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Reduction Of Effect Of Atmospheric Turbulence In FSO Communication

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Abstract

FSO communication is used to communicate between ground and satellite links wirelessly through free space. The transmission of data gets affected due to various atmospheric turbulence regimes. This causes degradation in both the intensity as well as the phase of the received signal. Over the time different methods have been implemented in order to minimize these affects.

The main objective of this paper is to prepare a comparison between the performances of two such methods: (i) Aperture averaging (ii) Employing multiple transmitters and receivers and also try combining the two for better performance. The comparison will be done on the basis of received power and BER. The simulations will be performed in Optisystem 7.0 by Optiwave.

In the first phase, the theoretical calculations for both the methods will be performed and the simulation model will be prepared. The second phase will be about analyzing both the methods under different conditions and preparing a comparison between the two. The analysis will lead to the conclusion of which method is better over the other based on the above parameters.

Index Terms—Free Space Optics (FSO) link, Aperture Averaging, Multiple TX/RX, Bit Error Rate (BER), eye diagram

I. INTRODUCTION

Free-space optics (FSO), also called free-space photonics (FSP), is a line of site technology that is used to communicate between the transmitter and the receiver in a similar fashion as in the optical fiber communication with the exception that the medium here is air. Transmission using FSO technology is relatively simple. It involves two systems each consisting of an optical transceiver which consists of a laser transmitter and a receiver to provide full duplex capability. Each FSO system uses a high power optical source (like laser) plus a telescope that transmits light through the atmosphere to another telescope that receives the information.

It is capable of sending up to 1.25 Gbps of data, voice and video communications simultaneously through air, enabling fiber optic connectivity without requiring physical fiber-optic cable or securing spectrum licenses. It enables optical communications at the speed of light. Figure 1 shows the general FSO communication link.

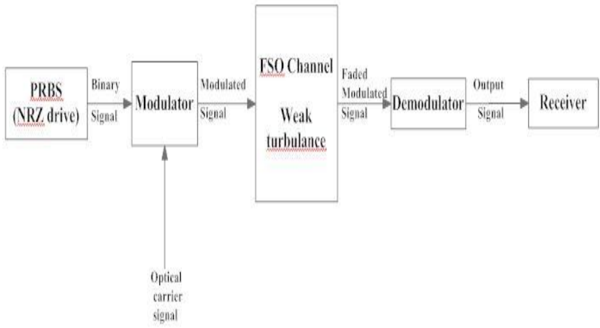


FIG 1: Free Space Optical Communication Link

However, since an open medium is used in the FSO communication i.e. the atmosphere, it is subject to potential disturbances such as rain, cloud, snow etc. The major issue related to the FSO system is the atmospheric turbulence which depends upon the temperature and pressure of the atmospheric region through which the signal has to pass. This atmospheric turbulence causes a significant reduction in the received signal power. Thus, the performance of the system is severely degraded.

Networks with FSO must be designed to counter the atmosphere to increase FSO's system capacity. Various techniques like adaptive optics before transmission, forward error correction technique, employing multiple TX-RX and aperture averaging have been used to improve the reliability of a FSO system and enhance its performance. In this paper, two such techniques have been analyzed-

i) Aperture Averaging Technique.
ii) Employing Multiple TX/RX

The aperture averaging technique suggests that the amount of measured radiations can be increased by increasing the size of receiver collecting lens aperture. Thus the lens averages out all fluctuations in the received signal. Figure 2 shows how averaging is done at receiver aperture.

