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Performance Analysis of FSO System for Diverse Link Range & Temperature Conditions

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ABSTRACT

A free space optical communications system is analyzed for the different link range and temperature conditions. The transmission performance of the proposed system is confirmed experimentally and parameters Bit Error Rate and Signal to Noise Ratio are taken to be in major consideration to analyze the system.

Keywords: Bit Error Rate ,Free Space Optics, Irradiance, Signal to Noise Ratio, Turbulence

I. INTRODUCTION

Optical communication grown to be more and more attractive over as an adjunct or alternative to the radio frequency communication over the last few decades. The employs a modulated light source that transmits an optical signal and a photo-detector which make a replica of the transmitted signal received end and is further converts to an electrical signal. Fiber-optic communication uses optical fiber to transmit the light along its path. Optical fibers have property to carry light signals across greater distances with less loss as compared to the metal wires and are immune to electromagnetic interference. Fiber optic communication systems are widely used in the telecommunications industry and have largely replaced copper wire communications due to their many advantages over electrical transmission. Optical fiber hve considerably less attenuation and prone to interference compared to existing copper wire in long-distance high-speed applications. For wireless communication technology optical system shows potential that can complement the rapid growth of wireless network devices. Free Space Optics (FSO) the communication technology uses light propagating in free space for communication between transmitter and receiver. Free-space-optical links can be implemented using infrared laser light, even if low-data-rate communication over short distances is possible using LEDs. Maximum range for terrestrial links is in the order of few kilometers, but the stability and quality of the link is extremely dependent on atmospheric factors such as dust, fog, rain and heat. In space, the communication range of free-space-optical communication is currently in the order of several thousand kilometers, and operate in large swathes of different unlicensed spectrum amenable to wavelength-division multiplexing. FSO requires clear line-of-sight (LOS) alignment between the transmitter and receiver for communication. Upholding of line-of-sight (LOS) in-between transceivers during an enduring transmission is an important issue since FSO transmitters are highly directional. The bandwidth capacity gap between Radio Frequency wireless and optical fiber network speeds is huge because of the limited availability of the RF spectrum. To overcome this capacity gap a high-speed line of sight and free-space-optical communication has received attention particularly for sky-scraping altitudes e.g. space communications [2] and building-top metro-area communications. Different techniques have been developed for such fixed deployments of FSO to tolerate small vibrations, swaying of the buildings using mechanical auto-tracking or beam steering but none of these techniques target mobility. The main focus of these efforts have been on reaching long communication distances with highly expensive FSO components e.g., lasers. Free Space Optic provides angular diversity and spatial reuse, which formulates FSO even more attractive once combined with its optical transmission speed. Still FSO requires clear line-of-sight that is contrary to Radio Frequency.

II. ATMOSPHERE TURBULENCE

In describing the power density function of the irradiance fluctuation in a turbulent atmosphere, the beam is first represented by its constituent electric field $\vec{E}$ By employing Maxwell's electro-magnetic equations for the case of a spatially variant dielectric like the atmosphere, the following expression is derived

$$\nabla^2\vec{E}+k^2n_{as}^2\vec{E}+2\nabla\left[\vec{E}.\vec{\nabla}In\left(n_{as}\right)\right]=0 \tag{1}$$

where the wave number is $k=2\pi/\lambda$,

The vector gradient operator $\vec{\nabla}=\left(\partial/\partial x\right)i+\left(\partial/\partial y\right)j+\left(\partial/\partial z\right)k$ with i, j and k being the unit vectors along the x, y and z axes, respectively The last term on the left-hand side of Equation 1 represents the turbulence-induced depolarization of the wave. In a weak atmospheric turbulence regime, which is haracterized by single scattering event, the wave depolarization is negligible. In fact, it has been shown both theoretically and experimentally that the depolarization is insignificant even for strong turbulence conditions Equation 1 then reduces to.

$$\nabla^2\vec{E}+k^2n_{as}^2\vec{E}=0 \tag{2}$$

The position vector will henceforth be denoted by *r* and $\vec{E}$ represented by *E*(*r*) for convenience.

