ARPN Journal of Engineering and Applied Sciences

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INVESTIGATION OF SINGLE BEAM NEAR-INFRARED FREE SPACE OPTICAL COMMUNICATION UNDER DIFFERENT WEATHER ANOMALIES

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ABSTRACT

The Free space optics (FSO) is a wireless optical communication system that connects directly to the atmosphere, where the connection is established between transmitter and receiver within in the line of sight. The FSO poses a high-speed broadband, which is the last mile wireless optical communication, deployed relatively fast. However, there are some weather factors may affect the performance of FSO transmission. In this paper, we analyzed the performance of Non-Return to Zero (NRZ) modulation schemes, which is used in FSO communication under extreme weather conditions over a range of 2Km. The performance has been analyzed under 980nm wavelength, Bit Error Rate (BER), and Q-factor using Optisystem. The largest attenuation measured is 340dB/Km, correlate to the visibility of 50m. In addition the visibility exceeding about 50m, The Kruse formula provides a good measurement of optical attenuation over long distances under the clear weather and haze conditions respectively.

Keywords: free space optical communication (FSOC), Q-Factor, bit error rate (BER), link performance, simulation, visibility.

1. INTRODUCTION

The Internet has been rapidly developed over the last decade. In a good clear weather, FSO can transmit up to its full specification [1, 2]. But it can decrease its transmission capacity in turbulence climatic conditions [3, 4]. This low maintenance free technology is required to setup between buildings in local and metropolitan networks. FSO Mobile platform station communication also achieves the required bandwidth of 1.5Gbps, remote access, and disaster management system for perfect voice, video and data networks. However, the weather and the atmospheric turbulence is a significant challenge that has to be addressed for the benefit of an optimal optical link performance. In addition, an optical link deteriorates from the atmospheric turbulence causing the optical wave distortions by obstructions such as clouds, fog, haze, and rain [5, 6].

1.1 Background

In free space communications, the atmosphere plays a significant role specifically in optical signal attenuation. Moreover, bending of an optical beam by highly dense aerosol molecules present in the air deviates an optical beam from its original path consequently causing link optical losses [6]. Also, an optical receive signal strength fluctuations are influenced by the variation of refractive index in the atmosphere. Whereas, the atmospheric attenuation is the primary factor in establishing the proper optical wireless link [2].

1.2 AEROSOLS

The aerosols are small suspended particles in the air, which can be seen when they become larger. They scattered into the air and blocked the direct sunlight. This lowers the visibility in term of haze, fog, and clouds. The aerosols can be of many types natural and human-made. Dust pollution and smoke are human-made. Whereas, fog in the forest and the agricultural fields are natural. The aerosol particles are different in size according to the weather condition and depend upon the concentration dust and water. The bigger part of concentrated aerosols exists in the stratosphere layer [7]. The wavelength of a laser beam is comparable with the sizes of aerosol particles, which an interest in optical communications [8]. Mie-scattering describes the aerosol scattering theory while, on the contrary, the radii of an atmospheric particle in micrometer are described in Table-1. The Mie scattering theory defines the scattering coefficient of aerosol particles. Their particle-sizes, cross section, density, and working with the wavelength is calculated from equation (1) [8], with different types of the weather molecule sizes with 980nm and 1550nm wavelength are described in Table-1.

$$\sigma = \frac{2\pi r}{\lambda} \quad (1)$$

Where
σ = Scattering coefficient
λ = Wavelength of Laser
π = 3.14(Constant)
r = Radius of the scattering weather particles

Table-1. Scattered particles in the atmosphere with their radii at 980nm and 1550nm.

