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A Case Study of Free Space Optic Performance Using Simulation Tools – OptSim

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ABSTRACT

Free space optics (FSO) has received a great deal of attention lately both in the military and civilian information society due to its potentially high capacity, rapid deployment, portability and high security from deception and jamming. A proper understanding of optical signal propagation in different atmospheric conditions has become essential, and thus there arises the need to rationalize the effects of atmospheric channel on terrestrial FSO links. This paper studies and evaluates free space transmission by varying the distance. It focuses on their performance in atmospheric effect. This is achieved by observing the output spectrum and eye-diagram that are obtained using OptSim simulator. The behaviors of FSO model with different distances of data transmission are evaluated and compared.

Keywords*:Free space optics, Atmosphere attenuation, Scintillation, Scattering,Transmiss -ion quality parameters

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INTRODUCTION

Free-space optical (FSO) communication system [1, 2] is becoming more widespread in wireless communication nowadays. Both their low cost and a lack of stringent regulatory requirement are the major reasons for their popularity. They utilize optical signal transmission in a free space, through the atmosphere. The optical signal is transmitted from the fixed transmitter to the receiver through the atmosphere, which is an inhomogeneous medium varying in time
.
Characteristics of this medium relate to one of the most serious concerns about free-space optical communication links, which is their availability. In examining FSO performance, it is important to take several system parameters into consideration. In general, these parameters can be divided into two different categories – internal parameters and external parameters. Internal parameters are related to the design of an FSO system and include optical power, wavelength, transmission bandwidth, divergence angle, and optical loss on the transmit side and receiver sensitivity, bit-error rate (BER), receive lens diameter, and receiver field of view (FOV) on the receive side. External parameters, or non-system-specific parameters, are related to the environment in which the system must operate and include visibility and atmospheric attenuation, scintillation, deployment distance, window loss, and pointing loss. It is important to understand that many of these parameters are not independent but are linked together in specifying overall system performance [3]. The aim of the paper is to compare the behavior of an FSO link located at University Technology Malaysia (UTM) with an FSO quality of service prediction software (OptSim). It

includes different effects – geometrical attenuation, atmospheric fading, rain, and scintillation and refraction attenuation due to atmospheric turbulence. The different elements contributing to the total power loss are described and evaluated. The organization of the paper is as follows: Sections 2, 3 and 4 describe several attenuation effects on the FSO transmission. Experimental set-up and the simulation scenarios are mentioned in Section 5. Section 6 presents the results and discussion. Conclusions are presented in Section 7.

GEOMETRICAL ATTENUATION

The beam emitted by the transmitter being diverging (1–7 mrad), the receiving cell will collect only a part of the emitted energy. The following relation gives the geometrical attenuation:

$$A_{ffgeometrical} = S_d / S_{capture} = \frac{\pi / 4(d\theta)^2}{S_{capture}} \quad (1)$$

where
S_d = Spot surface at the distance d
$S_{capture}$ = Receiver capture surface
θ = Beam divergence
d = Transmitter-Receiver distance

ATMOSPHERIC ATTENUATION

Atmospheric attenuation results from an additive effect of absorption and dispersion of the infrared light by aerosols and gas molecules present in the atmosphere. Transmittance in function of the distance is given by BEER relation:

$$\tau(d) = \frac{P(d)}{P(0)} = e^{-\sigma d} \quad (2)$$

where
τ(d) = Transmittance at the distance of the transmitter
P(d) = Power of the signal at a distance of the transmitter
P(0) = Emitted power
− σ = Specific attenuation or extinction coefficient per unit or length.

The extinction coefficient σ is the sum of 4 terms:

$$\sigma = \alpha_m + \alpha_a + \beta_m + \beta_a$$

where
α_m = the molecular absorption coefficient (N_2, O_2, H_2, H_O, CO_2, O_3,..).
α_a = the absorption coefficient by the aerosols (small solid or liquid particles present in the atmosphere (ice, dust, smoke, …).
β_m = the Rayleigh scattering coefficient resulting from the interaction of the wave with particles of size smaller than the wavelength.