As the received average power is given by $P_r=P_t\,exp\left(-\gamma_T L\right)$, where γ_T represents the overall channel attenuation, then the average received photoelectron count is given by [2]

$$\langle n\rangle=\frac{\eta\lambda T_b P_r}{hc} \tag{3}$$

where *h* and *c* are the Planck's constant and the speed of light in vacuum, respectively, and η is the quantum efficiency of the photo detector However, the instantaneous count *n*, unlike the average count, is not constant [2] it varies with time due to the following reasons:

1 The quantum nature of the light or photo detection process, that suggests that the instantaneous number of counts *n* follows the discrete Poisson distribution with an associated quantum noise of variance $\langle n\rangle$ accordingly mean and variance of a Poisson distribution are the same

2 The received signal field varies randomly due to the effect of scintillation.

This implies that the number of counts is now doubly stochastic and based on the log-normal turbulence model.

III. NOISE IN FREE SPACE OPTICAL COMMUNICATION

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In FSO systems the noise from the background radiation could be dominating whereas in fiber optics communication, the background radiation noise is negligible. The photocurrent is proportional to the incident light power the photon shot noise increases with respect to the increase of the incident power (in square root fashion) The lower end of presented relation is restricted by the noise from the dark current, that is present even when there is no input light It is produced by the transition of electrons from the valence to the conduction band due to causes other than photon induced excitation; its magnitude is closely related to the energy band-gap of the photo detector material. Large band gap materials, e.g. silicon, gallium arsenide and indium phosphide show very low values of mean dark current, while for germanium, the value could be significant when they are operated at room temperature [2] The dark current is a combination of bulk and surface leakage currents, carries no useful information and thereby constitutes a shot noise.

Another type of noise is background radiation this is due to the detection of photons generated by the environment Further it is of two types of sources contribute to background radiation noise: localized point sources (the Sun) and extended sources (the sky) Background radiation from other celestial bodies such as stars and reflected background radiation are assumed to be too weak to be considered for a terrestrial FSO link; however, they contribute significantly to background noise in deep space FSO the following are the irradiance (power per unit area) expressions for both the extended and localized background sources [4]

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

$$I_{Sun} = W(\lambda)\Delta\lambda \tag{5}$$

where $N(\lambda)$ and $W(\lambda)$ are the spectral radiance of the sky and spectral radiant emittance of the sun, respectively, $\Delta\lambda$ is the bandwidth of the OBPF that precedes the photo detector and Ω is the photo detector's field of view angle in radians By carefully choosing a receiver with a very narrow FOV and $\Delta\lambda$, the impact of background noise can be greatly reduced OBPF in the form of coatings on the receiver optics telescope with $\Delta\lambda < 1$ nm are now readily available Empirical values of $N(\lambda)$ and $W(\lambda)$ under different observation conditions are also available in the literature [4] . The background radiation is a shot noise with variance

$$\sigma_{bg}^2 = 2qBR\left(I_{sky} + I_{sun}\right) \tag{6}$$

For a coherent receiver, use Equation and change B to Bc In most practical systems, the receiver SNR is limited by the background shot noise that is much stronger than the quantum noise and/or by thermal noise in the electronics[3].

IV. RESULTS & DISCUSSIONS

In this paper we have presented a detailed analysis of Free Space Optical Communication system, for different temperature conditions. Different parameters such as bit Error Rate and Signal to Noise ratio are considered to get better analysis of a FSO link. A simulation setup for a free space optic (FSO) link in matlab software was developed.. Graphs are plotted for the different values of the Signal to Noise ratio versus Bit Error Rate at different atmospheric temperature. Further on the range of the link is also changed from 1 Km to 5 Km for each value of temperature i.e. -20 °C, 0 °C, 20°C and 40 °C .

Table 1 Parameters used for performance analysis of FSO link.

