BER PERFORMANCE OF FREE-SPACE OPTICAL COMMUNICATION WITH WAVELENGTH DIVERSITY

[1]Rachana Jadvani, [2]Rina Parikh,
[1]PG Student, [2]Assistant Professor,
[1]Electronics and Communication,
[1]Silver Oak College of Engineering, Ahmedabad, India

Abstract: Free space optical (FSO) communications, is a cost-effective and high bandwidth access technique, which is receiving growing attention with recent commercialization application. This paper analyses the performance of FSO communication and investigates the techniques to improve the performance of free space optics. Spatial and wavelength diversity techniques are studied and the effect of diversity on the performance of FSO communication link in atmospheric turbulence conditions is analyzed. Wavelength diversity technique is used to reduce the fading under strong atmospheric turbulence condition. Mathematical expressions for the estimation of the outage probability under strong atmospheric turbulence conditions are derived and considerable improvement is found using wavelength diversity. Performance of FSO link with different wavelengths and different aperture area of optical detector has been analyzed. Effects of different wavelengths on visibility range and quality factor of optical receiver is simulated to find the performance of FSO link. It is concluded that due to reduction in scattering loss at higher wavelength; as wavelength increases, quality factor of receiver improves. Quality factor of optical receiver is also improving with increment in aperture area of detector due to increment in sensitivity of receiver due to large aperture area. The link availability calculations were made based on the power budget analysis of FSO link and on the statistical analysis of visibility data. Four different cities were selected across different geographical conditions across the country to compare the weather conditions and the performance of FSO link for different cities of India is calculated. It is concluded that, for a given link. the performance of FSO link is not similar for all the geographical area as the visibility conditions are different. It is shown that the availability and reliability of the FSO link can be improved by making survey of the geographical area where the link has to be established. These data are varying seasonally and with location of the particular area. Scattering and attenuation may be caused more in low visibility condition. Link design of the FSO link can be made after that and better link can be proposed so the desirable availability and BER performance can be achieved.

I. Introduction

Free-space optics, also known as wireless optical, is a potentially high-capacity and cost-effective communication technique, which has been receiving attention and commercial interest. Furthermore, FSO communications are not subject to frequency spectrum regulations and are not jamming from external sources. However, the performance of FSO communication systems is highly susceptible to adverse atmospheric conditions caused by the variations in the refractive index because of inhomogeneities in temperature and pressure changes. As a result, the optical signal intensity rapidly fluctuates, known as scintillation, degrading the system performance particularly for ranges greater than 1 km. Hence, it is reasonable to expect that FSO channels appear to have randomly time-varying characteristics, and thus, channel capacity becomes a time-dependent random variable (RV). Consequently, metrics such as average capacity, representing the average best for error-free transmission, and the outage probability can be considered as particularly useful in evaluating the wireless optical channel performance. In this work, we study the performance of FSO channels by investigating their outage probability and the average (ergodic) capacity, respectively. Thus, we derive closed-form expressions for the outage probability and the average capacity of optical links over atmospheric turbulence-induced fading channels modelled by the log-normal and the gamma–gamma distribution with respect to the turbulence strength, as well as the influence of other important systems' parameters, such as optical link length and the receiver's aperture diameter. we introduce the FSO channel model.

II. SYSTEM MODEL

We consider a point-to-point FSO communication system using intensity modulation/direct detection (IM/DD). The laser beam propagates along a horizontal path through a turbulence channel with additive white Gaussian noise (AWGN). The channel is assumed to be memoryless, stationary and ergodic, with independent and identically distributed (i.i.d.) intensity fading statistics. We also consider that the channel state information (CSI) is available at both the transmitter and the receiver. In this case, the statistical channel model is given by

y ¼ sx þ n ¼ hIx þ n

a) The log-normal turbulence model:

The probability density function (PDF) of the log-normal model is given by

$$f_I(I) = \frac{1}{I\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln(I) + \sigma^2/2)^2}{2\sigma^2}\right)$$

where s is the standard deviation of the log-normal distribution, which depends on the channel's characteristics as given by[13]

$$\sigma^2 = \exp\left[\frac{0.49\delta^2}{(1 + 0.18d^2 + 0.56\delta^{12/5})^{7/6}} + \frac{0.51\delta^2}{(1 + 0.9d^2 + 0.62d^2\delta^{12/5})^{5/6}}\right] - 1$$

