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Investigating Wavelength Dependency of Terrestrial Free Space Optical Communication Link

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ABSTRACT

Free space optical communication involves fiber-less optical based data transmission using visible and infrared bands of the spectrum. This technology has gained huge popularity in the past decades. In recent past a lot of research has been carried out to improve the FSO link performance which is seriously affected due to atmospheric inconsistencies. This paper investigates the performance of free space optical link for different wavelengths. As the laser beam propagates through atmosphere it undergoes attenuation and this attenuation has been calculated for different wavelengths. Moreover the attenuation and scattering due to haze has been studied for different wavelengths. The wavelengths used for this research work are 10 μm, 1.55 μm and 0.85 μm. Finally bit error rate performance of DPSK modulation has been investigated for above mentioned wavelengths and atmospheric turbulence has been modeled using gamma-gamma model. It has been observed that higher wavelengths show less attenuation and moreover the BER performance of DPSK modulation techniques for higher wavelengths is better than that of lower wavelengths.
Keywords: FSO, BER, DPSK, Wavelength, Atmospheric Turbulence

I. INTRODUCTION

Free Space Optical Communication uses atmosphere as communication link between transmitter and receiver separated by certain distance.

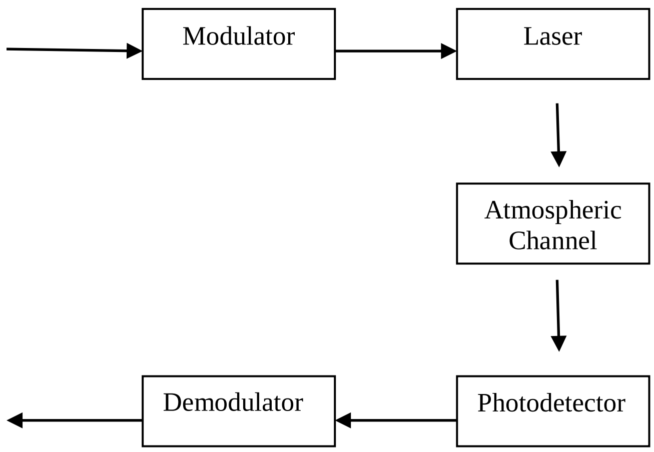

Figure 1. Schematic of FSO

The data which has to be transmitted is modulated on the intensity, phase and frequency of the carrier signal. FSO systems operate in the infrared (IR) range of spectrum. FSO systems use wavelengths around 850 and 1550 nm and the frequencies corresponding to this range of wavelengths is around 200 THz [1]. The main requirement for proper operation of an FSO system is unobstructed line-of-sight between the transmitter and receiver.

FSO has now become a commercially viable technology to radio frequency (RF) and millimetre wave wireless systems and it is being used for the reliable and rapid deployment of data, voice and video within the access networks. Radio Frequency based wireless networks are offering data rates in the range of tens of Mbps (point-to-multipoint) up to several hundred Mbps (point-to-point) [2]. But the main drawback or major limitation is that the spectrum is getting congested day by day because of increasing demands of bandwidth. The most efficient solution to this problem of spectrum congestion is the use of FSO system which provides abundant bandwidth. By an optical carrier, we can get bandwidth upto 2000 THz and on the other hand in Radio Frequency systems the usable bandwidth is comparatively lower by a factor of 10^5. The advantages of FSO include lesser time to deploy and there is no need of digging of trenches rights. We need not to purchase any frequency spectrum. Moreover the cost of implementing FSO system is also lower than that of RF system [3].

The greatest problem that FSO system has to face comes from the atmospheric channel, which results in signal, absorption, scattering and fluctuation. The optical beam travelling through the atmosphere comes across aerosols (which consist of fog, smoke and other particles) and gases resulting in huge attenuation of signal. The other main factor responsible for the degradation of performance of FSO system is the atmospheric scintillation caused by in homogeneity of atmospheric temperature. Signal fading takes place because of scintillation which in turn further degrades the system performance. High attenuation and extinction of optical signal is caused by small particles which are present in fog and clouds and this attenuation can be in the range of 30 dB/Km and even more than this. So the laser beam travelling through turbulent atmosphere suffers a lot of attenuation.

