DEVELOPMENT OF FREE SPACE OPTICAL LINK FOR BROADBAND DATA COMMUNICATION

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ABSTRACT

To transfer high speed data streams, a line of sight (LOS) broadband free space optical (FSO) communication link has been designed between two private local LANs located at an aerial distance of about 2 km. A laser diode (LD) – avalanche photodiode (APD) combination operating at 1550nm is used to work as an optical trans-receiver system while an Erbium-doped optical amplifier (EDFA) is used to boost up the laser power for launching into the atmosphere. In this work optical pulse position modulation (PPM) along with convolution coding is used at the receiver side. The system performance impairment due to atmospheric turbulence such as scintillation and attenuation produced by fog and rain are theoretically analyzed to study the channel characteristic of the FSO link. The preliminary results of simulation will be presented for predicating the performance of FSO link operating under normal weather conditions

KEYWORDS: *Wireless Network, LAN, Line Of Sight, FSO*

I. INTRODUCTION

In 1880, Alexander Graham Bell made his first wireless optical communication in which the Sun rays are replaced electric wires and air acts as a medium of transmission called as photo-phone.[1] After 100 years, the engineers took up the same idea of the photo-phone and use in free space optical links for broad band indoor and outdoor wireless communication. Now days LANs are design to accommodate not only for high speed data traffic but also avail the facility of broadband multimedia communication [2]. Ethernet LAN using optical fiber based technology becoming more popular for such applications. However, there are some applications where more than one local LANs are to be accommodate to form a MAN (example: - In Hospitals or Universities Campus [3]). Now it may be necessary to connect two high speeds LANs (Indoor/ Outdoor) to exchange information among them, where the possibility of connecting the LANs using fiber optic cables (lese lines) may not be cost effective and geographically permissible. Under such a situation, a broadband link using Free Space Optical technology can be a good proposition to create such an independent link. [4]

Atmospheric turbulence, scattering and molecular absorptions affect the propagation of optical waves through the atmosphere. Temperature induced fluctuations of refractive index (scintillation) of the atmosphere and absorptions of radiation due to fog and rain are major concerns for design of a faithful optical wireless system [5]. Again the effects are prominent at specific wavelengths of the propagating optical beams. Among all, the problem of mitigating the effects of atmosphere is a real challenge to obtain improved performance in a FSO system.

In the following sections, first the basic model of FSO link is described with trans-receiver devices followed by theoretical analysis with fundamental mathematical expressions of Intensity profile, log irradiance fluctuations of the field and scintillation index. In further section, Aperture averaging factor 'A' is analysed. Simulation results are given for different lens diameter 'D' at photo-detector section by assuming suitable distance between transmitter and receiver. Finally, a conclusion is made on the basis of simulation results obtained by altering various parameters like wavelength, distance for different atmospheric channel conditions.

II. BASIC MODEL

Bi-directional FSO link set-up is shown in figure.1 having three functional elements: The transmitter, the atmospheric channel, and the receiver. The transmitter converts the electronic signal into light. The light propagates through atmospheric to the receiver, which converts the light back into electronic signal. The modulator converts bits of information into signals in accordance with chosen modulation method. In model we are using binary level optical PPM modulator due to its high power efficiency in combination with convolution coding techniques. The laser diode driver provides power for the laser and stabilized its performance. The telescope aligns the laser radiation to a collimated beam and directed towards receiver. The receiver section includes a telescope, a filter, a photo detector and amplifier. The telescope collects the incoming radiation and focuses it onto the electronic filter. The filter removes the background radiation and allows only spacific wavelength signal to pass through it. The photo detector converts the optical radiation into an electronic signal. The position of pulse is use to determine the nature of the bits and bit error rate is maintained at minimum level 10^{-7} by convolution encoder.