Parameter	Value
Symbol rate R_b	155 Mbps
Spectral radiance of the sky $N(\lambda)$	$10^{-3} W/cm^2 \mu m Sr$
Spectral radiant emittance of the sun $W(\lambda)$	$0.055 W/cm^2 \mu m$
Optical band-pass filter bandwidth Δλ at λ = 850 nm	1 nm
PIN photodetector field of view (FOV)	0.6 rad
Radiation wavelength λ	850 nm
Number of subcarriers N	1
Link range L	1 km, 2 km, 3 km, 4km, 5 km
Index of refraction structure parameter Cn^2	$0.75 \times 10^{-14} m^{-2/3}$
Load resistance RL	50Ω
PIN photo detector responsivity R	1
Operating temperature Te	-20 °C, 0 °C, 20 °C, 40 °C
Optical modulation index ξ	1

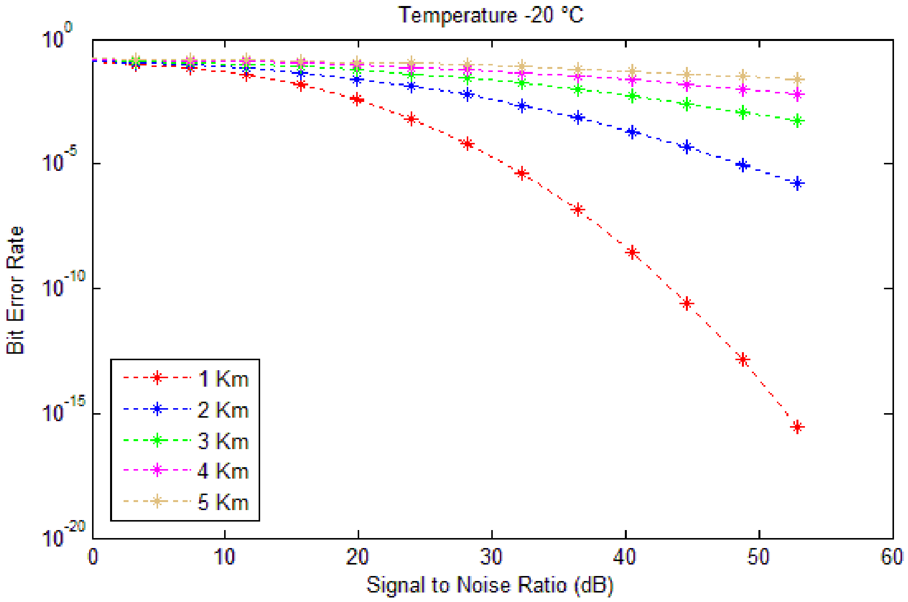

Figure 1 Shows the Bit Error Rate (BER) versus Signal to Noise Ratio in (dB) at -20 °C temperature for link range 1 Km to 5 Km.

Table 2 Difference between the values of Bit Error rate for Signal to Noise Ratio at link range of 1Km, 2 Km, 3Km, 4 Km & 5 Km at -20 °C

SNR	Bit Error Rate				
	1 Km	2 Km	3 Km	4 Km	5 Km
3.2796	1.0220E-01	1.1645E-01	1.3246E-01	1.4697E-01	1.5867E-01
7.4175	6.8557E-02	9.2125E-02	1.1481E-01	1.3432E-01	1.5050E-01
11.5554	3.6606E-02	6.6915E-02	9.5817E-02	1.2001E-01	1.3979E-01
15.6934	1.4374E-02	4.3823E-02	7.5872E-02	1.0538E-01	1.2810E-01
19.8313	3.8491E-03	2.5548E-02	5.7088E-02	8.8714E-02	1.1700E-01
23.9692	6.5870E-04	1.3090E-02	4.0611E-02	7.2310E-02	1.0382E-01
28.1072	6.8353E-05	5.7767E-03	2.6700E-02	5.8328E-02	8.8555E-02
32.2451	4.1286E-06	2.2297E-03	1.6917E-02	4.3898E-02	7.5494E-02
36.3830	1.4076E-07	7.1645E-04	9.4997E-03	3.1733E-02	6.4320E-02
40.5210	2.6544E-09	1.9893E-04	5.2536E-03	2.3240E-02	5.1170E-02
44.6589	2.7371E-11	4.7008E-05	2.5495E-03	1.5246E-02	3.8848E-02
48.7968	1.4578E-13	8.7112E-06	1.1618E-03	9.5312E-03	3.0927E-02
52.9348	2.8969E-16	1.5669E-06	5.1356E-04	6.3291E-03	2.3833E-02