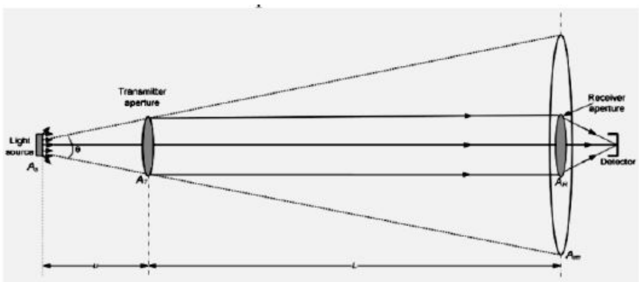


FIG 2: Receiver aperture receiving radiations

In the latter technique, multiple laser beams are used with a FSO unit to analyze it performance. Multiple TX/RX i.e. multiple laser beams within a FSO based unit are employed to analyze its communication link performances. Therefore, it will be useful to know how much error the different combinations can tolerate before the BER is significantly increased based on the received power and the number of transmitters and receivers used. Both the methods are studied and compared in terms of received power and BER.

II.THEORY

The FSO link performance is determined by considering several parameters including geometrical loss, system loss, channel loss received power and BER. We focus on two parameters to evaluate the FSO link performances which are the received power and BER.

Theoretically, the basic communication principle stated that received power must be less than transmitted power, i.e.

$$P_R \leq P_T$$

So,

$$P_R = P_T - Total\ Losses$$

Where P_R (dBm) is the received power, P_T (dBm) is the transmitted power. Total losses in a FSO communication system, covers all the losses caused by the atmospheric factors. In our simulation, we have included atmospheric losses, *LATM* (dB) which can be calculated as :

$$L_{ATM} = e^{-\sigma l}$$

Where ℓ (km) is the transmittance range of the laser and σ is the typical attenuation coefficients

geometrical losses , *LGEO* (dB) which can be calculated as

$$L_{GEO} = -10\log_{10}\frac{4A_{Rtotal}}{\pi(l\theta)^2}$$

where ℓ (km) is the distance of the optical path where the laser beams travel and θ (mrad) is the divergence angle which is the angle of the cone of light emitted from the transmitter. Meanwhile, A_{Rtotal} (m^2) is the total area of the receiver apertures on a single FSO unit.

and system loss, *LSYS* (dB). Therefore, the new equation for FSO received power is:

$$P_R = P_{Tcomb} - L_{ATM} - L_{GEO} - L_{SYS}$$

Since the work involved the usage of multiple TX/RX architecture, the total transmitted power denoted by *PTcomb* (dBm) from each of the transmitters has been taken into consideration. The total transmitted power can be obtained by:

$$P_{Tcomb} = P_T + 10\log_{10}(N_T)$$

Where *NT* is the number of transmitter lenses on a single FSO unit.

III.SYSTEM MODELLING

Aperture Averaging with Multiple TX/RX system modeling is done for multiple Tx-Rx using Optisystem 7 by Optiwave. Figure 3 shows the layout model for 2TX and 2RX combination**.** A general FSO system consists of an optical transmitter, a FSO channel and the optical receiver. The frequency of the TX is set to be 353 THz or 850 nm in wavelength and the power is 10 dBm. The bit rate used in this setup is 1 Gbps. The actual transmitted power for a single TX of the is 7.348 dBm. The drop in the TX power is due to the extinction ratio of the TX, which is set to 10 dB. The output of the TX is connected to the fork which is a component used to duplicate the number of output ports so that each of the signals coming out from the fork's output has the same value with the input coming to the fork. The fork connected to the TX will produce a multiple optical signals from one source. The multiple Optical signals are then sent to the FSO channel which is the reproduction of the free space channel. It is a subsystem of two telescopes with the FSO channel between them. The aperture diameters of the TX and RX are initially set to 2.5 cm and 8 cm respectively. The beam divergence is set to 2 mrad and the length of the channel is set to 1 km. The theoretical model gives the relation between the TX power and the RX power in the FSO channel. Hence, the work will involve the modification of the single TX and single RX layout design and the receiver aperture diameter in each case to enable the simulation of the aperture averaging with multiple TX/RX technique.