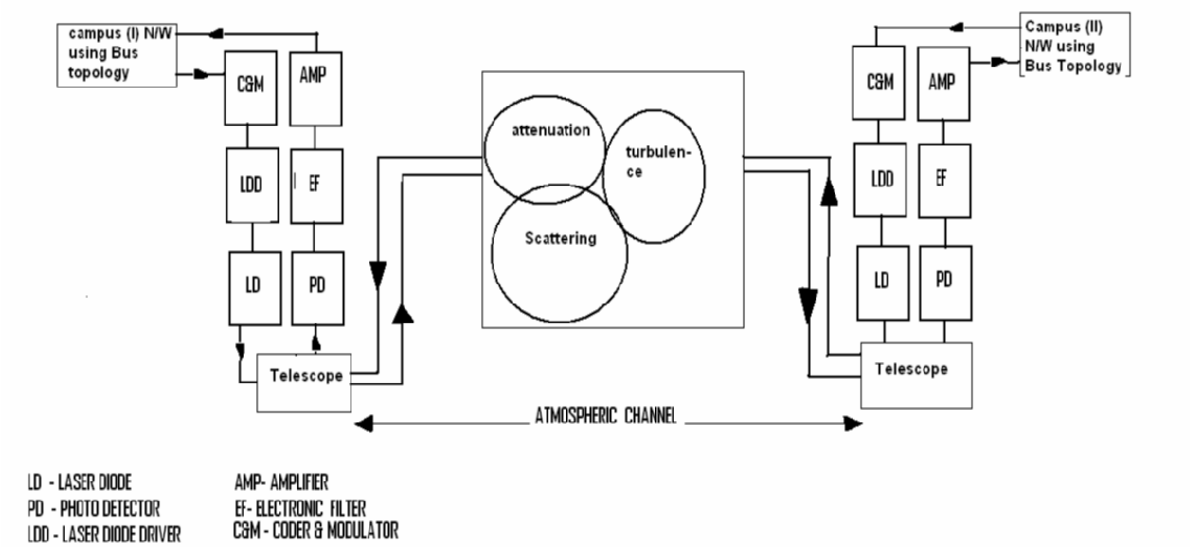

Fig. 1 LAN to LAN link via atmospheric channel

III. THEORETICAL ANALYSIS

The schematic diagram of the overall LAN to LAN (is shown in Fig.2). The diagram shows the horizontal connection between an Ethernet Bus LAN and a Ring topology LAN at the sites of two campuses being bridge by the FSO communication link. Optical telescope have been used as optical transmitting and receiving antennas on both the sides of trans-receiver system facing atmospheric channel. The optical transmitter has been design using single mode distributed feedback [DFB] semiconductor laser operating at 1550nm wavelength with power output of 5mw. A binary level PPM modulation is used due to its average high power efficiency in combination with convolution coding techniques.

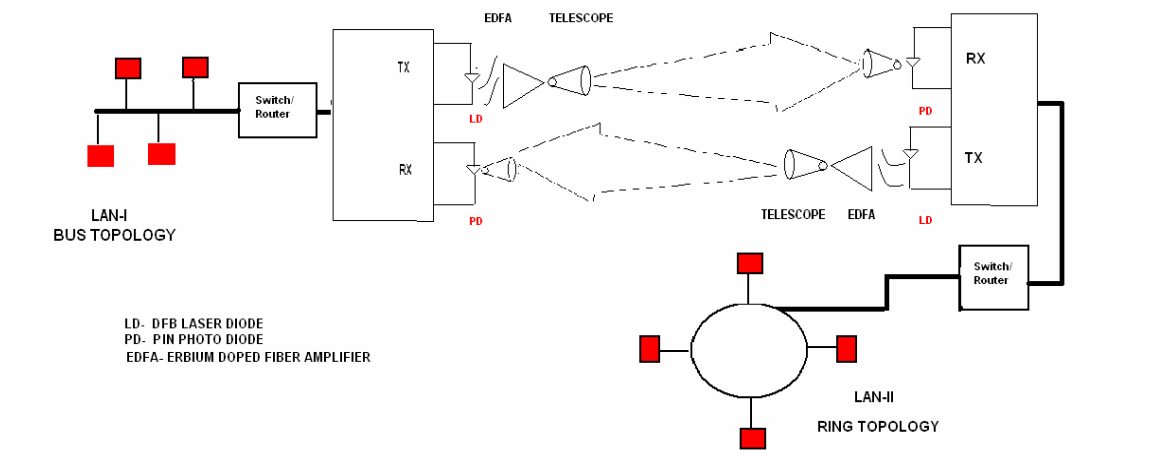

Fig. 2 Schematic Diagram of the LAN-to-LAN FSO link

Now, the propagation characteristics of a laser beam is influence by attenuation due to Absorption (due to Fog and Rain) denoted by Ia
Scattering (due to Dust particles)- Is
Refractive Index variations (due to Temperature)- Isc
If I_p is the intensity received at photo detector.

