction of effective log normal variance of the diversity channel is achieved by scaling the effective variance by a number of transmit antennae, which does not hold if there is a correlation among the transmitting antennae. In this case the effective variance is given by

$$\overline{\sigma^2} = \left[\frac{\sigma^2}{N} + \frac{1}{N} \sum_{p=1}^N \tau_{pi} \right] \tag{20}$$

Where τ_{pi} , $p, i=1,2,3,\dots,N$, $p \neq i$ are correlation coefficients. For non-coherence modulation, during each bit intermission, data is transmitted by switching the light source ‘OFF’ or ‘ON’, this scheme is known as On-Off Keying(OOK) modulation. To detect the incoming data bit without an error a careful adjustment of threshold should be done at the receiver side. In Q-PPM, the Q adjacent time slots are placed with optical pulses which expresses a data word but not the bit.

IV .RESULTS AND DISCUSSIONS

In this section, we use above discussed relationship for calculating SNR and BER for a range of parameters. The wavelength used is 1500nm. Fig. 1 Shows the plot of SNR against distance, it portrays that SNR becomes progressively worse with distance. Fig.2 Illustrates the plot of SNR versus distance for a various values of C_n^2 . It indicates that, the maximum distance increases the SNR value decreases which depicts that signal degrades with distance. Fig. 3 Display’s the plot of BER performance for range of C_n^2 as in [5]. It delineates that the maximum distance between transmitter can be 3000m for

$C_n^2 = 10^{-15} m^{-2/3}$ and 690m for $C_n^2 = 10^{-14} m^{-2/3}$ for an effective communication.

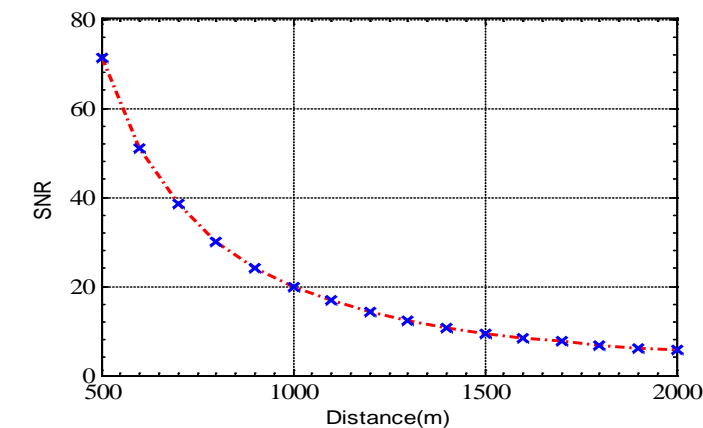


Fig.1 Plot of SNR versus length.

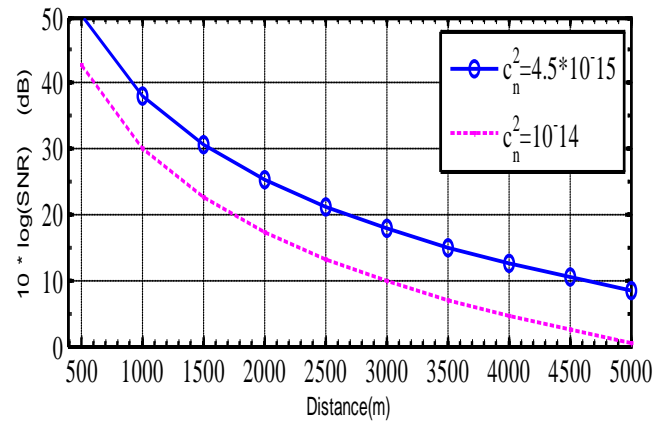


Fig.2 Plot of SNR versus distance for various values of C_n^2 .

