Free Space Optical Communication Link under the Weak Atmospheric Turbulence

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Abstract-The terrestrial optical wireless communication links have attracted significant research and commercial worldwide interest over the last few years due to the fact that they offer very high and secure data rate transmission with relatively low installation and operational costs, and without the need of licensing. So in this project, we analyze the performance analysis of FSO links under weak atmospheric turbulence using different parameters: modulation techniques, symbol rate, the distance between the FSO links and the wavelength on the basis of bit error rate (BER) versus received average irradiance E[I]. Due to the influence of turbulence effects, it is necessary to study, theoretically and numerically very carefully before the installation of such a communication system. The scintillation effect, which results in random and fast fluctuations of the irradiance at the receiver's end. These fluctuations can be studied accurately with statistical methods. We present a statistical channel model called as log-normal distribution to describe the irradiance fluctuations.

Key Words: --- Free space optics, turbulence strength, BER, Lognormal distribution, On-off keying modulation, direct detection FSO system, coherent detection FSO system

1.INTRODUCTION

Optical wireless communications (OWC) is an innovative technology that has been around for the last three decades and is gaining more attention as the demand for capacity continues to increase OWC is one of the most promising alternative technologies for indoor and outdoor applications It offers flexible networking solutions that provide cost-effective, highly secure high-speed license-free wireless broadband connectivity for a number of applications, including voice and data, video and entertainment, enterprise connectivity, disaster recovery, illumination and data communications, surveillance and many others.

Due to the unique properties of the optical signal, one can precisely define a footprint and hence can accommodate a number of devices within a small periphery; thus offering a perfect OWC system OWCs, also referred to as free-space optical communication systems for outdoor applications, will play a significant role as a complementary technology to the RF systems in future information superhighways. In access networks, the technologies currently in use include the copper and coaxial cables, wireless Internet access, broadband radio frequency (RF)/microwave and optical fibre These technologies, in particular, copper/coaxial cables and RF-based, have limitations such as a congested spectrum, a lower data rate, an expensive licensing, security issues and a high cost of installation and accessibility to all.

To design efficient optical communication systems, it is imperative that the characteristics of the channel are well-understood Characterization of a communication channel is performed by its channel impulse response, which is then used to analyze and offer solutions to the effects of channel distortions. Free-space optical (FSO) communication technology can provide high data rate transfer and can be easily installed, moved or reconfigured as needs change.

1.1 PHOTODETECTION TECHNIQUES

Photodetection is the process of converting information-bearing optical radiation into its equivalent electrical signal with the aim of recovering the transmitted information At the transmitter, the information can be encoded on the frequency, phase or the intensity of the radiation from an optical source This encoded radiation is then transmitted to the receiver via the free-space channel or the optical fibre The receiver front-end devices (telescope and optical filter) focus the filtered radiation onto the photodetecting surface in the focal plane There are two possible detection schemes widely adopted in optical communications:

A. IM/DD FSO Systems

An IM/DD FSO system collects the transmitted optical field that is directly imaged through the receiver lens system onto the photo-detector. The photo-detector is a power detecting device, which reacts to the instantaneous intensity of the received optical field. At the transmitter, the information can be directly modulated or subcarrier-modulated on the intensity of the optical field. Assuming a turbulence free channel, the received instantaneous intensity can be expressed as

$$I(t) = I_r(1 + km(t)) \qquad (2.1)$$

Where I_r is the average received intensity, m(t) is the modulating signal and k is a scaling factor. Since the transmitting intensity is a non negative quantity, $|km(t)| \leq 1$ is required. In IM/DD FSO systems, the OOK modulation is widely used because of its simplicity. The modulating signal can be 1 for a logic "on" or-1 for a logic "off" with k = 1. At the n_{th} symbol duration, we have

$$m(t) = 1, \quad nT < t < (n+1)T \quad \ldots ONN \qquad (2.1)$$

$$m(t) = -1, \quad nT < t < (n+1)T \quad \ldots OFF \qquad (2.2)$$

where T denotes the symbol duration. Another modulation scheme for IM/DD systems is the subcarrier modulation. In such modulation scheme, the modulating signal can have the form

$$m(t) = \Re\left[\left(\sum_i a_i \exp\left(j(2\pi f_i + \theta i)\right)\right)\exp(j2\pi f_c\right] \quad \ldots.. \quad (2.4)$$