$$I_P = I_{transmitted} - I_{loss}$$

$$I_{loss} = (I_a + I_{sc} + I_s + I_N)$$

Where I_N is the intensity not collected by detector aperture. Optical absorptions and scattering depends on the characteristics of fog molecules rain drop and aerosols. The attenuations are strong function of incident wavelength λ of light. In addition to this atmospheric temperature produces variations in refractive indices of an air influences the intensity distributions and produce distorted wave-front which influences receiver performance.
Now, if a plane wave propagates normally incident upon a semi- infinite region containing random particles. The coherent intensity I_c is the square of the magnitude of the coherent field noted as $\langle u \rangle$
The incoherent intensity I_i is the average of the square of the incoherent field $\langle u_f \rangle$ and the total intensity I_t is the sum of I_c and I_i. Then, Total intensity is given by [6]

$$I_t = \langle u \rangle = \langle |u^2| \rangle = I_c + I_i$$

$$I_c = |\langle u \rangle|^2$$

$$I_i = \left| \langle u_f \rangle^2 \right|$$

$$u = \langle u \rangle + u_f$$

The coherent intensity I_c attenuates due to scattering and absorption, and therefore it is expect that it will decrease with the attenuation constant equal to the product of density b and the total cross section C_t. The parameter b, is the number density, define as the number of particles per unit volume.
The index of refraction η fluctuates about the average value $\langle \eta \rangle$, and thus using the wave number for the average $K^2 = K_0^2 \langle \eta_0 \rangle^2$ we can write

$$\left[\nabla^2 + K^2 (1 + \eta_1)^2\right] U(r) = 0$$

where η_1 represents the fluctuations of the index of refraction .

For Weak fluctuation, i.e. for small η_1 the solution is given by Rytov equation

and U can be written as

$U = U_0 + U_1 + U_2 + U_3 + ---$

or $U = \exp(\psi_0 + \psi_1 + \psi_2 + \psi_3 + ----)$

$U(r) = \exp^{\psi(r)}$.

Or $U(r, L) = U_0(r, L)\exp[\psi(r, L)]$ where ψ is the complex phase perturbation and

$U_0(r, L)$ is a reference field with definite amplitude and phase.

To study the influence of turbulence on optical beam, consider a lowest order transverse electromagnetic (TEM) [7-10] Gaussian optical beam wave ($TEM_{0,0}$ wave) . It is assumed that the transmitting aperture located at z=0 and the amplitude distribution is Gaussian with effective beam radius w_0 .

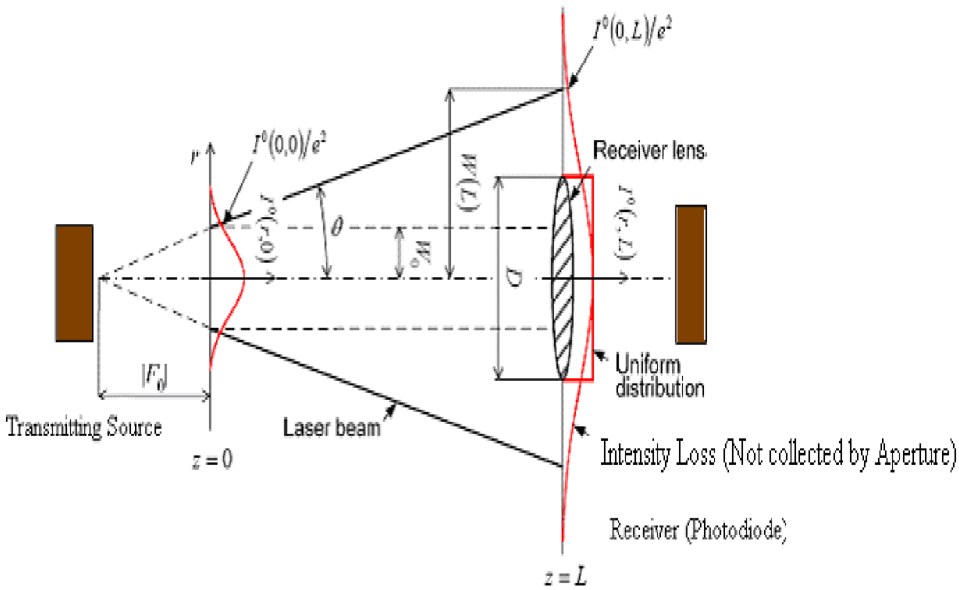

Fig 3. Beam statistics

The optical field unit amplitude written as [4],

$$U(r,0) = \exp\left(-\frac{r^2}{w_0^2}\right) \quad \text{at} \quad z=0. \qquad \text{------------------(1)}$$