Type	Radius (μm)	(α) Parameter size	
		980nm	1550nm
air molecules	0.0001	0.0006	0.0004
haze particle	0.01-1	0.06-6	0.04-4
fog droplet	1-20	6.40-128	4-80
rain	100 - 10000	640-64081	400-40000
snow	1000-5000	6408-32040	4000-20000
hail	5000-50000	32040-320408	20000- 400000

1.3 KRUSE visibility formula

The Kurse formula is commonly used for estimating the optical attenuation in different weather condition. In decibel per kilometer (dB/Km) for optical networks at a different wavelength of lasers, this is expressed in equation (2) [1].

$$\Gamma = \frac{17}{V}\left(\frac{550}{\lambda}\right)^{q} \quad (2)$$

Where
Γ = Attenuation in dB/Km
λ = Wavelength of Laser
V = Distance in Kilometers (Km)
q = Exponent of visibility
= if (V > 50Km) = 1.6 for high visibility
= if (6 Km<V<50Km) =1.3 for average visibility
= if (6 < Km) = $0.585\ V^{1/3}$ for low visibility

The equation (2) has an exponent of visibility, which changes according to the visual distance in the atmosphere. In this equation, the values of "q" changes with the visibility distance that defines the association between the optical signal attenuation and high-low visibility in extreme weather condition. The Kurse formula is a blend of Koschmieder's visibility and Beer's law of exponential attenuation. The method is given in term of (dB). According to the Beer's Lamberts law, the beam intensity becomes weaker when to pass through the dense atmosphere. So the visibility in (Km) and attenuation in (dB/Km) will be encircled. The rest of the paper describes the different weather conditions and are calculated in Table-2 [8].

Table-2. Atmospheric Attenuation in (dB/Km) for visibility with 980nm laser.

Weather	Fog			Mist	Haze							Clear			Very Clear
Visibility (Km)	0.1	0.2	0.5	0.6	1	1.5	2	2.5	3	3.5	4	10	23	50	60
980nm (db/km)	340	85	34	27	13	8.7	6.5	5.2	4.3	3.7	3.2	0.8	0.3	0.1	0.1

1.4 Optical link performance

The FSO link performances are determined by several parameters including link-margin, BER, the optical power received and geomatic loss. There are two parameters to evaluate the FSO Communication performances, which are the received power and BER [9]. Hypothetically, the basic communication principle states that received power must be less than the transmitted power [10]. The optical losses are calculated by following equation (3) and described in Table-3.

$$P_R = P_T - Total\ Optical\ Losses(OL) \quad (3)$$

Where
$P_R = Recieved\ Power\ in\ dBm$
$P_T = Transmit\ Power\ in\ dBm$

Table-3. Optical loss at different distance and the weather condition.

Km	0.05		0.1		0.5		0.6		1		1.4		2		2		2	
db/Km	340		340		34		27		13		9		4.5		0.3		0.1	
PT	PR	OL	PR	OL	PR	OL	PR	OL	PR	OL	PR	OL	PR	OL	PR	OL	PR	OL
16.4	-11.1	27.53	-32.8	49.15	-28.4	44.83	-29.2	45.55	-30.3	46.67	-32.7	49.14	-32.2	48.6	-23.8	40.2	-23.4	39.8

2. BASIC FREE SPACE OPTICAL SYSTEM

In FSO communication, an optical carrier is employed by transferring the data wirelessly. FSO has a potential to support the broadband data with rapid deployment without regulation frequency requirement and high data security. It is a Line of Sight (LOS) optical system; it requires a little power, to produce a powerful narrow beam of light for optical communication. This beam emitted by the transmitter and collected in the receiver. The FSO links are highly vulnerable to atmospheric effects, causing the random fluctuations in the received irradiance of the optical laser beams [7], and showing performance degradation significantly. One method in these circumstances is to improve the reliability and the performance, by enhancing in FSO transmitter and receiver [11].

2.1 System parameters

The FSO system consists of three major parts i.e. 1) Transmitter, 2) FSO channel, 3) Receiver. The transmitter consists of Pseudo-Random Bit Sequence (PRBS) Generator, non-return to zero (NRZ) Pulse Generator [12], Mach-Zehnder modulator and pump-laser 980nm. The FSO channel is the atmosphere consists of distances and the attenuation weather factors, which affect the optical line of sight transmission. The receiver comprises a photodetector, Low Pass Gaussian Filter, a demodulator. Whereas, the BER analyzer, optical power meter, Optical time domain analyzer and Spectrum analyzer are used to visualize, the simulation value. The particular design detail parameters are in the Table (4). The parameter is taken from the existing available product in the market, for a particular implementation [11].