where $\Re[z]$ gives the real part of z, a_i, f_i respectively denote the amplitude, frequency, phase of i_{th} baseband equivalent signal, and f_c is the carrier frequency. In an IM/DD FSO system, the main noise source is background noise and circuit thermal noise, and we can express the receiver SNR as

$$\gamma = C_s I^2 \qquad (2.5\ )$$

where R denotes the photodetector responsivity, A is the detector area, q is the electronic charge, Δf denotes the noise equivalent bandwidth, Nb, Nc respectively denote the power spectrum density of background noise and circuit thermal noise, and C_s can be treated as a constant when the system parameters are set.

B. Coherent FSO Systems

A coherent FSO system mixes the received optical field with a local field generated by a local oscillator at the photodetector to downconvert the optical carrier to an intermediate frequency carrier. The basic block diagram of a coherent receiver is shown in fig 2.1 For simplicity, we discuss a coherent FSO system with BPSK modulation. At the photodetector, the incident mixed optical field is being detected and a beat term containing both the amplitude and phase of the optical carrier and local field is generated.

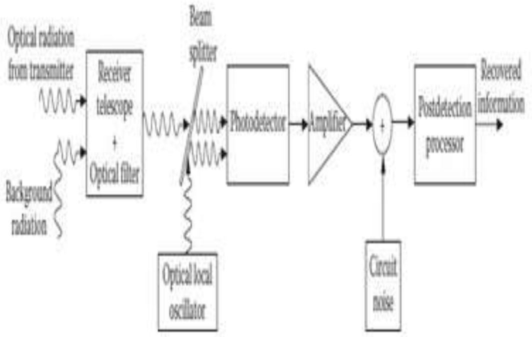

Figure 1.1: Block Diagram of a Coherent Detection Optical Receiver

$$i(t) = 2a_L a_s(t)\cos((\omega_0 - \omega_L)t + \theta_s(t) - \theta_L) \qquad (2.6)$$

where a_s(t), ω_0 and $\theta_s(t)$ respectively denote the amplitude, frequency and phase of the received optical carrier, a_L, ω_L and θ_L respectively represent the amplitude, frequency, phase of the local field. After the filtering process, the received signal power can be expressed as

$$P_{signal} = E[(Ri(t))^2] = 2R^2 P_L P_S \qquad (2.7)$$

$$P_L = a^2{}_L A \qquad (2.8)$$

$$P_S = E[a^2{}_s(t)]A \qquad (2.9)$$

where E[.] denotes the expectation, P_L is the local field power term, P_S is the received optical field power term. Considering the shot noise, background noise, circuit thermal noise, we can express the instantaneous SNR for coherent FSO systems as

$$\gamma = \frac{2R^2 P_L P_S}{2qR\Delta f P_L + 2qR\Delta f N_b + 2\Delta f N_c} \qquad (2.10)$$

In order to suppress the circuit thermal noise, we can use a strong local source with large P_L, and assuming negligible background noise, we can simplify the SNR in (2.7) as

$$\gamma \approx \frac{R}{q\Delta f} P_s = C_c I \qquad (2.11)$$

$$C_c = \frac{RA}{q\Delta f} \qquad (2.12)$$

where C_c is a deterministic value for particular FSO system

II. TURBULENCE CHANNEL MODELS

The atmospheric channel can impose attenuation and scintillation effect on the light beam propagating through it. The attenuation of atmospheric channels is determined by the weather condition. Under clear weather conditions, the attenuation is approximately 6.5 dB/km, and at a fog event, the attenuation can be 115 dB/km or even 173 dB/km. Therefore the fog can usually cause the outage of the FSO. We can use scintillation index to describe the strength of turbulence induced fading, which is given as

$$\sigma_{si}^2 = \frac{Var\ (I)}{(E[I])^2} = \frac{(E[I^2]}{(E[I])^2} - 1 \qquad (2.13)$$

The scintillation index is the normalized variance of the intensity and is used as a measure of scintillation. Another parameter related to the strength of the turbulence is Rytov variance, which approaches the scintillation index under weak turbulence conditions.