Where $r = \sqrt{x^2 + y^2}$

w_0 is the initial beam size and x and y are the horizontal and vertical coordinator of the incident beam field from beam centre respectively.

The irradiance function of the beam at a distance L from the source can be express as

$$I(x, y, L) = \frac{w_0}{w(L)^2}\exp\left[-\frac{2(x^2 + y^2)}{w(L)^2}\right] \qquad \text{------------------(2)}$$

where $W(L)$ is the average beam size or radius at the receiver

Given by,

$$w(L) = w_0\left[1 + (\frac{2L}{kw_0})^2\right]^{1/2}\left[1 + 1.63\sigma^{12/5}\Lambda(L)\right]^{\frac{1}{2}} \qquad \text{-------------------(3)}$$

where k= $2\pi/\lambda$ is wave number, λ is the wavelength of the beam , σ^2 is the Rytov variance for plane wave and $\Lambda(L)$ is the fresnel ratio for vacuum propagation.
Let us define first scintillation index for Coherent Gaussian beam with moderate to strong turbulence ,scintillation index is given by [4]

$$\sigma_{I,s}^2 = \exp\left\{ \frac{0.49\sigma_{I,w}^2}{\left[1+0.56(1+\Theta)\sigma_{I,w}^{\frac{12}{5}}\right]^{\frac{7}{6}}} + \frac{0.51\sigma_{I,w}^2}{\left(1+0.69\sigma_{I,w}^{12/5}\right)^{\frac{5}{6}}} \right\} - 1 \qquad \text{---------- (4)}$$

Above equations described on-axis scintillation index for point receiver, where diameter D $\approx$ 0.
Now, let us define scintillation index for receiver detector having lens diameter 'D $\neq$ 0' [10-11]. For that we assume Ω is the normalized receiver aperture define as

$$\Omega = \frac{2L}{kW_G^2}$$ where W_G^2 is the Gaussian lens radius.

Log irradiance due to large scale eddies is given as

$$\sigma_{\ln,x}^2(D) = \frac{0.49\left(\frac{\Omega-\Lambda_1}{\Omega+\Lambda_1}\right)\sigma_{I,s}^2}{\left[1+\frac{0.4\left(2-\overline{\Theta}_1\right)\left(\frac{\sigma_{I,s}}{\sigma}\right)^{\frac{12}{7}}}{(\Omega+\Lambda_1)\left(\frac{1}{3}-\frac{1}{2}\overline{\Theta}_1+\frac{1}{5}\overline{\Theta}_1^2\right)^{\frac{6}{7}}+0.56(1+\Theta_1)\sigma_{I,s}^{\frac{12}{5}}}\right]^{\frac{7}{6}}}$$

Log irradiance due to small scale eddies is given as

$$\sigma_{\ln,y}^2(D) = \frac{\left(0.51\sigma_{I,s}^2\right)/\left(1+0.69\sigma_{I,w}^{\frac{12}{5}}\right)^{\frac{5}{6}}}{1+\left[1.20\left(\frac{\sigma}{\sigma_{I,s}}\right)^{\frac{12}{5}}+0.83\sigma^{\frac{12}{5}}\right]/(\Omega+\Lambda_1)}$$

Therefore the total scintillation index due to small and larger size eddies is is given by

$$\sigma_I^2(D) = \exp\left[\sigma_{\ln,x}^2(D)+\sigma_{\ln,y}(D)\right]-1 \qquad \text{---------------(5)}$$

IV. NUMERICAL RESULT

In this section we compared Scintillation index of two FSO system which uses same input parameter except the lens diameter is different.
All simulation was realized in the MATLAB environment with beam parameters considered as follows.
Wavelength

$\lambda = 1550nm, 1310nm, 980nm, 780nm$.