In this paper we are trying to investigate the FSO system performance in terms of wavelength. The attenuation due to snow and fog will be studied for different wavelengths and then BER performance of DPSK modulation technique will be studied for different wavelengths.

II. METHODS AND MATERIAL

1. Wavelength Analysis

As the optical signal travels through the atmosphere, it encounters many atmospheric conditions which contribute to the attenuation. We have taken into account only the effect of haze and scattering in this work.

A. HAZE

Attenuation present in a system can affect its performance. Atmospheric attenuation and geometric losses constitute all attenuation. We have not considered geometric losses in this work as it has been assumed that there is no spreading of signal. Atmospheric attenuation arises because presence of particles in the air for e.g. haze. As haze particles present in the atmosphere can stay for longer time, so the attenuation values for any particular instant of time depend on the level of visibility at that time. There are two ways in which we can gather information regarding the attenuation of FSO link in order to check the performance of FSO system. Firstly, we can do it by installing FSO system temporary at the site and check its performance. Secondly, by using Kim & Kruse Model to find the attenuation for different values of visibilities. The law is given by the following expression given as follows [4,5] :

$$\gamma(\lambda) = \frac{3.912}{V}\left(\frac{\lambda(nm)}{550}\right)^{-q} \quad (1)$$

$$q = \begin{cases} 1.6 & si \quad V > 50\,kms \\ 1.3 & si \quad 6kms < V < 50kms \\ 0.585V^{1/3} & si \quad V < 6kms \end{cases} \quad (2)$$

where q is a quantity that depends on the physical properties of the scattering particles such as particle concentration, size of particle and their distribution, visibility range etc. The visibility is a parameter that defines the opacity of the atmosphere. We can define this parameter as the distance to an object where the contrast of the image will drop to 2% of what it would be if the object were nearby instead. For the visible and near IR spectral band (up to 2.4 µm), the formula defined in eq. (2) relates the attenuation of light to the visibility range V in kilo meters for a given wavelength λ (nm) whereas γ represents the attenuation expressed in Km^{-1}. The visibility is generally measured at a wavelength of 550 nm because this wavelength corresponds to maximum intensity of solar spectrum and is given by Koschmieder Law as;

$$V = \frac{3.912}{\lambda(550nm)} \quad (3)$$

Where V is visibility range expressed in Kms.

B. Scattering

The presence of Fog affects the FSO link performance. The scattering of the optical beam propagating through the caused by water particles attenuates the signal. We can characterize fog by a number of physical parameters such as particle size distribution, temperature of fog, liquid water content, and humidity. As the size of fog particles is comparable to the transmission wavelength of optical and near infrared waves, it results in attenuation due to Mie scattering, which in turn reduces link availability of FSO system [6,7]. In order to study the attenuation of laser radiation by fog we need to find a relation between some physical parameters. For this we need to find a link between liquid water content, particle concentration and visibility. We can define Visibility can be defined as the greatest distance under given weather conditions to which it is possible to see without instrumental assistance. A relationship is given in [8]:

$$PC=\frac{3.912*q^2}{V_m F(0.5)*\pi*a^2*(q+2)(q+1)} \quad (4)$$

$$LWC=\frac{3.912*4a*(q+3)*\rho_m}{3*V_m F(0.5)*q} \quad (5)$$

PC = particle concentration
LWC = liquid water content
Vm = visibility
Q = characteristic of half-width of the distribution
a = most-likely radius of particles
F(0.5) = effective attenuation factor for wavelength $\lambda = 0.5$ µm
ρ_m = water density

The water content and particle concentration can vary but there is no change in visibility. The attenuation factor given by α_{scat} caused by scattering can be given as:

$$\alpha_{scat}=\frac{17}{V_m}\left(\frac{0.55}{\lambda}\right)^{0.195*V_m} \quad (6)$$

Where λ is wavelength and V_m is the visibility in Kms.

