Pointing Error in FSO Link under Different Weather Conditions

Nazmi A. Mohammed, Amr S. El-Wakeel and Mostafa H. Aly

***Abstract*— Pointing errors is one of the main challenges that face free space optical communication and affects its performance specially at high range links, in this paper, an evaluation for the pointing error for practical Bit Error Rate is carried. This is done for an FSO link under different weather conditions at 1.55 μm. Under practical simulation conditions it was found that maximum pointing error allowed to achieve 10^{-9} bit error rate for clear weather can reach 13.53 μ rad, Heavy fog is found to be the worst weather condition, where small pointing error can lead to link failure.**

***Index Terms*— Free Space Optics (FSO), Pointing Errors, scattering, Optical Wireless Communication**

I. Introduction

FREE SPACE OPTICS (FSO) is a major hot topic in communication systems nowadays; it's a technology that uses light beam propagating from the transmitter through Free Space to transmit data received at the other side of the two point communication system. FSO is often referred to as Fibreless Optics or Optical Wireless Communication [1]. It can be considered as an Optical Fiber replacement especially when the physical connections are impractical due to several considerations.

Rapid increase of Wireless communications applications are usually faced by many of obstacles such as Bandwidth regulations, Power limit and high data rates. Where FSO may appears as its main advantages are: 1) no licensing requirements or tariffs for link utilization; 2) absence of radiofrequency radiation hazards; 3) no need of road digging as in the case of optical fiber; 4) large bandwidth which enables high data rates; 5) low power consumption [2] . FSO Links are suitable for few Gb/s rates over distances in the range 1-5 km [3].

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Major Challenges that face FSO is that it use the air as a transmitting media between transmitters and receivers where various weather conditions can affect the performance of FSO Link, most likely known weather phenomena are scattering and Turbulence which causes attenuation in the transmitted Signal those results in high bit error rate or signal loss at the receiver end [4].

Among the hot research points of FSO, The Link availability, Design of transmitters and receivers (types of LASER, Wave length selection, Modulation techniques, Types of Detectors) [2, 5].

Pointing error is one of the challenges that face FSO links and its availability; many researches discussed the effect of pointing error such as its effect at different wavelengths, and its effect on the performance of FSO links in the presence of atmospheric turbulence [6, 7].

In this paper, we have embarked to the authors' knowledge; Maximum allowable pointing error is estimated for FSO link under various weather conditions for fixed practical bit error rate. This is done by Matlab 2008 & Optisystem 7.0 from Optiwave Inc..

The remainder of this paper is organized as follows. The mathematical review is presented in Section II. Based on the theory presented, a numerical analysis and simulation of the FSO link in presence of pointing errors process is carried out in Section III. This is followed by the main conclusion in Section IV.

II. FSO Mathematical Model

A. Link Budget

Link Distance, Link's Wave length, Laser modulators, Types of detectors & Efficiencies of transmitters and receivers are many factors that draw the performance of the FSO link For the link budget, the received power at the detector is given by the Friis transmission formula [5,6,8].

$$P_R = P_T \,\eta_T \,\eta_R \,(\lambda/4\pi z)^2 \; G_T \, G_R \, L_T \, L_R \qquad (1)$$

Where the signal power at the receiver is P_R, P_T is the transmitted signal power, $\eta_T \, \eta_R$ are the transmitter's and receiver's efficiencies, λ transmitted signal's wave length, Z is the link distance.
The two factors G_T, G_R are the transmitter and receiver gain, where

$$G_T = (\pi D_T/\lambda)^2 \quad (2)$$

$$G_R = (\pi D_R/\lambda)^2 \quad (3)$$

D_T, D_R are Transmitter's & Receivers' Apertures.

L_T L_R Are the transmitter's and receiver's pointing loss factor (Due to pointing error angels) (assuming Gaussian beam).

$$L_T = \exp(-G_T(\theta_T)^2) \quad (4)$$

$$L_R = \exp(-G_R(\theta_R)^2) \quad (5)$$

As θ_T θ_R, are the transmitter's and receiver's pointing error.

B. Atmospheric Attenuation

Atmospheric attenuation is one of the important factors that must be considered in evaluation of FSO systems, It shows how the signal power attenuated due to various weather conditions, one of the most important phenomena is scattering which affects the power of the transmitted signal through air.