β_a = the Mie scattering coefficient. It appears when particles are of the same order of magnitude as the transmitted wavelength.

Absorption dominates in the infrared while scattering dominates in the visible and ultraviolet band. Being given the low values of molecular and aerosols absorption coefficients as well as Rayleigh scattering coefficient, extinction coefficient can be written by the following relation:

$$\sigma \approx \beta_\eta = \frac{3.91}{V(\lambda_{mn}/550)^{-Q}} \quad (3)$$

RAIN ATTENUATION

Attenuation due to rain, independent of the wavelength, is a function of the precipitation intensity R (mm/h) according to the following relation [1]:

$$Att_{rain} = 1.076 * R^{0.67} (dB/km) \quad (4)$$

It is the interference caused by raindrops on electromagnetic signals traveling through the atmosphere. When this phenomenon occurs, the transmission is weakened by absorption and scattering of the signal by raindrops.

CASE STUDY MEASUREMENT SETUP

A free space optics link was set up within Universiti Teknologi Malaysia campus between P03 and P05 buildings of the electrical faculty. The link comprises two transceivers or link heads both operating at 850 nm wavelength. The link head at P05 is at a height of about 10 m while the one at P03 is at a height of approximately 14 m from a level ground. The distance between the two transceivers is about 100 m.

The location was chosen so that there are no obstacles in the line of sight that can interrupt the connection and no work activity that could interfere with the transmission of data. Figure 1 shows a typical equipment setup. Also, the link heads were mounted in stable and vibration-free platforms. The link head at P03 is mounted near the roof edge to avoid interruption of transmission whereas the one at P05 is near the window.

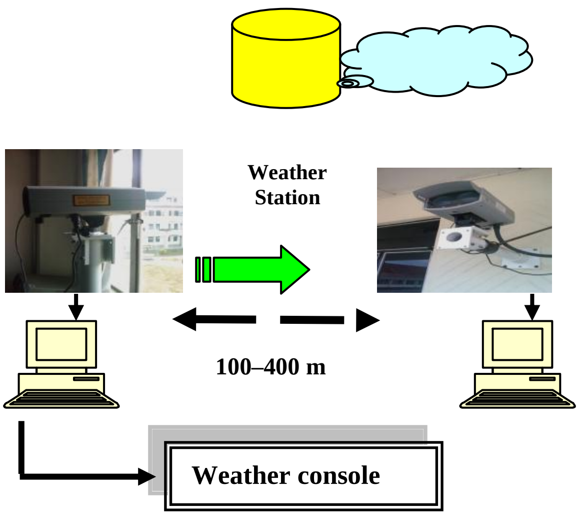

Fig. 1 FSO Antenna setup within UTM Campus.

Table I shows the transceivers specifications, used for the case study.

Table I Describes the Transceivers Specifications.

Power Transmitted	P_T = 0dBm (1 mW)
Transmitter Aperture	D_T = 1.7 cm
Receiver Aperture	D_R = 8 cm
Optical Losses	− 4 dB
Maximum Distance	350 m
Bandwidth	10 Mbs
Optical Transmitter	VCSEL
Wavelength	850 nm
Beam Divergence	7 mrad
Receiver Sensitivity	− 42dB
Receiver Type	PIN

The two computers were configured to have the same working group name and both were given the following addresses:

- P05 : IP : 192.168.0.1 / Subnet : 255.255.255.0
- P03 : IP : 192.168.0.2 / Subnet : 255.255.255.0

The connection between the two computers was successfully established via the free space optics link tested using ping command at both ends. Figure 2 shows the ping command, corresponding to the number of packets sent and received

```
C:\>ping 192.168.0.2-18192-t

Pinging 192.168.0.2 with 8192 bytes of data

Reply from 192.168.0.2: bytes=1892 time=15ms TTL=128
Reply from 192.168.0.2: bytes=1892 time=15ms TTL=128
Reply from 192.168.0.2: bytes=1892 time=15ms TTL=128
Reply from 192.168.0.2: bytes=1892 time=15ms TTL=128
Ping statistics for 192.168.0.2
Packet sent=5, Received=5, Lost=0 (0% loss)
```

Fig. 2 Ping Command Used between the Two Computers.

study of system level design, an OptSim simulator is used as computer-aided tool to analyse FSO performance in atmospheric

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environment. The simulator OptSim is from Rsoft Design Group.