Table-4. FSO system parameter in simulation.

Parameter	Bandwidth	Modulation	Wavelength	Beam width	Tx/RxType	Tx/Rx Size	Tx Type	Tx Power
Details	155Mbps	NRZ	980nm	8 mrad	Squared	16.925 cm^2	Pump Laser	19 dBm

2.2 Beamwidth

The beam width is the term used for spread beam from the single source with an angle [9]. There are two types of the laser beams are used in FSO, narrow beam for LOS communication over long distance and wide beam for NLOS without tracking. The wide-beam used for indoor and short range, where the LOS and the narrow beam system used for broadband, high data rate, and long distance communication. The angle of the beam is measured in milli-radians.

2.3 Receiver area

In optical communication, the receiver should provide high sensitivity and fidelity, with a high data rate of optical conversion to electricity. And a large detection area with minimum noise and short response time and a low-cost higher reliability [3]. The distortion introduced due to the signal degradation produces noise. There are many types of noises in the atmosphere; that interfere with the required system performance as calculated from equation (2). The optical beam from the receiver must maintain the accurate position from source to reduce the signal noise and other pointing errors in the optical link [13]. Thus, a square 16.925cm2 receiver area is implemented, as shown in Table-4.

2.4 Link distance

The fundamental FSO link geometry is a direct point to point link. The major hindrance in this configuration is its limited coverage area and susceptibility to link blocking. After the careful alignment, the link distance depends upon the extreme weather conditions that result in signal degradation and poor performance [14]. The extreme low visibility fog can cause the signal to attenuate up to several hundreds of dB/Km. The simulation set to perform at minimum 50m to the maximum 2Km.

2.5 The system design

This system developed in OptiSystem v13.0. The OptiSystem is an extensive design simulator software [10]. The working wavelength is 980nm pump laser [15]. The power level of a transmitter is set to 19dBm, and receiver aperture of the lenses kept at 16.925 cm2. Whereas, the beam divergence is 8mrad. The data rate for this system is set to 155 Mbps for all weather conditions with NRZ modulation [16]. Attenuation for the very clear weather is calculated in terms of optical loss, bit error rate, spectrum, optical time domain and dual port WDM analyzer as shown in Figure-1 [3, 17].