$$\sigma_R^2 = 1.23 C_n^2 K^{\frac{7}{6}} Z^{\frac{11}{6}} \qquad (2.14)$$

where C2n is the index of refraction structure parameter of atmosphere, $k = 2\pi/\lambda$ is the optical wavenumber with being the wavelength, and z denotes the link distance. Depending on the value of Rytov variance, we can approximately categorize the turbulence regime as follows: the weak turbulence regime (σ_R^2<0.3), the moderate turbulence regime ($0.3 \le \sigma_R^2 < 5$), and the strong turbulence regime ($\sigma_R^2 \ge 5$). Under different levels of scintillation, there are different statistic models to describe the distribution of channel states. For weak turbulence conditions, the most widely accepted model is lognormal turbulence model. For moderate to strong turbulence conditions, Gamma-Gamma turbulence model is often used (describing a much wider irradiance fluctuations ranges with the K- distributed turbulence model being its special case).

A. Lognormal Fading Model

Lognormal model is often used for FSO systems with short link distance (several hundred meters) or under weak turbulence conditions. Lognormal is an important fading model because it fits empirical fading measurements well in many transmission scenarios of practical interest. A lognormal RV h has the PDF

$$f_h(h) = \frac{1}{2h\sqrt{2\pi\sigma_x^2}}\exp\left(-\frac{(lnh+2\sigma_x^2)^2}{8\sigma_x^2}\right) \quad (2.15)$$

where σ_x^2 is the log-amplitude variance given by

$$\sigma_x^2 = \frac{\sigma_R^2}{4} = 0.31 C_n^2 K^{\frac{7}{6}} Z^{\frac{11}{6}} \quad (2.16)$$

The parameters of the lognormal fading model can be measured directly for FSO systems.

III.ERROR RATE PERFORMANCE ANALYSIS

The error rate performance analysis is important for FSO system design. It can provide the designers with standard performance metrics of the system, which includes but not limit to the BER, outage probability asymptotic error rate. For simplicity, we conduct the error rate performance analysis on an IM/DD FSO system with OOK modulation. Since the channel coherence time is on the order of msec and the data rate is assumed to be on the order of Gbps, we can, therefore, adopt a slow fading channel model. Assuming additive white Gaussian noise (AWGN) for the noise source and unit detector responsitivity, we can express the received signal y at the detector as

$$y = hx + n \quad (2.20)$$

where x is the transmit intensity being either 0 or $2P_t$ where P_t is the average transmitted optical power, h is the channel state, n is zero mean AWGN with variance σ^2. We can express the instantaneous SNR of the system as

$$\gamma = \frac{2P_t^2}{\sigma_h^2} h^2 = \bar{\Upsilon} h^2 \quad (2.21)$$

where $\bar{\gamma}$ denotes the average SNR

Table 3.1. The common parameter values of an FSO communication link.

Parameter	Symbol	Value
Symbol Rate	Rb	155Mbps
Spectral radiation of the sky	N (λ)	$10^{-3} w / c.m^2 \mu m Sr$
Spectral radiant emittance of the sun	W(λ)	0. 055 W/$c.m^2$μm
Optical bandpass filter B.W at λ=850 nm	Δλ	1nm
Number of subcarrier	N	1
Radiation wavelength PIN photodetector field of view	FOV	.6 rad
Link range	L	1 k.m
Index of refraction structure parameter	C_n^2	.75$\times 10^{-14} m^{\frac{-2}{3}}$
Load resistance	RL	50Ω
PIN photodetector responsivity	$\Re$	1
Operating temperature	Temp	300k
Optical modulation index	ξ	1

IV. EXPERIMENTS AND RESULTS

A.BER ANALYSIS WITH DISTANCE

BER of SISO BPSK SIM FSO under weak turbulence using the Gauss-Hermite Quadrature integration approach for different distance:1000 meter, 1500 meter, 2000 meter has been simulated and shown in fig 4.1

As per the results it is clear that with the increase in distance between the transmitter and receiver BER increases rapidly so the system performance. Higher frequency signals attenuate faster with compare to lower frequency signals. So, distance is also being one of the limiting factors in FSO.