The types of scattering (Rayleigh scattering , Mie scattering , Geometrical scattering) is determined according to the relation of the radius of the atmosphere particles to the selected wave length of the FSO system, the attenuation of laser power through atmosphere is described by the exponential Beers-Lambert Law [9,10,11]

$$P_R = P_T \exp(-\sigma Z) \quad (6)$$

As σ is the atmospheric attenuation coefficient

$$\sigma = 3.91/V\,(\lambda/550nm)^{-q} \quad (7)$$

V is the Visibility (in Km), q is the size distribution of the scattering particles where,

q = 1.6 for high visibility (V > 50 km)
= 1.3 average visibility (1 km < V < 50 km)
= 0.16 V + 0.34 for haze visibility (1 km < V < 6 km)
= V - 0.5 for mist visibility (0.5 km < V < 1 km)
= 0 for fog visibility (V < 50 km)

For different cases of weather conditions we calculated the attenuation value that affect the signal power for a transmitted signal wavelength 1550 nm.

C. FSO Link Specifications

FSO transmitters and Receivers have several specifications that affect the performance of the Link such: Types of lasers used in the transmitters, Receiver's Detectors types, transmitter's and receiver's efficiencies. In this research a wide survey through FSO vendors and Research Labs was done and practical FSO links were investigated.

FSO market is supplying links up to 5km with bit rates in range of few Giga bits and transmitter power up to 640 mw [12, 13, 14, 15].

In Table 1 we are presenting the specifications for our FSO Link according to the survey done.

TABLE 1
FSO LINK PARAMETERS

Parameter	Symbol	Value
Transmission Rate	Bit Rate	1 Gbps
Link Distance	Z	1km
Optical Transmitted power	P_T	320 mw
Transmitter wave length	λ	1550nm
Transmitter's & Receiver's optics efficiencies	η_T , η_R	0.8 , 0.75
Transmitter's & Receiver's Apertures	D_T , D_R	10cm

III. NUMERICAL RESULTS AND DISCUSSIONS

According to the Mathematical model presented previously (II-B) and using Matlab we regenerate Power loss due to different weather conditions as indicated in Table 2, where the attenuation factor for clear air is 0.155 dB/km and increased for heavy fog to 84.904 dB/km which agrees with the decreasing in the visibility for difficult weather conditions.

TABLE 2
SIGNAL ATTENUATION AT DIFFERENT WEATHER CONDITIONS

Weather	Power loss dB/Km 1550nm	Visibility(km)
Clear	0.155	23
	0.441	10
Haze	1.537	4
	4.285	2
	10.115	1
Fog	15.55	0.8
	33.961	0.5
	84.904	0.2

Now, Using Optisystem 7.0 we constructed an FSO link based on the previous mathematical model and fed by System specs chosen from practical FSO Links in Table 1and Atmospheric loss factor calculated in Table 2. Link Construction is presented in Fig.1

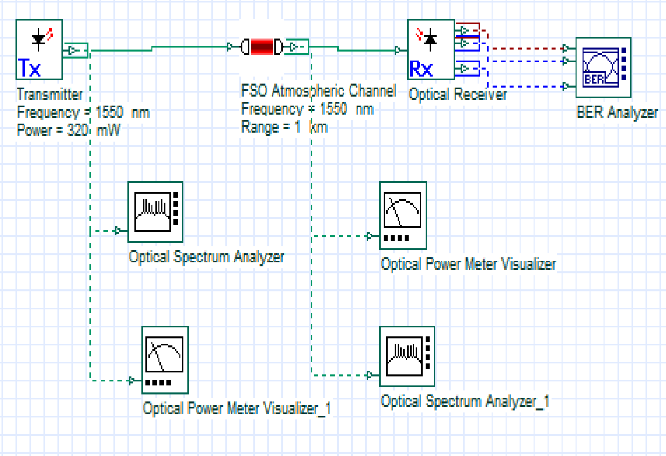

Fig.1 Free Space Optical Link

We choose APD for receiver which is common in FSO receivers [16, 17]. A bit error rate of 10^{-9} is considered as a threshold in all simulations, since it's a desired target to all practical FSO link designs [18, 19].

The Results in Table 3 shows that the range of maximum pointing errors allowed in order to ensure bit error rate not exceed 10^{-9} are in the range of 10's micro radians for clear and haze. In the case of moderate fog the range is decreased. Finally, for heavy fog there is no allowance of any pointing error in the transmitter or the receiver under previously mentioned design specifications and bit error rate.

We think previous observations is due to the exponential nature of the pointing error loss factor based on Eq.4, Eq.5 and the narrow beam width of the commonly used laser sources in FSO links, both reasons make any very small miss alignment causes large power loss and hence exceeding the desired threshold bit error rate resulting in minimizing the range of allowable pointing error.