This software is an intuitive modeling and simulation environment supporting the design and the performance evaluation of the transmission level of free space optic systems. Figure 3 shows the FSO block diagram for simulation. Transceivers' specifications values are used as parameter setting in simulation properties.

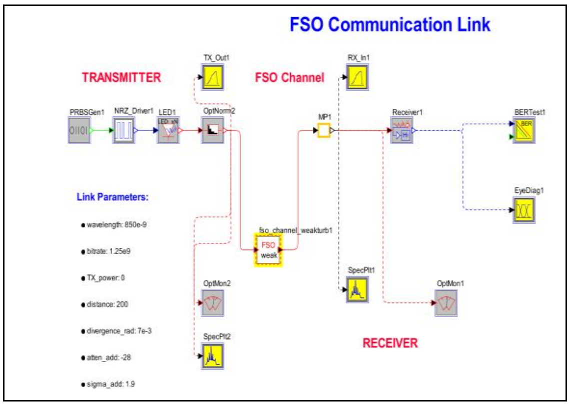

Fig. 3 FSO Block Diagram.

Figure 4 shows the system parameter in simulation properties.

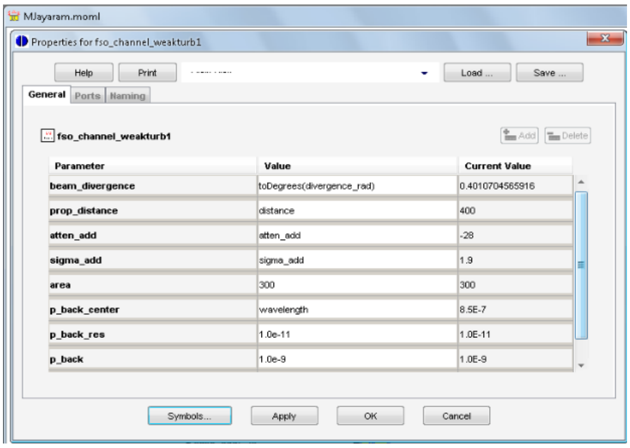

Fig. 4 Simulation Properties.

The transmitter consists of a PRBS generator at bit rate 1.25 Gb/s and NRZ driver and a directly modulated LED at 850 nm. Optical power out of transmitter is 0 dBm (1 mW).

The FSO link has a maximum range of 350 m with a beam divergence angle of 7 mrad. The receiver sensitivity is − 42 dB and the optical transmitter is a VCSEL. To use the prediction models, the necessary parameters of the equipment are:

a. Emitted power
b. Sensitivity
c. Capture area of the receiver
d. Divergence of the emitted beam

Geometrical attenuation is one of the important elements to define the receiver power at the receiver and a function of the beam divergence; and the distance and the receiver capture area.

RESULTS AND ANALYSIS

Figure 5 shows the geometrical attenuation with various distances for divergence of 7 mrad and the capture area is constant and equal to 0.05 m^2. When the distance increased, the attenuation also increased and caused a loss in receiving signal. An increase of the receiver's diameter helps to decrease the geometrical attenuation.