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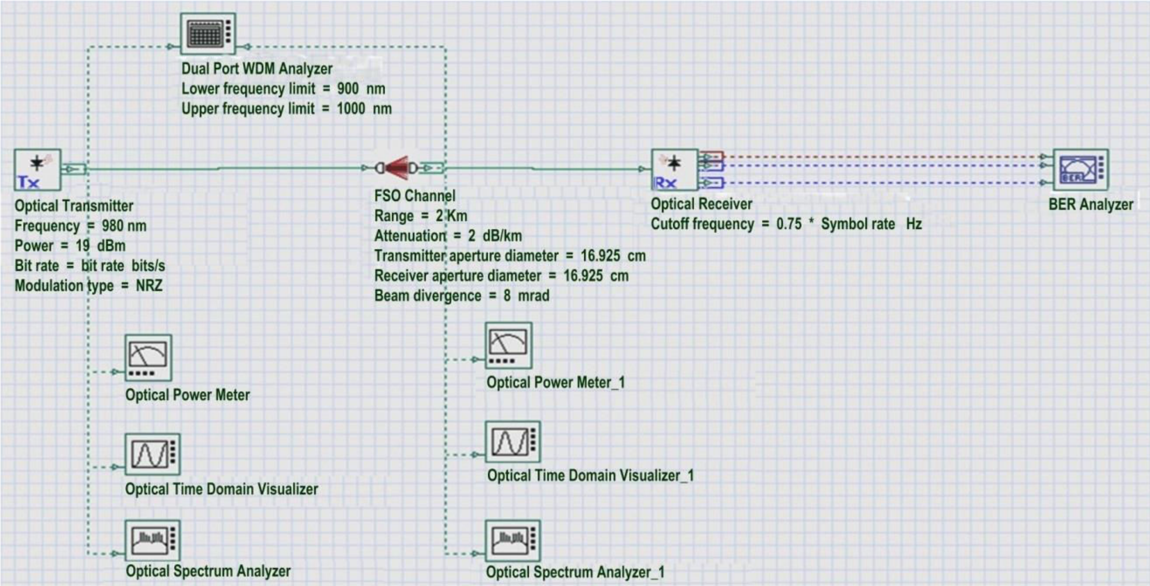
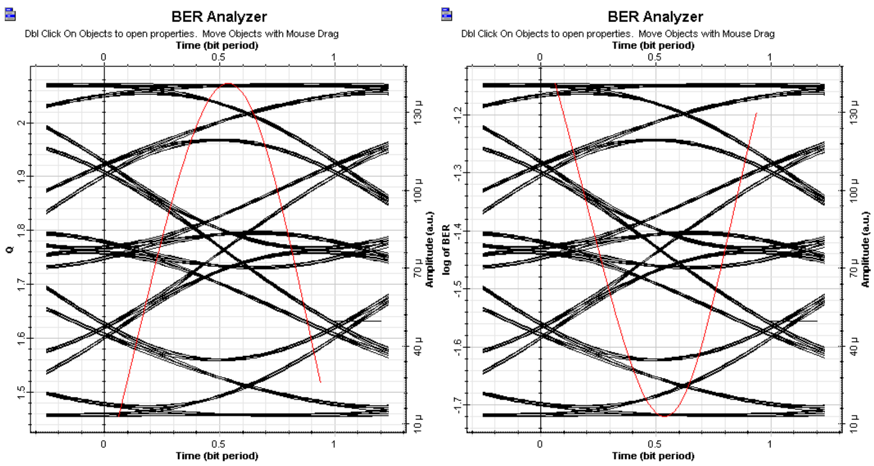


Figure-1. Schematic for system design integration at 980nm.

RESULTS AND GRAPHS

Table-5. Max Q-factor and Min BER values at different distance and the atmosphere.

Atmospheric	Attenuation (dB/Km)	Distance (Km)	Max Q Factor	Min BER
Dense Fog	340	0.05	2.07265	0.0190651
Dense Fog	340	0.1	1.85993	0.0309666
Light-fog	34	0.5	2.1299	0.0165584
Mist	27	0.6	2.11678	0.0171224
Haze	13	1	2.07622	0.0189369
Haze	9	1.4	1.86171	0.0308500
Light-Haze	4.5	2	1.92518	0.0268867
Clear	0.3	2	2.11678	0.0170808
Very Clear	0.1	2	2.11372	0.0172119



(a) (b)

Figure-2. Eye Diagram for system at a 0.05Km with 340dB/Km:

VOL. 11, NO. 9, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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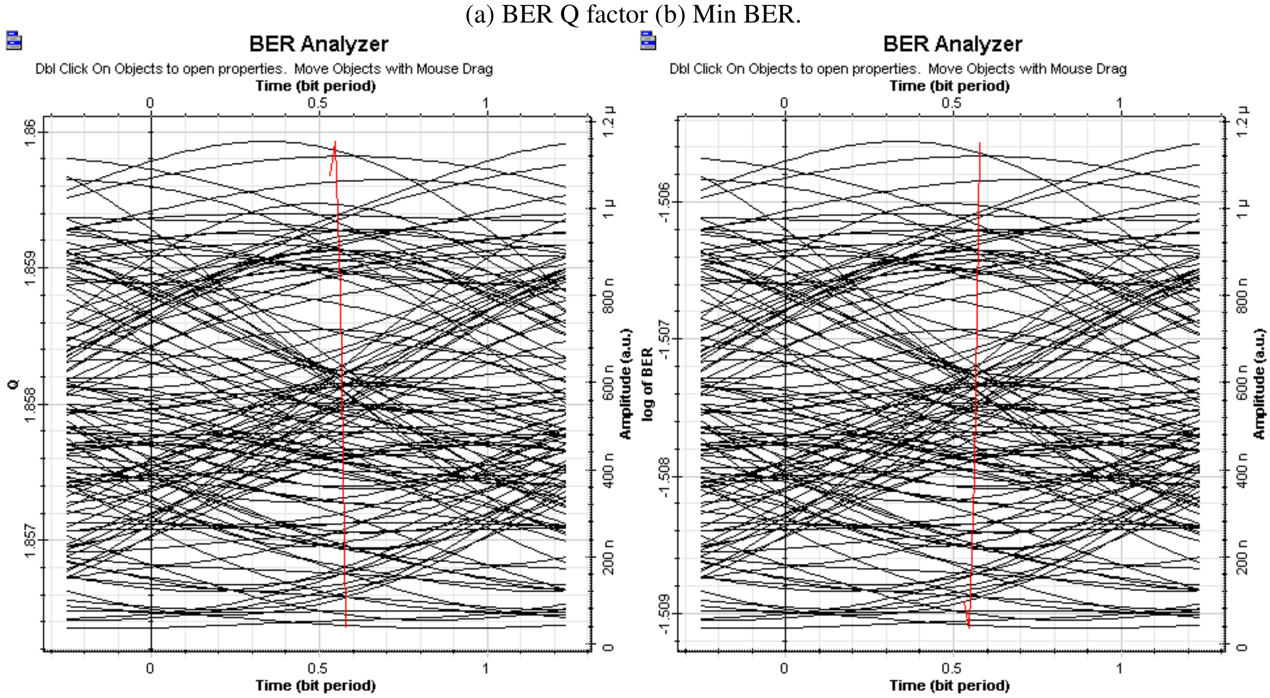
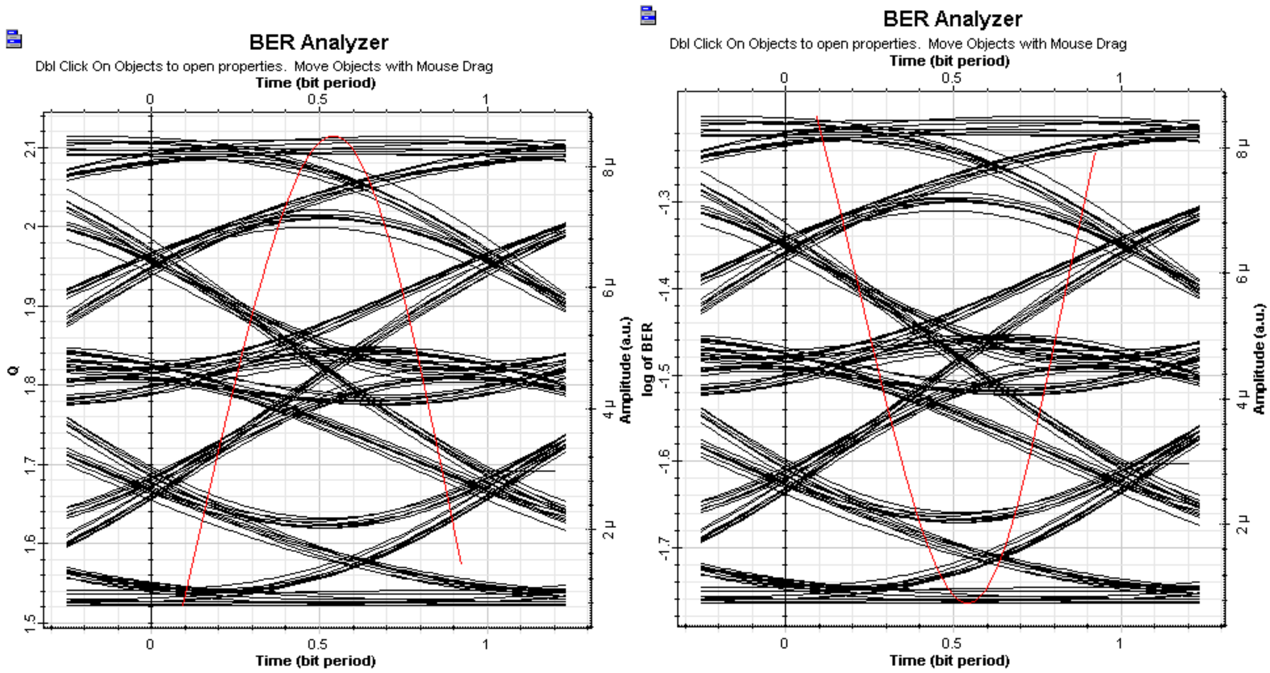
(a) BER Q factor (b) Min BER.