Distance $L = 2000m$,

Refractive Index structure parameter $C_n = 10^{-12}, 10^{-14} \& 10^{-16} m^{\frac{-2}{3}}$ for strong, moderate and weak turbulence conditions [13].

4.1 Fix Diameter

Beam width W and diameter D of receiver aperture for coherent beam is chosen as 0.025m and 0.08m (fix). We compare aperture averaged scintillation index of the beam using different wavelengths (1550nm to 780nm) shown in Fig.3. From graph it is observe that using coherent beam with aperture averaging for 1550nm wavelength scintillation index is progressively decreases.

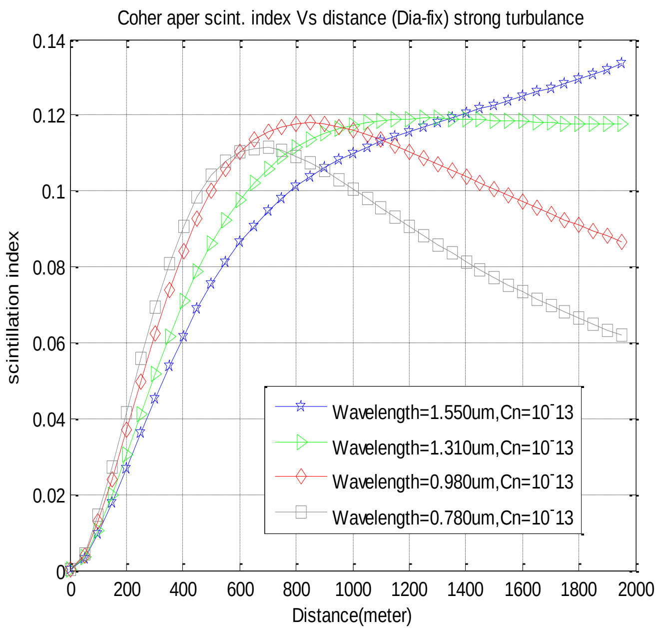

Fig.4 Scintillation index for coherent beam Vs Distance for Strong turbulence

4.2. Variable Diameter

Here we consider Beam width is same but diameter D of receiver aperture is increased 10 times i.e. from 0.08 to 0.8meter for the same distance L=2km. Following fig5. shows the effect of large aperture diameter on scintillation index for strong turbulence conditions using 1550nm and 780nm wavelength.

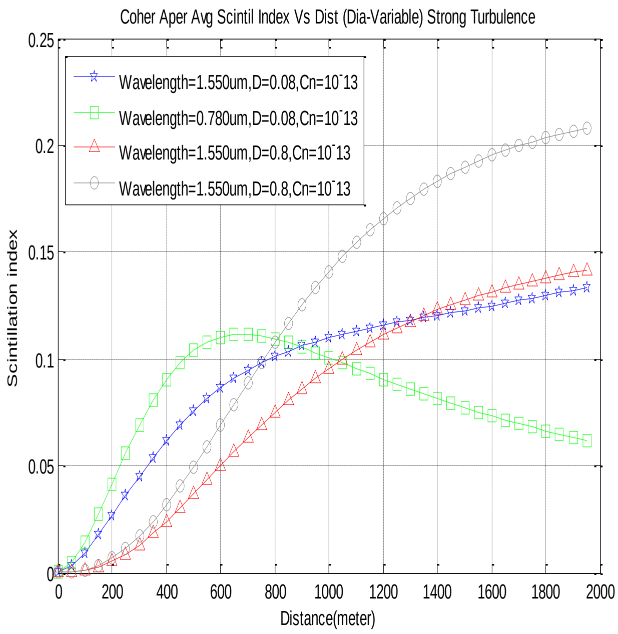

Fig.5 Scintillation index for coherent beam Vs Distance for strong turbulence with variable aperture

V. CONCLUSIONS

A free space optical link has been designed for high speed connectivity between two local area networks (LANs) located at 2km distance. The characteristic performance of the FSO link is studied under different atmospheric conditions in day and night time. It is observed that if the diameter of aperture is increases the effects of scintillation decreases. The performance of the system was studied at the 780nm, 980nm, 1310 nm and 1550nm wavelengths by analyzing scintillation index for different atmospheric turbulence conditions. Results are verified using MATLAB simulation. It is observed that, scintillation index variations are more pronounced for 785nm coherent Gaussian beam compared 1550nm wavelength.

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