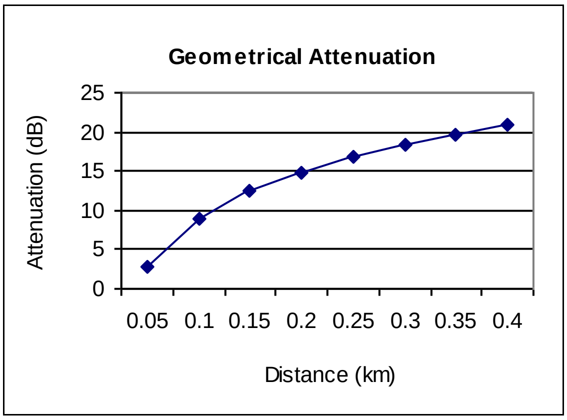

Fig. 5 Geometrical Attenuation for Various Distances.

Two different distances were applied for the case study purposes. The distance of 50 m was set as minimal value and 400 m as maximum distance. Figures 6 and 7 show the corresponding simulation output power at the distance of 50 m and 400 m, respectively.

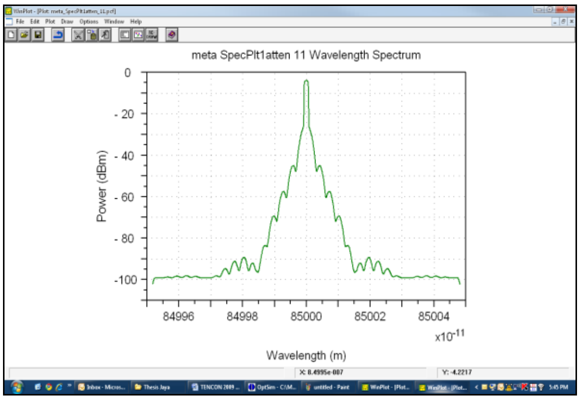

Fig. 6 Output Spectrum at the Distance of 50 m.

The output spectrum of − 4.22 dBm obtained at the distance of 50 m is higher than the power received at the distance of 400 m, i.e.,− 21.81 dBm.

Less power received at the distance of 400 m is due to low power transmission and the effect of attenuation (geometric loss).

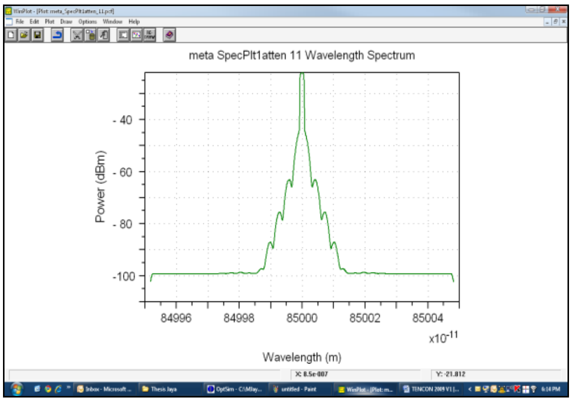

Fig. 7 Output Spectrum at the Distance of 400 m.

The preamp output amplitude shows a decreasing trend over distance; this is a function of both atmospheric absorption and beam divergence. More power can penetrate further through the atmosphere to get longer distance. As we move the receiver away from the transmitter, the beam diverges to diameters that are larger than the receive telescope, and any transmitted energy that is not collected results in geometrical path loss. Figure 8 shows the undistorted eye diagram (very wide eye opening) of the transmission signal, thus less error occurred.

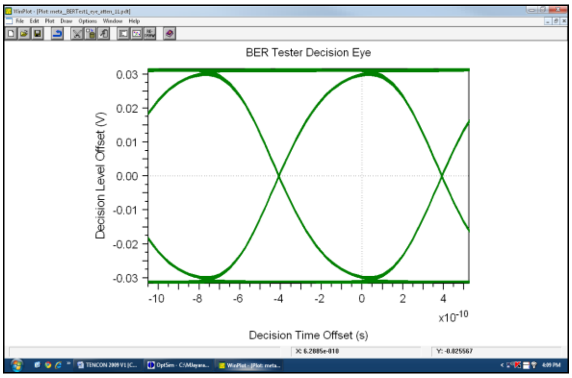

Fig. 8 Receiver Eye Diagram at the Distance of 50 m.