(2.20)

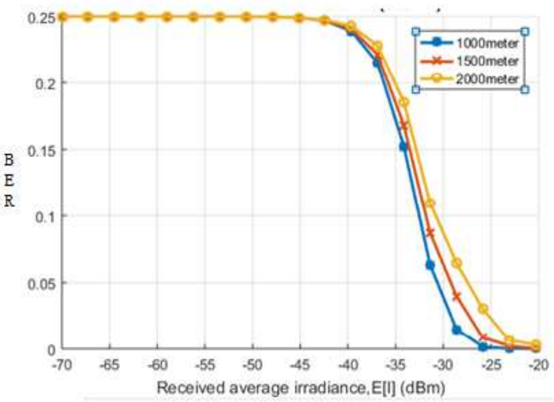

Figure 4.1: BER Analysis with Distance

Table 4.1: BER Variation with Distance

BER			
Irradiance(dBm)	850 nm	1300 nm	1550 nm
-39.66	0.239	0.238	0.238
-36.9	0.215	0.2121	0.221
-34.14	0.152	0.145	0.143
-31.38	0.063	0.05	0.04
-25.86	0.001	0.0003	0.0001

B. BER ANALYSIS FOR DIFFERENT NOISE

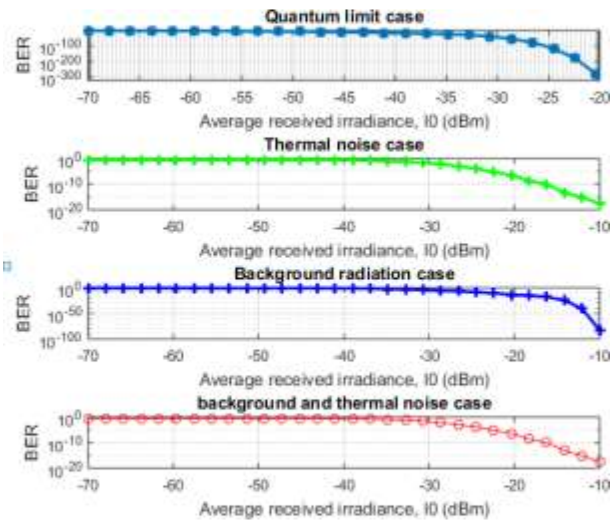

Figure 4.2: BER analysis for different Noise

BER of SISO BPSK SIM FSO under weak turbulence using the Gauss-Hermite Quadrature integration approach for different noise sources: Background, thermal and dark has been simulated. Moreover, under this thermal noise limited condition, the SIM-FSO still requires about additional 30 dB of SNR compared with the theoretical quantum limit shown in fig 4.2

C. BER Analysis With Symbol Rate

BER of SISO BPSK SIM FSO under weak turbulence using the Gauss-Hermite Quadrature integration approach for different symbol rates has been simulated and shown in fig 5.3. Simulation results show that the for low received irradiance, the increase in symbol rate result in a rapid increase in BER while for the high received irradiance changes are very less.

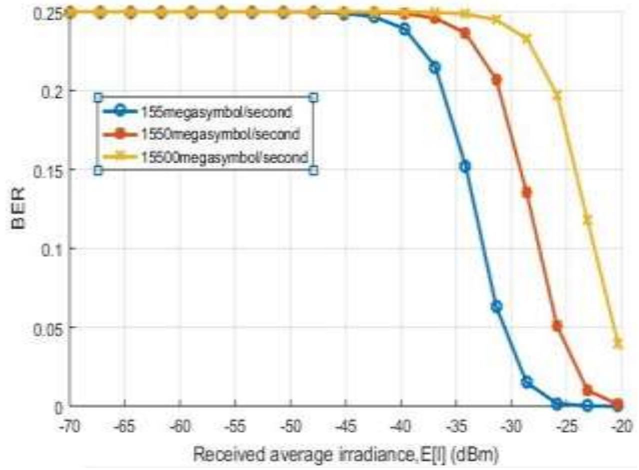

Table 4.2: BER Variation With Symbol Rate

BER			
Irradiance (dBm)	155×10^{6} sym/sec	155×10^{7} sym/sec	155×10^{8} sym/sec
-36.9	0.21	0.246	0.249
-31.38	0.06	0.2	0.24
-28.62	0.01	0.13	0.23
-25.86	0.001	0.05	0.19
-23.1	0.00005	0.01	0.12

Figure 4.3: BER Variation With Symbol Rate

D. BER ANALYSIS WITH WAVELENGTH

BER of SISO BPSK SIM FSO under weak turbulence using the Gauss-Hermite Quadrature integration approach for different wavelengths:850nm, 1300nm,1550nm has been simulated and shown in fig 4.4. With an increase in wavelength, atmospheric turbulence effects on the signal decrease. Simulation result shows that FSO performance for 1550nm is much better to compare to 850nm wavelength in the weak turbulence environment