(a) (b)

Figure-3. Eye diagram for system at a 0.1Km with 340 dB/Km: (a) BER Q factor (b) Min BER



(a) (b)

Figure-4. Eye diagram for system at a 2 Km with 0.1 dB/Km: (a) BER Q factor (b) Min BER.

RESULTS AND DISCUSSIONS

The result shows the combined impact of atmospheric turbulence and visibility on the performance of free space optical communication system. Furthermore, to evaluate the BER and Q factor at a different distance starting from 50 meters to 2000 meter. The result shows that in the dense fog at 340dB/Km with the minimum distance of 100 m, the Q factor is same (1.8), as in hazy weather condition with very less attenuation of 9dB/Km with the long distance of 1400m. In addition, the Q factor fluctuates from dense fog attenuation of 340/dB/Km with 50m is (2.07). However, in a very clear weather with attenuation of 0.1dB/Km at a distance of 2000m, the Q factor increases to (2.11). The Q factor does not depend on weather attenuation rather than the distance. The Q factor and BER both are interrelated in any communication system. The Q factor and BER versus attenuation are calculated by putting the input signal power. The Q factor measures the quality of an analog transmission signal in terms of its signal-to-noise ratio (SNR). The greater the Q factor values, the better the SNR and the lower the chance of bit errors. The bit-error-rate (BER) is defined as the probability of incorrect identification of a bit by the decision circuit of the digital receivers.

The 'SNR' in the "eye" of a digital signal is the human eye-shaped pattern on an oscilloscope that shows the transmission performance as presented in Figure (2-4). The best place for knowing whether a particular bit is a 1's or 0's is using the sampling phase with a big "eye-opening." The bigger the eye opening, the greater the difference between the mean values of the signal levels for a "1's" and "0's". The bigger that difference is the higher the Q-factor value and the better the BER performance. In this paper, the minimum BER values are the same (0.03) for the weather condition of dense fog at 100m and the hazy weather condition at 1400m. On the other hand, minimum BER is (0.019) for dense fog at a distance of 50m and (0.017) for very clear weather at 2000m. The results show that the attenuation alone does not have much effect on the FSO link rather both the distance and attenuation together.

CONCLUSIONS

The reliability of FSO in extreme weather condition can be achieved by implementing more and multiple high power lasers and multiple receivers. This can produce better BER and Q-factor values at the minimum optical loss for long distance communication. Also, it improves the channel quality. The signal coding can be introduced for less power consumption, in extreme weather condition transmission for long distance communication. After considering the FSO benefits, FSO has highly potential as a real future for widespread implementation. FSO is ready for utilization at point-to-point and portable mobile platform links for the disaster management system.

ACKNOWLEDGEMENTS

The authors acknowledge Mr. Stephen Patrick from Cable-free gigabit wireless network system from the United Kingdom for his scientific guidance. We are also thankful to the Research Management Centre (RMC) of Universiti Teknologi Malaysia and Mehran University of Engineering and Technology, Jamshoro, Pakistan for facilitating this research.

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