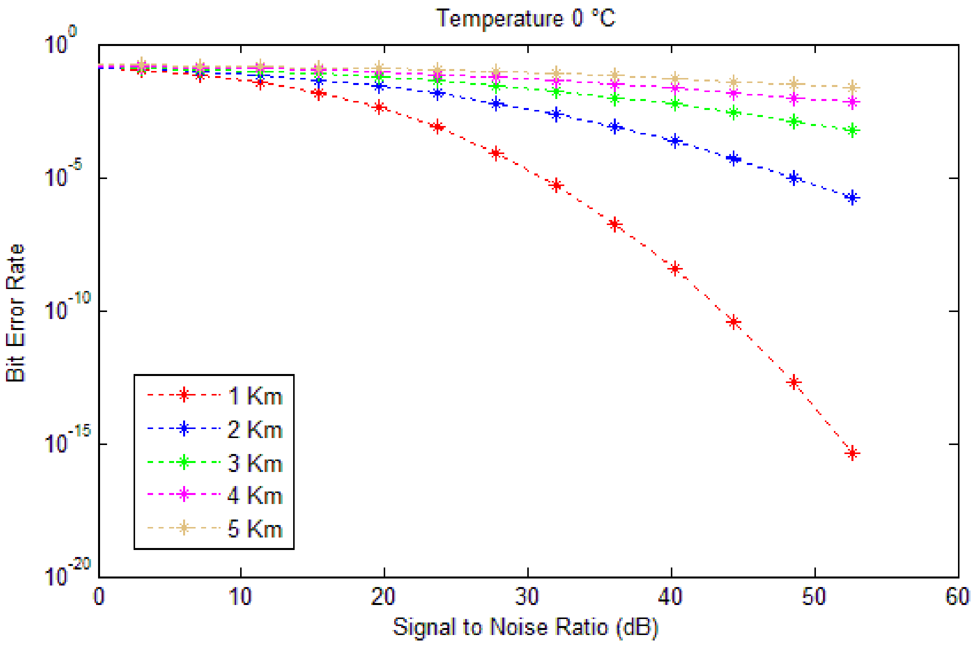

Figure 2 Shows the Bit Error Rate (BER) versus Signal to Noise Ratio in (dB) at -0 °C temperature for link range 1 Km to 5 Km.

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Table 3 Difference between the values of Bit Error rate for Signal to Noise Ratio at link range of 1Km, 2 Km, 3Km, 4 Km & 5 Km at 0 °C

SNR	Bit Error Rate				
	1 Km	2 Km	3 Km	4 Km	5 Km
2.9968	1.0435E-01	1.1800E-01	1.3356E-01	1.4773E-01	1.5915E-01
7.1348	7.0904E-02	9.3851E-02	1.1608E-01	1.3527E-01	1.5114E-01
11.2727	3.8551E-02	6.8606E-02	9.7140E-02	1.2099E-01	1.4058E-01
15.4106	1.5497E-02	4.5263E-02	7.7245E-02	1.0643E-01	1.2888E-01
19.5486	4.2693E-03	2.6624E-02	5.8276E-02	8.9900E-02	1.1779E-01
23.6865	7.5464E-04	1.3755E-02	4.1694E-02	7.3334E-02	1.0483E-01
27.8244	8.1143E-05	6.1385E-03	2.7500E-02	5.9281E-02	8.9578E-02
31.9624	5.0916E-06	2.3938E-03	1.7511E-02	4.4871E-02	7.6268E-02
36.1003	1.8071E-07	7.7594E-04	9.9036E-03	3.2412E-02	6.5137E-02
40.2382	3.5488E-09	2.1939E-04	5.4756E-03	2.3793E-02	5.2104E-02
44.3762	3.7867E-11	5.1876E-05	2.6962E-03	1.5754E-02	3.9553E-02
48.5141	2.0451E-13	9.8667E-06	1.2206E-03	9.8111E-03	3.1382E-02
52.6520	4.3360E-16	1.7758E-06	5.4889E-04	6.5291E-03	2.4357E-02