TABLE 3
MAXIMUM POINTING ERRORS AT VARIOUS WEATHER CONDITIONS

Weather	Attenuation (dB/Km) At 1550nm	Max.pointing error at Tx (μ rad)	Max.pointing error at Rx (μ rad)
Clear	0.155	13.53	13.52
	0.441	13.49	13.49
Haze	1.537	13.37	13.37
	4.285	13.1	13.05
	10.115	12.43	12.43
Fog	15.55	11.8	11.8
	33.961	9.4	9.4
	84.904	0	0

Testing the previous FSO link leads to another observation. Any small increase in the pointing error will lead to a large decrease in the received optical signal power indicating the important effect of the pointing error in designing FSO links.

To address the previous point Fig.2, Fig3 and Fig.4 is presented.

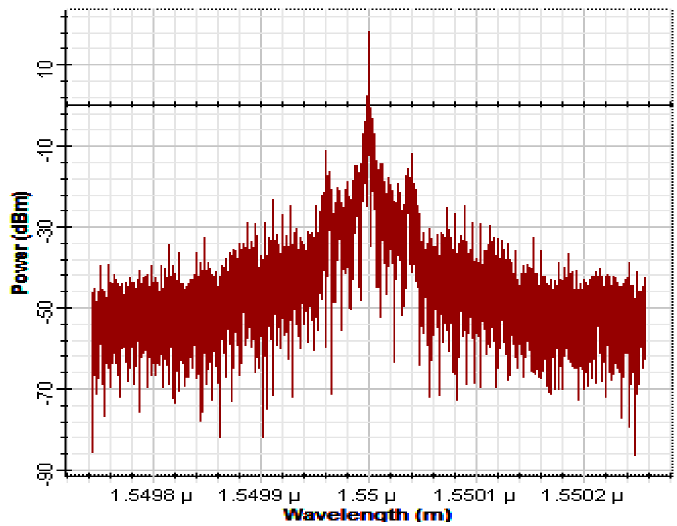

Fig.2 Signal power at transmitter for moderate fog weather condition

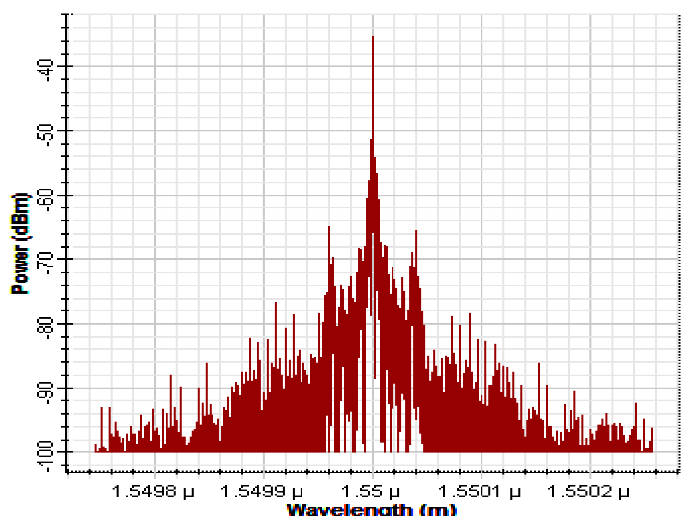

Fig.3 Signal power at receiver for moderate fog weather condition at the maximum pointing error calculated at Table 3

Fig.2 shows the signal power at the transmitter in the case of moderate fog weather condition as an example. We chose the signal to be at 1.55 µm mid of C-Band to give the compatibility with standard optical fiber systems. The maximum transmitted power is set to be 22.63 dbm.

Fig.3 shows the signal at the receiver in the same weather condition under the maximum pointing error calculated in Table 3 and achieves the threshold bit error rate of 10^{-9}. The power level is reduced to -30.97 dbm.

To address the effect of the destructive behavior of high pointing error we present fig.4

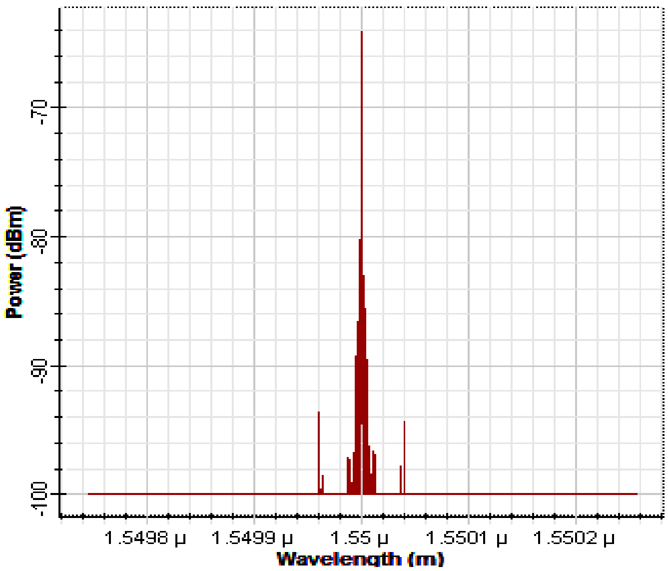

Fig.4 Signal power at receiver for moderate fog weather condition after exceeding maximum pointing error calculated at Table 3

