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Feasibility Study of Optical Wireless Communication under Turbulent Conditions

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Abstract: Free Space Optical Communication is one of the most emanate form of high data rates transmission. FSO communication system has the ability to fulfill the craving demand of high data rate users. It has the potential for both indoor and outdoor communication links. But there are multiple factors which demean the performance of FSO communication link. The optical communication link is highly affected by the Scattering, Scintillation, Refraction and Turbulence which degrade the execution of optical link in outdoor environment. FSO can be intensively employed as back-hall communication link to join data communication terminals due to its ease of deployment, license free long range operation, high bit rates, full duplex operation, protocol transparency and immunity to electromagnetic interference. The optical radiations which travel through atmosphere spread out and suffer from propagation losses. Some part of radiation is absorbed while other is scattered in the form of optical losses. This paper proposes a technique by which the reliability of the communication system can be improved by adjusting the transmitting parameters like transmitting wavelength. The conditions and physics of atmosphere cannot be changed but the signal propagation parameters can be adjusted. The contribution of the author is to develop an efficient transmission network which contains an optical transmitter and an optical receiver. There exists an outdoor channel link in between these. The uthor adopt an approach to achieve a reliable mode of communication in the operation of FSO link under turbulent conditions by utilizing previously developed models. Therefore; an important parameter transmitting wavelength is varied and its corresponding variations in the evaluating parameters like SNR and BER are observed and analyzed. Finally, a best transmitting wavelength window has been devised for the best operation of FSO Link under turbulent conditions.

Keywords: Communication system; Electromagnetics; Optical losses; Optical Propagation; Propagation losses.

I. INTRODUCTION

Free Space Optical Communication is a wireless LOS (line of sight) communication technology that transmits higher data rates signals by using narrow beam of light through air as a transmission medium. Optical transmitter emits directed beam of light which propagates through air and detected by receiver. It works in Tera Hz spectrum. FSO is preferable due to easy installation, full duplex operation and being a license free communication [1]. Further; FSO has a distinguished feature of frequency reuse. This property avoids the use of repeaters in the communication system after frequent intervals. One of the advantages of FSO is that the communication is through laser beam which propagates in the form of EM (electromagnetic) waves. EM waves are secure and difficult to intercept [1]. FSO transmits high bandwidth data as compared to the fiber optics and other conventional techniques i.e. coaxial cable etc. In spite of all these facts, there exists another side of picture. There are varieties of hurdles which can block the laser signal. These are the physical obstructions which exist in the atmosphere in the path of the signal. It may be sand/ dust particles, smoke particles, snow and fog etc. FSO is more vulnerable to bad weather conditions than the other technologies. Further; un-uniform motion of wind, differential temperature gradient variations over ground surface and at a far height from the ground surface will result in the misalignment of the FSO Link.

The atmospheric disturbances like scattering, absorption, refraction of light signal, scintillation and turbulence reduce link capacity and availability in different weather conditions [2]. The directed beam of light also deviates from its path due to phenomena like turbulence. In this paper, FSO system is studied and analyzed under turbulent conditions. The objective is to estimate the best transmission network operating conditions under the effect of turbulence. The life of an optical link is its signal strength therefore; the goal is to maintain its signal strength by adjusting parameters like transmitting wavelength on transmitter side. Practically, there exists no such transmitting wavelength window in which such losses are avoidable to some extent. In this work, the specific wavelength window has been proposed for reliable communication.

This specific transmitting wavelength window is devised through simulation analysis in which the losses due to the physical obstructions and the phenomenon like turbulence may be minimized. In this wavelength range SNR may be improved to a greater extent and BER may be reduced to some extent within a limited range of operation. In this way the reliability and efficiency of the signal may be improved in the presence of the atmospheric distortions. The huge bandwidth transmission of FSO system makes it attractive for a massive use in telecommunication industry. The only obstacle in the path of its progress is its reliability. If the reliability of the signal improves then this system is a revolution in the field of wireless communication. The upcoming changing trends in the field of smart grid communication can also be synchronized with the FSO Communication system. This research presents a unique approach for the analysis of the atmospheric effects by using appropriate models. The results are inferred by using simulation analysis on the Matlab software.