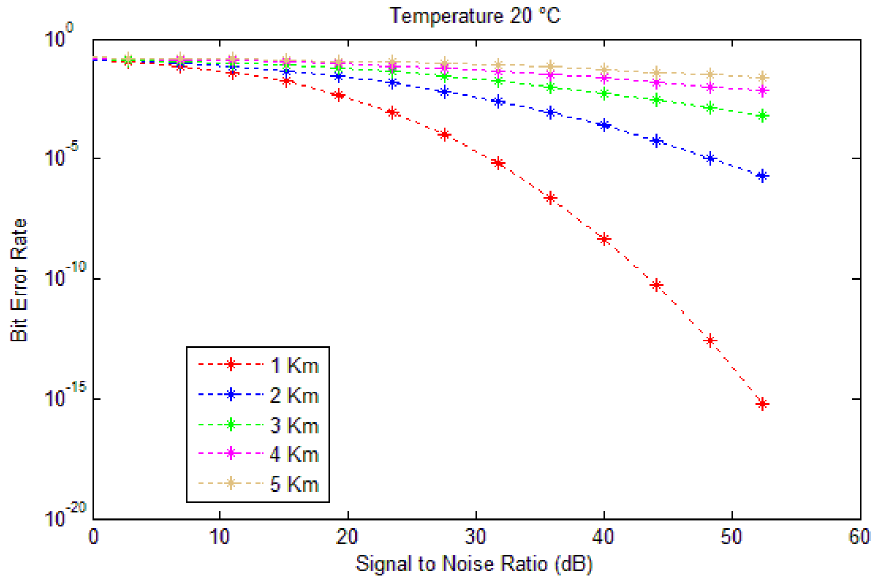

Figure 3 Shows the Bit Error Rate (BER) versus Signal to Noise Ratio in (dB) at 20 °C temperature for link range 1 Km to 5 Km.

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Table 4 Difference between values of Bit Error rate for Signal to Noise Ratio at link range of 1Km, 2 Km, 3Km, 4 Km & 5 Km at 20 °C

SNR	Bit Error Rate				
	1 Km	2 Km	3 Km	4 Km	5 Km
2.7314	1.0634E-01	1.1945E-01	1.3458E-01	1.4843E-01	1.5960E-01
6.8693	7.3111E-02	9.5467E-02	1.1727E-01	1.3615E-01	1.5173E-01
11.0073	4.0418E-02	7.0201E-02	9.8378E-02	1.2191E-01	1.4132E-01
15.1452	1.6605E-02	4.6637E-02	7.8537E-02	1.0740E-01	1.2961E-01
19.2831	4.6965E-03	2.7659E-02	5.9402E-02	9.1013E-02	1.1852E-01
23.4211	8.5557E-04	1.4402E-02	4.2718E-02	7.4310E-02	1.0576E-01
27.5590	9.5097E-05	6.4959E-03	2.8273E-02	6.0171E-02	9.0548E-02
31.6969	6.1822E-06	2.5561E-03	1.8076E-02	4.5793E-02	7.7007E-02
35.8349	2.2767E-07	8.3621E-04	1.0299E-02	3.3069E-02	6.5893E-02
39.9728	4.6383E-09	2.4022E-04	5.6893E-03	2.4311E-02	5.2981E-02
44.1107	5.1034E-11	5.6851E-05	2.8402E-03	1.6241E-02	4.0239E-02
48.2486	2.8072E-13	1.1096E-05	1.2790E-03	1.0087E-02	3.1812E-02
52.3866	6.5164E-16	1.9905E-06	5.8332E-04	6.7169E-03	2.4845E-02