2. BER Performance for different wavelengths

A. Gamma-Gamma Model

The gamma-gamma turbulence model is a model proposed by Andrews *et al.*[9] which models the atmospheric turbulence . A variety of turbulence conditions can be covered by this model. In this model the fluctuation of light radiation propagating through turbulent atmospheric conditions is supposed to consist of small scale and large scale fading effects. The normalized received irradiance which is basically defined as product of two statically independent random processes I_x and I_y and it is given by:

$$I=Ix\times Iy \quad (7)$$

Where I_x and I_y arsie from large scale and small scale eddies respectively and both of them are supposed to obey gamma-gamma distribution. The gamma-gamma model for the probability density function of received irradiance is given by:

$$P(I)=\frac{2(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta I}), I>0 \quad (8)$$

Where I is the signal intensity, α and β are parameters which correspond to the effective number of small scale and large scale eddies of the scattering process, Γ is the gamma function and $K_{\alpha-\beta}$ is the modified bessel function of the second kind having order α-β. Here, α and β are the effective number of small-scale and large scale eddies of turbulent environment. These parameters are given as:

$$\alpha=\{\exp[0.49\sigma^2/(1+1.11\sigma^{12/5})^{7/6}]-1\}^{-1} \quad (9)$$

$$\beta=\{\exp[0.51\sigma^2/(1+1.11\sigma^{12/5})^{5/6}]-1\}^{-1} \quad (10)$$

where $\sigma^2 = 1.23C_n^2 k^{7/6} L^{11/6}$ is the rytov variance representing the variance of log-intensity fluctuation in which C_n^2 is the refractive-index structure parameter, k is the wave number, and L is the distance between transmitter and receiver.

B. 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. 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:

$$I(t)=RI(1+\beta m(t)) + n(t) \quad (11)$$

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(ω_ct + Θ), 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≤ 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 [10-11]:

$$I_{sky}=N(\lambda)\ \Delta\lambda\pi\Omega^2/4 \quad (12)$$

$$I_{sun}=W(\lambda)\ \Delta\lambda \quad (13)$$

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 they 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 :

$$\sigma_{Bg}^2= 2qBR\ (I_{sky} + I_{sun}) \quad (14)$$

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:

$$\sigma_{Th}^2= = 4\ kT_eBR_L^{-1} \quad (15)$$

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

$$\sigma^2=\sigma_{Bg}^2 + \sigma_{Th}^2 \quad (16)$$

The electrical SNR per bit is given by[10] :

$$SNR=A^2\ R^2\ I^2/2\sigma^2 \quad (17)$$

The conditional BER for the DPSK technique is given by [12]:

$$P_{ec}=0.5exp(-0.5\ SNR) \quad (18)$$

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

$$P_e=\frac{(\alpha\beta)^{\frac{(\alpha+\beta)}{2}}}{\Gamma(\alpha)\Gamma(\beta)}\int_0^\infty x^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta I}) \times(0.5\exp(-0.5SNR))\ dx \quad (19)$$

III. RESULT AND DISCUSSION

The system described above has been simulated using matlab.The simulation parameters used are given below as :

Table I. Simulation Parameters

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

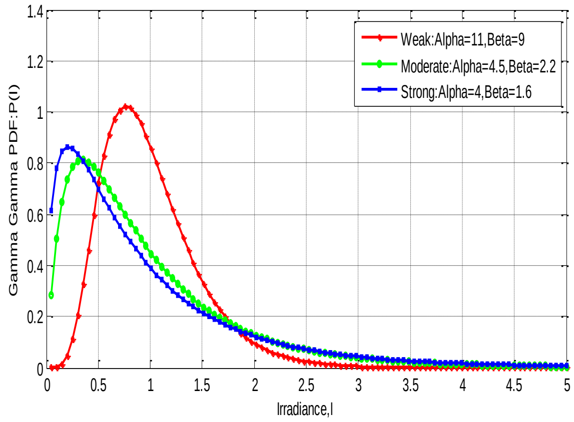

Figure 2. Gamma-Gamma PDF for weak, moderate and strong turbulent regimes

Fig. 2 shows the probability density curve for gamma-gamma model with different values of turbulent strength. The values of alpha and beta indicate whether the atmospheric turbulence region is weak, moderate or strong. In particular, the gamma-gamma model has a much higher density in the high amplitude region leading to a more severe impact on the system performance.