II. LITERATURE REVIEW

The outdoor atmospheric channel is very complicated and dynamic in nature that can influence the characteristics of the optical signal propagation which results in the optical loss. The radiations from the sun which are absorbed by the earth's surface cause air around the surface of the earth to be hotter than that of at higher altitude. The layer of hotter air becomes less dense and rises above to mix turbulently with the surrounding cooler air which causes air temperature to fluctuate randomly [3]. The inhomogeneity produced due to the turbulence can be regarded as discrete cells or eddies. The interaction between the laser signal and turbulent medium produces random phase and amplitude variations which is called Scintillation which causes the fading of received optical power due to which system performance degrades [4]. Khaleel S. ALTOWIJ et al in his work [5] has shown that the atmospheric turbulence produces phase shifts of propagating optical signals resulting in distortion in wave front which produces Scintillation. He analyzed the atmospheric turbulence by specific parameters like Refractive index structural parameter, Scintillation, Beam spreading. However; the above stated parameters have not been deeply analyzed for the case of optimum transmission network within a limited range of operation in [5]. Whereas, these parameters with the help of already developed mathematically models are deeply analyzed and a particular transmitting wavelength window has been proposed for the efficient communication System Link for the Line of Sight Communication in this work. The above-mentioned parameters are analyzed by using appropriate models of Refractive index structural parameter (H-V Model), Scintillation and Beam spreading. Two criterions are used to evaluate our methods, namely Bit error rate and Signal to noise ratio. In this paper, the mathematical models of [5] are utilized to select an optimum transmission wavelength window in which FSO transmission suffers from less losses as compared to the other wavelengths. By making comparison of the proposed method in this paper with the work [5] it has been found that by using this new technique an improved transmission network can be developed. The new Physical transmission network can be developed by utilizing the concept of adjusting transmitting parameters for the case of optimum transmission. So, the contribution of the author is to devise such an FSO Link communication system in which transmission is optimum under the turbulent condition.

III. METHODOLOGY

FSO transmits a narrow optical beam but due to diffraction in the outdoor channel beam spreads and receiver aperture collects fraction of beam. It will produce beam divergence.

A. Turbulence

The surface of ground heats up during day time. So, the air lies above the ground surface heats up too. Some air cells heat up more than others. It causes changes in index of refraction which in turn changes path that light takes while it propagates through air. This will produce a turbulent behavior. There are three effects which are produced under turbulence: Beam Wander, Scintillation and Beam spread.

Moisture, aerosols, temperature and pressure changes produce refractive index variation in the air [5]. These variations are called eddies. From geometrical optics point of view, eddies are considered as lenses that randomly refract optical wave front producing distorted intensity profile at receiver. The intensity fluctuations produce Scintillation. The purpose of the study of Turbulence Model is to elaborate the concept of Scintillation, Refractive index structural parameter variations and Beam spreading.

B. Refractive index structural parameter

Refractive index structure parameter is a measure of intensity of optical turbulence. It depends upon the geographical location, altitude and time of delay. To evaluate Refractive index structural parameter, different parametric models are used. One of these methods is Hufnagel Valley Model [6]. The Hufnagel proposed a revolutionary model in 1974 to evaluate the profile of Refractive index structural parameter. At a point close to the ground surface there is the largest temperature gradient which is associated with the largest value of atmospheric pressure so the value of C_n^2 (refractive index structural parameter) is largest. But as the altitude increases, the temperature gradient reduces, and the value of refractive index structural parameter decreases accordingly. Thus, the refractive index structural parameter is the measure of strength of fluctuation in the refractive index. The refractive index structural parameter can be measured by Hufnagel Valley Model which is formulated to describe C_n^2.

$$Cn^2 = 0.00594\left(\frac{v}{27}\right)^2 \left(10^{-5}h\right)^{10} \exp\left(-\frac{h}{1000}\right) + 2.7\times10^{-16}\exp\left(-\frac{h}{1500}\right) + A_0\exp\left(-\frac{h}{100}\right) \quad (1)$$

Where h is the altitude in m, v is the wind speed in m/s. A_0 is the turbulence strength at ground level particularly and A_0 = 1.7 x 10^{-14} $m^{-2/3}$. Therefore, the important parameters with respect to the variations in this model are altitude and wind speed.