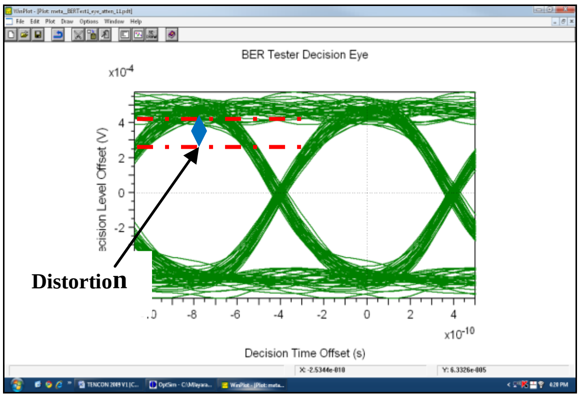

Fig. 9 Receiver Eye Diagram at the Distance of 400 m.

Figure 9 shows less wide eye-opening, which indicates more error occurred as compared at the distance of 50 m. Hence, it is observed that as the distance increased, greater channel loss is obtained and that absorption and scattering caused eye opening to be reduced.

The larger eye opening implies less attenuation of eye opening, hence better transmission. Comparing the two simulation signal waveform in figures 10 and 11, it can be clearly seen that the value obtained at the distance of 50 m is − 3 dBm, which is higher than the optical signal waveform at the distance of 400 m, i.e., −21 dBm. It is called signal fading fluctuations

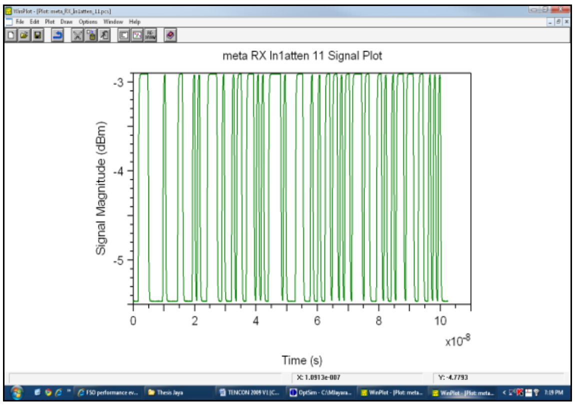

Fig. 10 Received Optical Waveform at the Distance of 50 m.

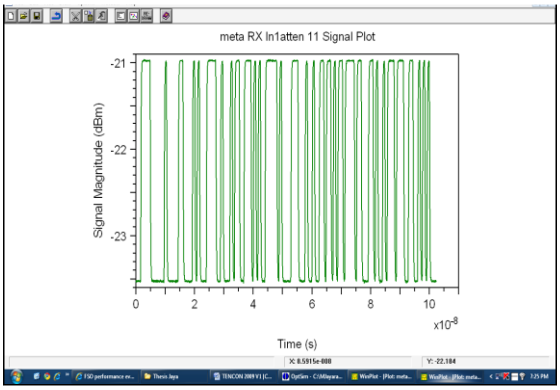

Fig. 11 Received Optical Waveform at the Distance of 400 m.

Signal fading fluctuations occur due to the scintillation effects. Turbulence (manifested as scintillation and beam wander) induces power fades whereby the received signal power level might occasionally drop below the receiver sensitivity. The amplitude and the frequency of scintillation depend on the size of the cells compared to the beam diameter. They have variable size (10 cm−1 km) and differ in temperature. Figure 12 describes the signal fading fluctuations when the transmit signal is affected by the scintillation. The intensity and the speed of the fluctuations (scintillation frequency) increase with wave frequency [4–12].