Where D= $\sqrt{kD^2/4L}$, $k = 2\pi/\lambda$ is the optical wave number, L is the length of the optical link and D is the receiver's aperture diameter. The parameter d2 is the Rytov variance given by

$$\delta^2 = 1.23C_n^2 k^{7/6} L^{11/6}$$

with Cn 2 being the altitude-dependent turbulence strength and varying from 10217 to 10213 m22/3 according to the atmospheric turbulence conditions. The cumulative distribution function (CDF) for the log-normal distribution model is obtained by integrating (2), yielding

$$F_I(I) = \frac{1}{2}\operatorname{erfc}\left(-\frac{\ln(I) + \sigma^2/2}{\sqrt{2}\sigma}\right)$$

where erfc is the complementary error function defined in[10].

By defining the instantaneous electrical signal-to-noise ratio (SNR) as m ¼ (hI)2=N0 ¼ s2=N0, the average electrical SNR will be given by m_ ¼ (hE[I])2=N0 as previously defined. where E[.] denotes the expectation. Then, considering that E[I] ¼ 1 since I is normalized to unity, and after a power transformation of the RV I in (2), the electrical SNR PDF can be written as

$$f_\mu(\mu) = \frac{1}{2\mu\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln(\mu/\bar{\mu}) + \sigma^2)^2}{8\sigma^2}\right)$$

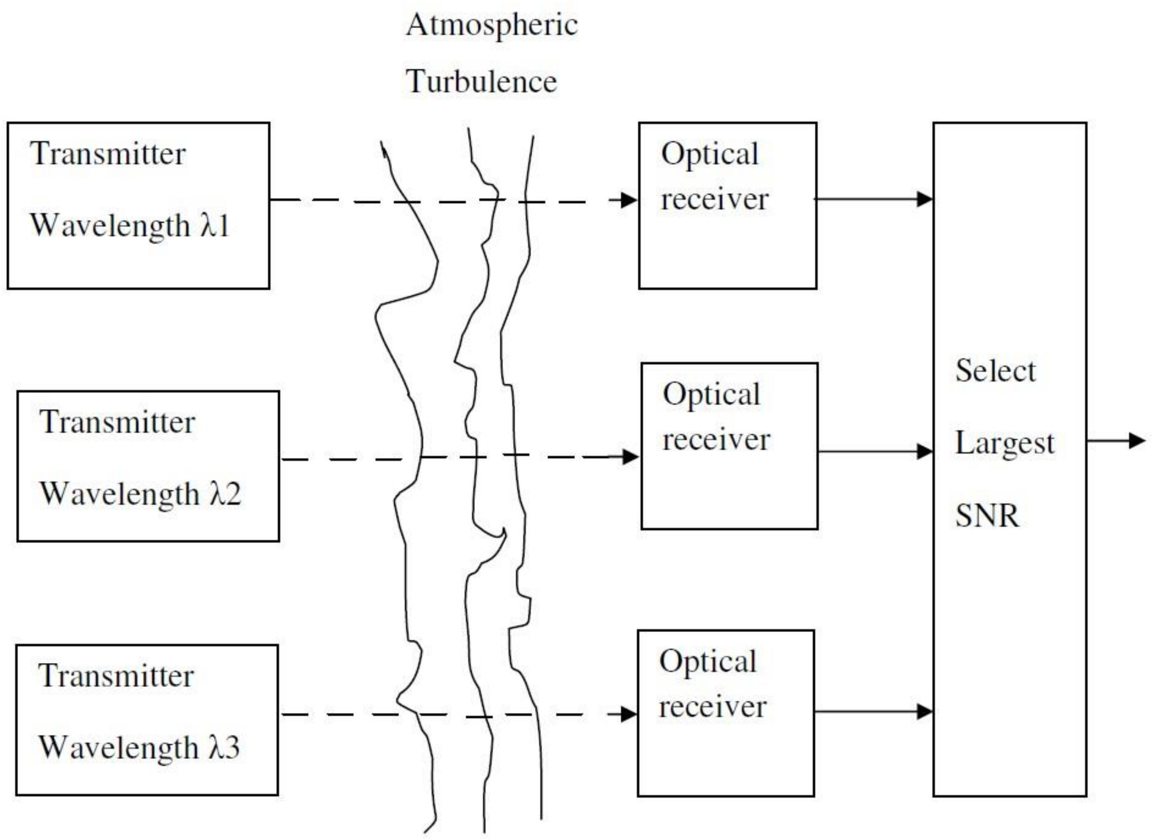
By integrating (6), the CDF with respect to m can be obtained as