C. Scintillation

When laser beam in the form of light propagates through scintillation will experience intensity fluctuations. The scintillation index σ_i^2 is the scale which describes intensity fluctuation. This scintillation index is called variance of the signal [8]. The strength of Scintillation can be measured in terms of variance of beam amplitude. The variance describes the value of deviation of a signal from its target point [7]. It is just like the Gaussian distribution function spectrum in which the variance is the deviation of the value of a function from its mean position.

$$\sigma_i^2 = 1.23 C_n^2 K^{\frac{7}{6}} l^{\frac{11}{6}}, \quad (2)$$

where σ_i^2 = variance, k = wave number= $2\pi/\lambda$; l= transmitting distance, C_n^2 = Refractive index structural parameter.

D. Beam Spreading

Beam spreading means the broadening of the beam size at a target beyond the expected limit due to diffraction as the beam propagates in turbulent atmosphere. The beam will degrade in quality which will result in the average beam waist [7]. To calculate the amount of beam spreading, we describe the effective beam waist average as [8]:

$$w_{eff}(l)^2 = w(l)^2 \left\{ 1 + 1.33\sigma_i^2 \left[\frac{2l}{kw(l)^2} \right]^{\frac{5}{6}} \right\}, \quad (3)$$

Where, $w_{eff}(l)$ is the effective beam waist while w(l) is the beam waist at a propagating distance l [7],

$$w(l)^2 = \left[w_0^2 + \left(\frac{2l}{kw_0}\right)^2 \right] \quad (m^2), \quad (4)$$

Where w_0 is the initial beam waist at l=0, and $w_{eff}(l)^2$ is the beam spreading under turbulence. In this paper, all the other noise sources are neglected, and the only main source of noise is the atmospheric turbulence.

E. SNR & BER

Both Signal to noise ratio and Bit error rate are used to estimate the quality of communication system. "BER Performance depends upon the average received power, Scintillation strength and the noise of the receiver" [7]. SNR is the ratio of the original signal to the noise added in the signal. SNR assess the quality of communication system. In the case of atmospheric turbulence, the SNR described as [9]:

$$SNR = \left(0.31 C_n^2 K^{\frac{7}{6}} l^{\frac{11}{6}} \right)^{-1}, \quad (5)$$

BER (bit error rate) is the ratio of the error bit received at the receiver to the total number of bits transmitted [10]. For example, 10^{-10} bit error rate means 1 error bit received at receiver to the total number of bits transmitted which are 10=(1/10).

$$BER = \frac{\exp(-SNR/2)}{(2\pi SNR)^{0.5}}, \quad (6)$$

The above models for refractive index structure parameters, Variance, Scintillation, Effective Beam Waist, SNR and BER in the methodology are utilized in the heuristic way to propose a new method of improving communication by adjusting transmitting parameters. The simulation analysis has been made in the next section.

IV. SIMULATION RESULTS

The simulations are based on above stated mathematical models. The values of variable parameters are based on assumptions. The purpose is to find out the transmitting wavelength window for which the communication is reliable and free from noise. The design 1 is considered from Eq. no.1 in which wind speed is assumed to be constant (21 m/s) while the altitude is varied from 500m to 1200m. The corresponding change in the refractive index structural parameter with respect to these parameters is plotted in the graph. From figure 1, it is clear that the value of refractive index structural parameter depends upon the altitude. It reduces with the increase in altitude which means that the strength of fluctuation in refractive index weakens as the height from the ground level increases. The value of C_n^2 is large at 500m but reduces gradually up to a lower value at 1100m.