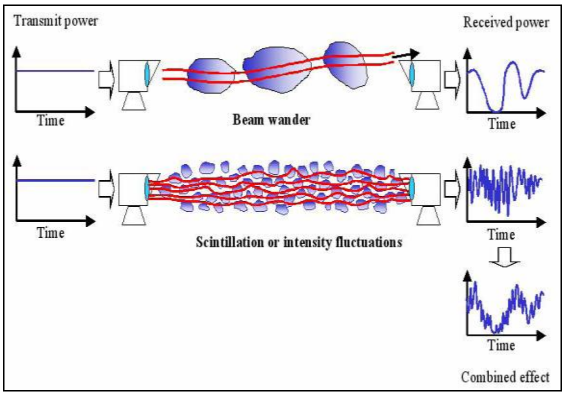

Fig. 12 Beam Wander and Scintillation Attributed to Atmospheric Turbulence.

CONCLUSIONS

In conclusion, demonstration of an example of system level design simulation of an FSO link in the weak turbulence approximation for free-space channels was presented. Simulation is done using OptSim and it is an intuitive modeling and simulation environment supporting the design and the performance evaluation of the transmission level of optical communication systems. It also describes the influence of turbulence on terrestrial laser-beam communication, to evaluate the probability of fade of optical signal propagated through turbulent atmosphere, and to determine the influence of system parameters such as beam divergence, diameter of the receiving aperture, power margin, link distance and wavelength on eliminating the turbulence effect.

Different settings of link parameters, such as distance D_{min} = 50 m, D_{max} = 400 m and beam divergence were applied simultaneously during the simulation.
Optical power decreases with increasing the link distance and the second is the scintillation index, which with increasing link distance initially grows rapidly in the weak fluctuation regime and then decreases slowly in the saturation regime. In future, a detailed study on weather attenuation will be analyzed by our team.

STM JOURNALS

REFERENCES

1. H. Willebrand, B. S. Ghuman. *Free-Space Optics: Enabling Optical Connectivity in Today's Networks*. Indianapolis, USA. SAMS. 2002.
2. O. Bouchet, H. Sizun, C. Boisrobert et al. *Free-Space Optics Propagation andCommunication*. London, UK. ISTE. 2004.
3. Ziping Hu, Pramode Verma, and James Sluss, Jr. *Journal of Optical Communications and Networking*. 2008. **7**. 436–448p.
4. Binbin Wu, Zeinab Hajjarian, Mohsen Kavehrad. *Applied Optics*. 2008. 47. 3168–3176.
5. M. S. Awan, E. Leitgeb et al. *International Symposium on Communication Systems, Networks & Digital Signal Processing* (CSNDSP). Graz, Austria. (IEEE). 23–25 July 2008. 260–264p.
6. M. S. Awan, E. Leitgeb et al. *2nd SatNEx International Propagation Workshop*. .Oberpfaffenhofen, Munich, Germany. 17–18 April 2008.
7. M. S. Awan, E. Leitgeb, C. Capsoni et al. *International Workshop on Satellite and Space Communications* Toulouse, France. 1–3 October 2008 (IEEE). 112–116p.
8. M. S. Awan, C. Capsoni, O. Koudelka et al. *IEEE Photonics Global*. Singapore. 8–11 December 2008. 1–4p.
9. F. Nadeem, E. Leitgeb, M. S. Awan et al. *2nd SatNEx International Propagation Workshop*. Oberpfaffenhofen, Munich, Germany. 17–18 April 2008.
10. F. Nadeem, E. Leitgeb, M. S. Khan et al. *International Symposium on Communication Systems, Networks & Digital Signal Processing* (CSNDSP). Graz, Austria. 23–25 July 2008. (IEEE). 278–282p.
11. F. Nadeem, E. Leitgeb, M. S. Khan, M. S. Awan et al. *International Workshop on Satellite and Space Communications (IWSSC).* Toulouse, France. 1–3 October 2008. (IEEE). 316–320p.
12. Popoola W. O., Ghassemlooy Z., Leitgeb E. *9th International Symposium on Communication Theory and Applications (ISCTA).* St Martin's College, Ambleside, The Lake District. 16–20 July 2007.