$$F_\mu(\mu) = \frac{1}{2}\operatorname{erfc}\left(\frac{\ln(\bar{\mu}/\mu) - \sigma^2}{2\sqrt{2}\sigma}\right)$$

Hence, (6) and (7) present the PDF and the CDF of the electrical SNR of the log-normal turbulence channel.

III. Wavelength Diversity

Scintillation can be reduced using the wavelength diversity i.e. sending the same signal using more than one laser with different wavelength. The time fluctuations in atmospheric temperature and refractive index variation will be different for different wavelengths. The effect of fading due to scintillation can be reduced because the fading is not the same for different wavelength at the same time. If we put three different lasers having wavelengths_1, _2 and _3 and arranging the lasers vertically at different positions (heights) and similarly employing three separate detectors at the receiver as shown in figure 4.3, the signals traveling through turbulent atmosphere undergo different amount of intensity fluctuations for the three different links. At the receiver, the signals are combined by a selective combiner, which results in better overall combined signal intensity.



Intensity fluctuation (_1, t) _ intensity fluctuation (_2, t) _ intensity fluctuation (_3, t), where _1, _2 and _3 are the wavelengths of the transmitters. As the normalized irradiance intensity at the receiver acts like a random variable, the SNR also becomes a random variable. Due to that probability of error also becomes a random variable. If the probability of error in link 1 with wavelength _1, is Px1(x1), that of link 2 with wavelength _2, is Px2(x2), and that of link 3 with wavelength _3 is Px3(x3), then generally Px1(x1)

_Px2(x2) _ Px3(x3). By using the diversity technique described here takes advantage of the reality that the atmospheric propagation path of optical beam is statistically independent for different operating wavelengths and the intensity fluctuations and BER performance will be enhanced because the joint probability of error is always less than the probability of error from individual channels.

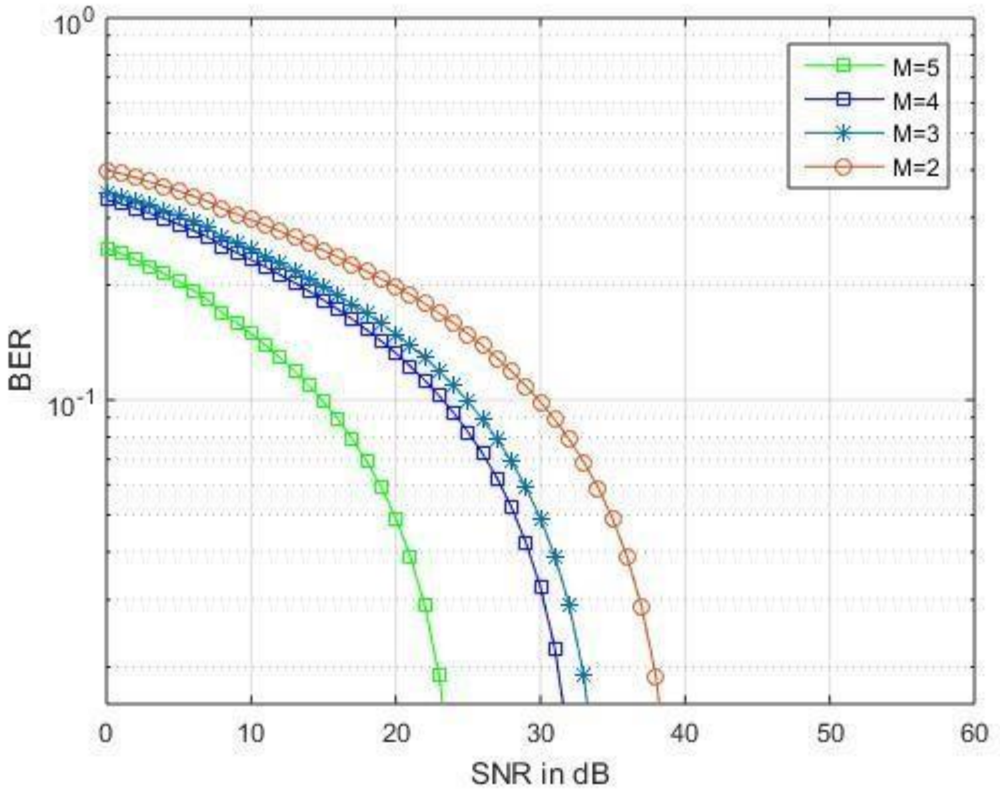
$$p_{x1x2x3}(x1,x2,x3) < p_{x1}(x1),$$
$$p_{x1x2x3}(x1,x2,x3) < p_{x2}(x2),$$
$$p_{x1x2x3}(x1,x2,x3) < p_{x3}(x3)$$