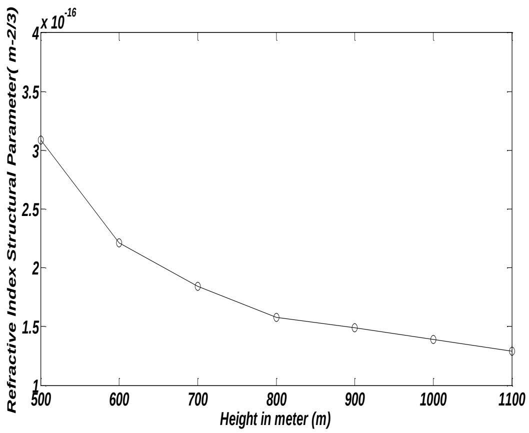

Figure 1: Height v/s Refractive index structural parameter

It is obvious from Figure 1 that the decrease in refractive index structural parameter is more from 500m to 800m and less than previous from the height 800m to 1100m. It means that as the distance from the ground level increases the value of the refractive index structural parameter decreases. It illustrates that the effect of turbulence is more prominent in the height range from 500m to 700m and it becomes less prominent from height range from 800m to 1100m.

By considering the scintillation effect from Eq. no.2, the design 2 is taken into account. In this design, the transmitting wavelength is kept fix. The link path is assumed to be varied from l=500m to l=1200m. From figure 2, it is shown that the value of variance increases accordingly as the link path increases. The wavelength is kept constant i.e. 850 nm. At l=500m, the variance=0.0108. When the length increases, the variance increases accordingly. At l=1200m, the variance is 0.0539. It illustrates that as the distance from the transmitter increases the variance of the signal increases accordingly and the effect of the scintillation becomes prominent at long transmitting length. The following Figure 2 is demonstrating this trend:

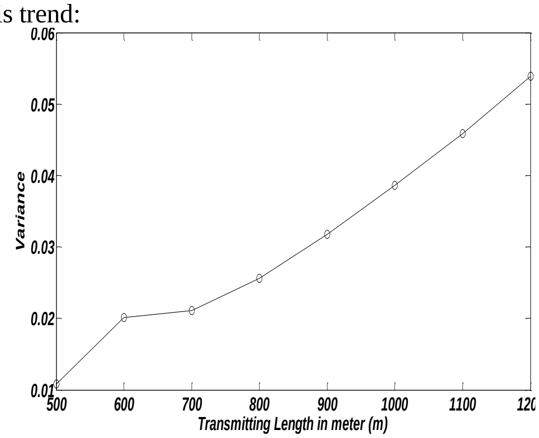

Figure 2: Path length v/s Variance

By considering Eq. no.3, design 3 is assumed. In this design, the link path is varied from l=500m to l=1100m. The transmitting wavelength is kept fix which is 750nm. At point l=500m, the effective beam waist average value is 0.0180. As the link distances increases, the beam broadens and the value of beam waist average increases accordingly. At point l=1200m, the beam waist average value is 0.0732. It means by increasing the transmitting length, the effective beam waist increases linearly. Figure 3 shows this trend:

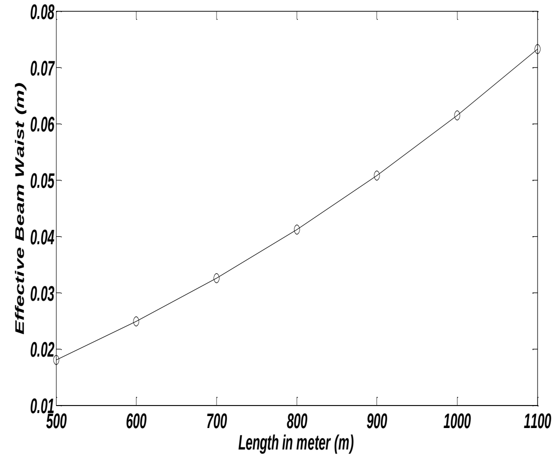

Figure 3: Link path v/s Effective beam waist

The SNR is the ratio of signal power to the signal noise. For calculating SNR, design 4 is considered from Eq. no. 5. In this design, the wavelength is varied from 750nm to 1550nm and the corresponding values of SNR (in dB) have been simulated. At wavelength=750 nm, the value of SNR=34.20dB. As the wavelength increases the SNR improves accordingly. At 850 nm, SNR= 34.83. At 950 nm so, the result is that the SNR may be improved by increasing the transmitting wavelength. Figure 4 shows the trend:

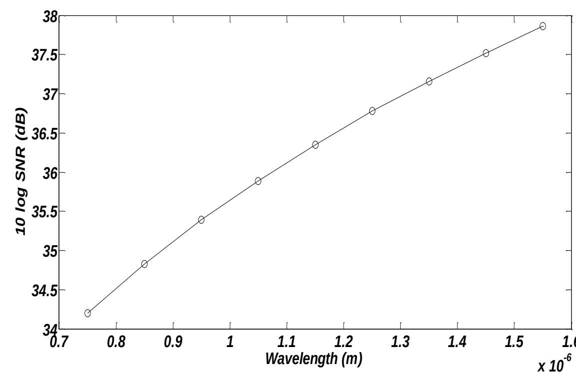

Figure 4: Wavelength v/s SNR (dB)

The BER (bit error rate) is the scale to measure the performance of communication system. Eq. no. 6 is used to calculate BER. The value of wavelength is varied from 750nm to 1550nm. The corresponding change in the BER is observed. At 750nm, the BER is $2.37x10^{-9}$. The value of BER reduces as the wavelength increases up to 950 nm (BER=$1.28x10^{-9}$). At 1050nm wavelength the BER jumps to $9.9x10^{-10}$. As the wavelength increases, the BER reduces too. At 1550nm, BER is $3.58x10^{-10}$. The value of BER in 10^{-9} indicates that 9 bits are transmitted in which 1 bit error bit is received at receiver. The 10^{-10} BER shows that 10 bits are transmitted in which only 1 error bit is received at receiver. So, the wavelength range 1050nm to 1550 nm range is the best window for the communication system in which BER is good. Figure 5 shows the trend of BER with respect to the wavelength:

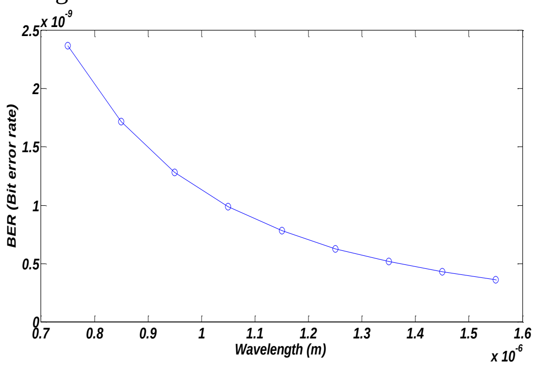

Figure 5: Wavelength v/s Bit error rate (BER)

V. CONCLUSION

FSO communication system is ideal for higher data rates but its performance impairs under turbulent atmosphere. The atmosphere cannot be changed but the transmitting parameters can be altered. The transmitting parameter like wavelength can be adjusted to improve SNR and to reduce BER. The wavelength and the path link are two important parameters which adjusted in such a way to achieve a good design for a reliable mode of operation of FSO communication system. In fact, the signal strength in this communication system can be preserved by the tuning of the transmitting parameter i.e. transmitting wavelength. The wavelength range 1050nm to 1550nm is good window for the optimum mode of communication. In future, the impact of changing the parameter of transmitting wavelength should be observed on variance, refractive index structural parameter and beam spreading can be analyzed and further results can be drawn by utilizing the above models. Moreover; the analysis might be carried on the link path of the distance greater than 1200m.

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