Fig. 3 shows the attenuation coefficient in dB/Km using Kruise relation for different wavelengths. The wavelengths used are 10 µm,1.55 and 0.85 µm.It is clear from the figure that higher wavelengths correspond to low attenuation.

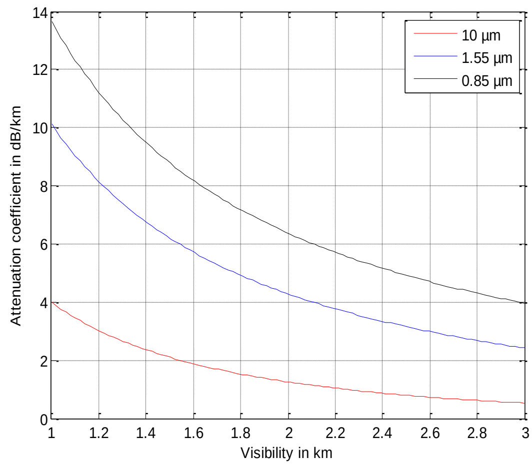

Figure 3. Wavelength Attenuation in dependency of wavelength

Fig. 4 shows the attenuation in terms of attenuation coefficient caused due to scattering of laser beam by water particles and it is clearly evident that scattering caused by water particles is more for smaller wavelengths as compared to higher wavelengths.

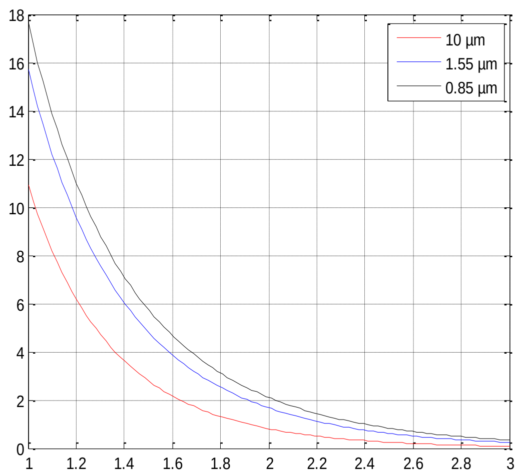

Figure 4. Wavelength Attenuation in dependancy of wavelength

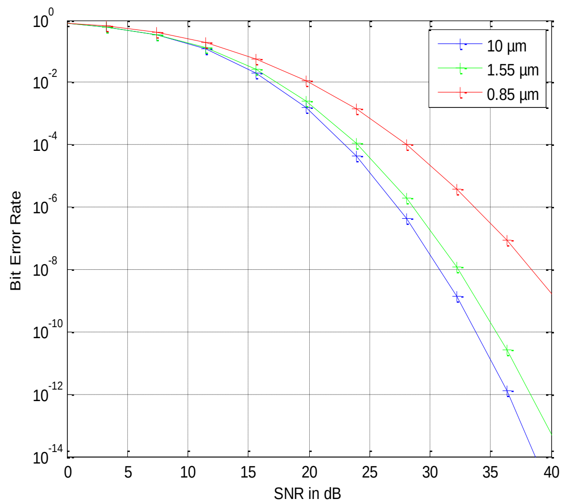

Figure 5. BER versus SNR for different wavelengths

Fig. 5 show BER performance of DPSK modulation technique for different wavelengths and we can see that DPSK modulation performs better for higher wavelengths as compared to lower wavelengths.

IV. CONCLUSIONS

As we can see that we have checked wavelength dependency of free space optical link for different wavelengths. According to Kruise law higher wavelengths undergo less attenuation and this fact is supported by attenuation caused due to scattering in which the attenuation coefficient is more for smaller wavelengths. Further BER performance of DPSK modulation is better for higher wavelengths as compared to smaller wavelengths. So we can say that smaller wavelengths undergo more attenuation.

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