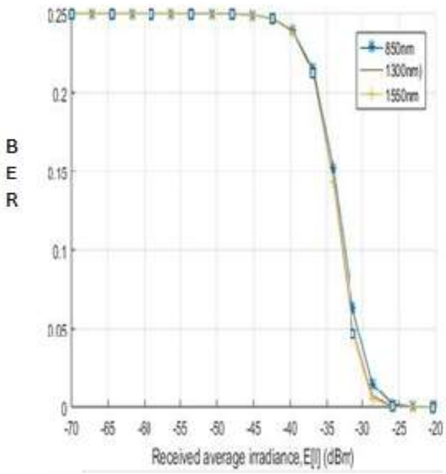

Figure 4.4: BER variation with wavelength

Table 4.3: BER Variation With Wavelength

BER			
Irradiance(dBm)	850 nm	1300 nm	1550 nm
-39.66	0.239	0.238	0.238
-36.9	0.215	0.2121	0.221
-34.14	0.152	0.145	0.143
-31.38	0.063	0.05	0.04
-25.86	0.001	0.0003	0.0001

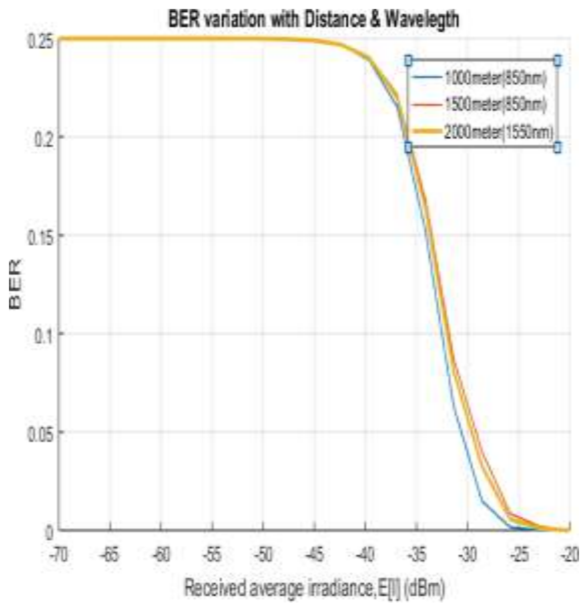

Figure 4.5: BER Analysis With Distance and Wavelength

With an increase in distance and frequency between the FSO links BER reduces. So to get the better performance for any distance low wavelength is an obvious choice. Simulation result shows that increase in BER by increase in distance between the FSO links can be mitigated by the reduction in a frequency of the transmitted signal and it is also observed that the system performance for the distance 2000meter at 1550nm is better compared to system performance for the distance 1500meter at 850nm.

Vi. CONCLUSION

In this paper, we summarize the results obtained in this paper. Also, we present several potential future research topics which are related to our accomplished work

Wavelength:

The atmospheric transmission in the wavelength bands around 850 and 1550 nm is much the same. The simulations showed that the transmission in weak turbulence was slightly better at 1550 nm. The transceivers for 850 nm are cheaper than the transceivers for 1550 nm. On the other hand, the fact that 1550 nm is eye-safe may be more important than cost and transmission

Distance:

BLL law describes the transmittance of an optical field through the atmosphere as a function of the propagation distance. simulation result shows that the ultimate increase in distance between transmitter and receiver results in a power transmission loss, which results in an increase in BER or in other way result in degrading in signal to noise ratio.

Symbol Rate:

Simulation results clearly show that the BER increases with increase in symbol rate. Upto an optimum symbol rate, BER increases slowly with the symbol rete but after an optimum symbol rate it increases rapidly.

Noise:

The BER is obtained at normalized SNR for different noise limiting conditions. Result shows that the for an FSO link receiver system performance is limited by thermal noise

FUTURE WORK

In the future work different diversity techniques will be used, which will help to improve the FSO performance in terms of outage probability, also MIMO will be introduced which will help to enhance the system capacity.

Also in future, the main aim would be to exploit the fading rather than mitigating the fading, which will further help to improve the system performance.

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