The diversity techniques that can be used under this situation are selection diversity, Equal Gain Combining (EGC) and Maximal ratio combining (MRC). Selection diversity which is used in here is one of the simplest diversity technique in which the signal with largest SNR is selected by the receiver. Let γ_th is the threshold value of SNR that must be achieved for proper demodulation and _k be the instantaneous SNR of the kth branch. If there are M links (M transmitters and M receivers), the probability that bit energy to noise ratio of all the links are below the threshold γ_th is

Three different carrier wavelengths were selected for this study: 0.85 µm, 1.55 µm, and 10 µm. The selection was not random. They are separate enough so that the fog effect on optical signals can be analyzed. Furthermore, commercial FSO equipment uses these carrier wavelengths for data transmission. The 0.85 µm laser is near infrared. At higher intensities, it is more harmful to the eye than the 1.55 µm and 10 µm lasers. The 1.55 µm laser is also in the near-infrared part of the spectrum. Since it is less harmful to the human eye than 0.85 µm, more power can safely be used with this wavelength. The 1.55 µm laser also is the best performing laser in clear skies. The 10 µm laser is in the thermal infrared spectrum. When compared to 0.85 µm and 1.55 µm wavelengths, this laser consumes more power, and it cannot modulate as quickly [8]. Currently, the 10 µm lasers are not widely used for FSO purposes, although they are being examined more closely in recent publications.

IV. Simulation Results

The results obtained from the simulation indicate improved optical signal detection using all three selected transmission wavelengths when compared to that of using only one. One must note here that for equal gain, combining the transmission power when one carrier is transmitted, is 20 mW; but it is reduced to one third of 20 mW when three carriers are simultaneously transmitted. The effect of advection fog on the 10 µm signal was more pronounced than on the 0.85 µm and 1.55 µm signals, as shown in Figure 3. On the other hand, the effect of radiation fog on 0.85 µm and 1.55 µm signals was greater than the effect on the 10 µm signal, as shown in Figure 4. Therefore, the implementation of the wavelength diversity technique demonstrated power reception improvements in tens of a percent under these two fog conditions. Both schemes of diversity used in this study have improved the performance of the FSO system. The following subsections provide illustrations of the power improvements and, thus, coverage distance improvements under the two different diversity schemes.



V. CONCLUSION

A review of the FSO technology has been described in this chapter. The basic block diagram of FSO communications system and the transmission parameters are discussed with detail analysis and mathematical expressions. Brief discussion about sources and detectors used in FSO communication are presented. Different atmospheric turbulence models and the communication performance parameters of FSO technology are also discussed. BER will be improved by using thee wavelength diversity and thus reliability and quality factor of FSO communication link. The proposed FSO based wavelength diversity technique is capable of providing reliable link between transmitter and receiver with better performance. Thus, we conclude that the BER and quality factor of FSO communication link can be done better by using wavelength diversity technique. We obtain the results that clearly shows the wavelength diversity significantly enhance the performance metrices of the link.