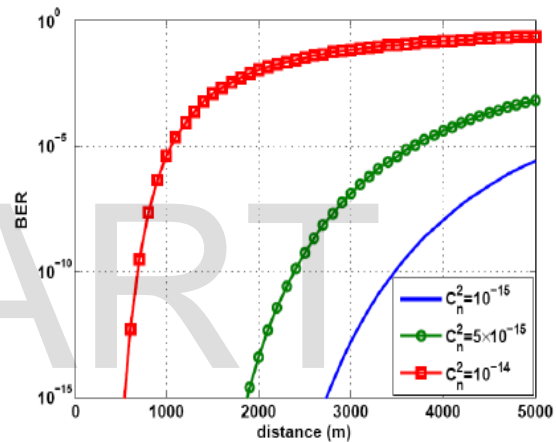


Fig.3 Performance of BER for a range of C_n^2

Fig. 4 and Fig 5 depicts the BER performance of OOK and 4-PPM schemes (for N=1,3 and 7) for uncorrelated beam of transmitting antennae as in s[6] . It is observed that degradation is less in performance of 4-PPM when compared with OOK. By increasing the transmit diversity order which reduces the log irradiance variance of channel by factor of N, thereby improving the performance. Fig5 illustrates the BER performance of 4-PPM modulation for three uncorrelated transmitting antennae beams with

$\sigma = 0.3$.

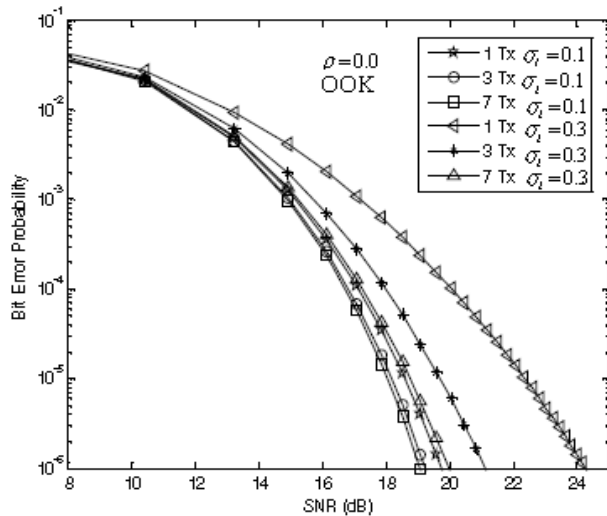


Fig.4 Performance of BER versus SNR for OOK ($\sigma = 0.1$ and 0.3) with or without diversity.

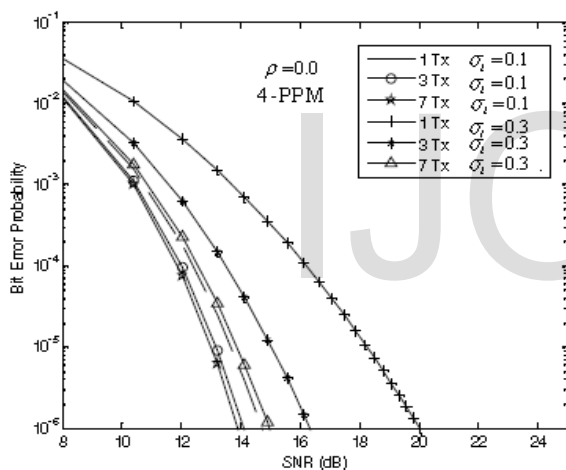


Fig.5 Performance of BER versus SNR for 4-PPM ($\sigma = 0.1$ and 0.3) with or without diversity.

The performance improvement of transmit diversity in non coherent modulation is observed. As N value increases the performance characteristics also increases but to a marginal level. Thus to achieve required diversity gain from multiple transmitters brings the need for sufficient separation among antennae.

V. CONCLUSION

In this paper scintillation is considered as a significant parameter affecting the performance of FSO links. Under weak turbulence regime (with approximation) analysis on SNR and BER were performed. It is observed that BER

performance degrades with higher values of C_n^2 . It is shown that the maximum distance between transmitter can be 3000m for $C_n^2 = 10^{-15} \text{m}^{-2}$ and 690m for $C_n^2 = 10^{-14} \text{m}^{-2}$ for an effective communication. In ground to satellite link, the performance of non-coherent modulation scheme has been analyzed using transmit diversity. It is also observed that transmit diversity improves the performance by reducing the log irradiance variance. This improvement brings a need for efficient separation of transmitters.

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