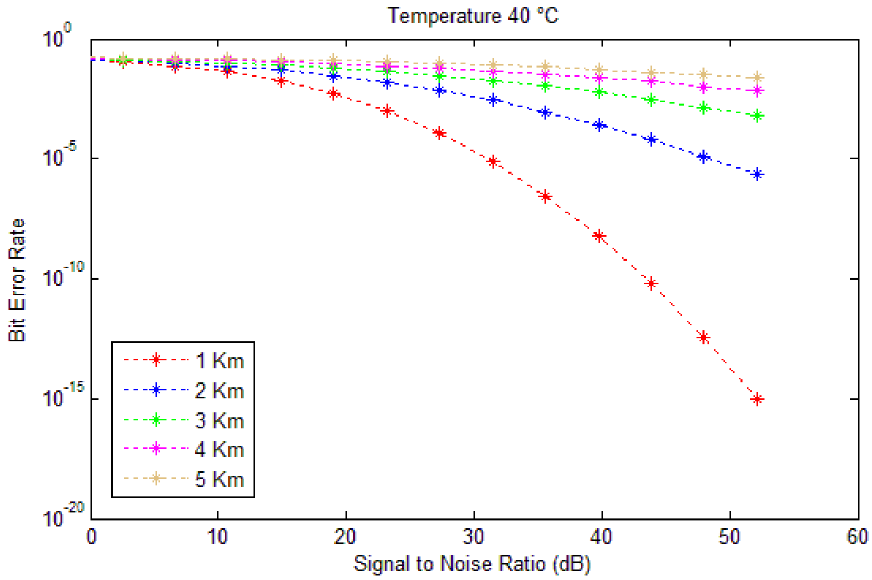

Figure 4 Shows the Bit Error Rate (BER) versus Signal to Noise Ratio in (dB) at 40 °C temperature for link range 1 Km to 5 Km.

Table 5 Difference between the values of Bit Error rate for Signal to Noise Ratio at link range of 1Km, 2 Km, 3Km, 4 Km & 5 Km at 40 °C

SNR	Bit Error Rate				
	1 Km	2 Km	3 Km	4 Km	5 Km
2.4813	1.0820E-01	1.2079E-01	1.3554E-01	1.4908E-01	1.6003E-01
6.6192	7.5192E-02	9.6985E-02	1.1838E-01	1.3697E-01	1.5227E-01
10.7571	4.2214E-02	7.1711E-02	9.9540E-02	1.2278E-01	1.4201E-01
14.8950	1.7696E-02	4.7951E-02	7.9757E-02	1.0831E-01	1.3031E-01
19.0330	5.1296E-03	2.8655E-02	6.0476E-02	9.2060E-02	1.1920E-01
23.1709	9.6122E-04	1.5032E-02	4.3689E-02	7.5244E-02	1.0662E-01
27.3088	1.1021E-04	6.8486E-03	2.9020E-02	6.1004E-02	9.1470E-02
31.4468	7.4058E-06	2.7165E-03	1.8615E-02	4.6668E-02	7.7716E-02
35.5847	2.8224E-07	8.9724E-04	1.0685E-02	3.3708E-02	6.6595E-02
39.7226	5.9473E-09	2.6134E-04	5.8960E-03	2.4798E-02	5.3808E-02
43.8606	6.7346E-11	6.1944E-05	2.9812E-03	1.6708E-02	4.0905E-02
47.9985	3.7938E-13	1.2394E-05	1.3371E-03	1.0360E-02	3.2222E-02
52.1364	9.7761E-16	2.2107E-06	6.1681E-04	6.8941E-03	2.5300E-02

The fig. 1 to 4 shows the effect of Temperature at -20 °C, 0°C, 20 °C & 40 °C for different values of link range from 1Km, 2 Km, 3Km, 4 Km & 5 Km. It s observed form the graphs that only if the link range is kept up to 1 Km the system will work required values of SNR and BER. It is also observed that the characteristics of the system remain approximately same for all the link range from 2 Km to 5 Km at temperature of -20 °C, 0 °C and 20 °C. The comparative study shows that as the temperature increases the BER is improved as the value of SNR increases 50 dB.

Exact numerical values for different Bit Error Rate Versus Signal to Noise Ratio at Link range of 1 Km, 2 Km, 3 Km, 4 Km and 5 Km in Table.

V. CONCLUSION

In this paper we have presented a detailed analysis of Free Space Optical Communication system, for different temperature conditions with respect to BER and SNR. Results shows that the effect of temperature is almost same. And the system is highly sustainable for link range of small distance.

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