Fig.4 shows that at high pointing error which leads to exceeding the threshold 10^{-9} bit error rate the signal was decreased to -59.75 dbm.

IV. Conclusion

In this paper we find that the presence of pointing error in an FSO link highly affects the power levels of the transmitted signals. For bad weather conditions which leads to high power loss evaluating of pointing error becomes more important.

To overcome this problem system designer may suggest auto tracking techniques – narrow and high power transmitted beams – high sensitive receivers and continuous – accurate monitoring of weather conditions.

For future work pointing error can be evaluated under different weather phenomena's like turbulence and scintillation which leads to more complex channel models.

References

[1] Scott Bloom, Eric Korevaar, John Schuster and Heinz Willebrand "Understanding the performance of free-space optics [Invited]," Journal of optical networking, vol. 2. No.6, Jun.2003.

[2] Shlomi Arnon "Optical Wireless Communications," Encyclopedia of Optical Engineering, 2003.

[3] A. A. Farid and S. Hranilovic, "Outage capacity optimization for freespace optical links with pointing errors," J. Lightwave Technol., vol. 25, pp. 1702–1710, July 2007.

[4] X. Zhu and J. Kahn, "Free space optical communication through atmospheric turbulence channels," *IEEE Trans. Commun.*,vol. 50, no. 8,pp. 1293–1300, Aug. 2002.

[5] Haim Manor and Shlomi Arnon,"performance of an optical wireless communication system as a function of wave length," J. Applied Optics, Vol. 42, No. 21, Jul 2003

[6] Xian Liu, "performance of the wireless optical communication system with variable wave length and Bessel pointing loss factor," proceeding of Wireless Communications and Networking Conference (WCNC), Las Vegas,NV, 2008.

[7] Deva K. Borah, David G. Voelz "Pointing Error Effects on Free-Space Optical Communication Links in the Presence of Atmospheric Turbulence," J. Lightwave Technol, vol.27, no.18, Sep 2009.

[8] J. A. Shaw, "Radiometry and the Friis Transmission Equation", Unpublished.

[9] Awan, M.S.; Marzuki; Leitgeb, E.; Nadeem, F.; Khan, M.S.; Capsoni, C., "Weather Effects Impact on the Optical Pulse Propagation in Free Space," *Proceeding of the69th Vehicular Technology Conference (VTC)*, Barcelona, 2009.

[10] Awan, M.S.; Leitgeb, E.; Marzuki; Khan, M.S.; Nadeem, F.; Capsoni, C.; "Evaluation of Fog Attenuation Results for Optical Wireless Links in Free Space," Presented at Satellite and Space Communications, 2008.

[11] Isaac I. Kim, Bruce McArthur, and Eric Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications," Proceeding of SPIE 4214, 26 ,2001.

[12] FSONA Wireless Optical, http://www.fsona.com., Last Access Jan. 2012.

[13] LightPointe, http://www.lightpoint.com., Last Access Jan. 2012.

[14] Hamamatsu, http://www.hamamatsu.com., Last Access Jan. 2012.

[15] Applied optoelectronics, Inc, http://www.ao-inc.com., Last Access Jan. 2012.

[16] *Kamran Kiasaleh, "Performance of APD-based, PPM free-space optical Communication systems in atmospheric turbulence,"IEEETransactions on Communications, vol. 53, pp.1455-1461, Sep. 2005.*

[17] M. Aharonovich, S. Arnon, "Performance improvement of optical wireless communication through fog with a decision feedback equalizer", J. Optical Society of America, vol. 22, no. 8, pp 1-9, 2005.

[18] M. Uysal, J. Li, and M. Yu. Error Rate Performance Analysis of Coded Free-Space Optical Links over Gamma-Gamma AtmosphericTurbulence Channels. IEEE Trans. Wireless Commun., 5:1229–1233, June 2006.

[19] *Murat Uysal and Jing Li, "BER performance of Coded Free-Space Optical Links over Strong Turbulence Channels," Proceeding of the 59th Vehicular Technology Conference (VTC), Milan, pp. 352-356,2004*