The equipments used in the FSO communication process also need to be accounted for losses. Since there are two FSO terminals involved, the transmitter and receiver, loss procured due to each is set to 1.8 dB. Hence, the system loss is set to be 3.6 dB for the two FSO terminals. The attenuation in the free space optical channel is set to be 0.50 dB/km. All the multiple signals coming out from the FSO channel are then combined using the power combiner before being received by the RX. The sensitivity of the RX is set to be -45 dBm. The two visualizer used in the simulation is the optical power meter and the BER analyzer. The first power meter is used to measure the transmit power signal coming out from the TX output port and the second power meter is used to calculate and display the average received power at the RX. As for the BER analyzer, it will automatically calculate the BER value and display the eye diagram of the designed system.

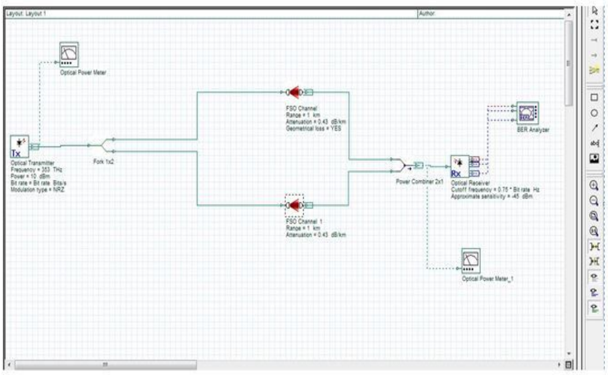


FIG 3 : TX-RX FSO link simulation layout

IV.RESULTS AND ANALYSIS

The analysis was done for various combinations of TX and RX with different receiver aperture diameters. The multiple output optical signals were measured and analyzed and the performance of the systems were compared in terms of received power and BER by fixing the parameter values of FSO channel, optical TX and optical RX. The analysis was done in two steps:

A. The Theoretical approach

Table 1 shows the results obtained after performing theoretical calculations for the evaluation of the received power using the equations discussed in section 2. The calculations were performed for 1TX-1RX, 2TX-RX, 3TX-RX and 4TX-RX with receiver aperture diameters 8 cm and 15 cm respectively.

As the number of TX/RX are increased, the received power increases accordingly. The 4x4 combination of TX and RX gives the highest value of received power. Now if we increase the receiver aperture diameter and change it to 15 cm, the received power further increases for the same no of TX-RX. It is predicted that these combinations will still give the highest received power value when measured using the experimental setup.
Transmitted power, P_t = 7.348 dBm

Table 1: Theoretical received power for multiple TX-RX

No of TX-RX	Received Power(dBm)
	Aperture diameter = 8 cm
1 TX- 1 RX	-24.8165
2 TX-2 RX	-21.8065
3 TX-3 RX	-20.045
4 TX-4 RX	-18.796
	Aperture diameter=15 cm
1 TX-1 RX	-19.356
2 TX-2 RX	-16.346
3 TX-3 RX	-14.5855
4 TX-4RX	-13.3365

B. The Simulations

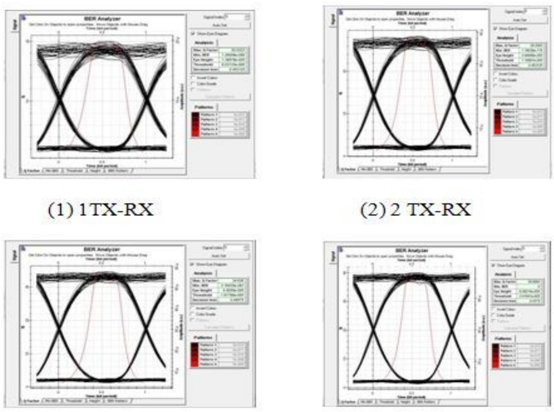
The received power(dBm) for each case are tabulated by changing the layout as per the requirement and simulating the project. Table 2 shows the tabulated results. Prior to the BER performance analysis, the average received power of the simulation setup for each of the TX/RX combinations are compared with the theoretical received power. From this comparison we ensure that the simulation is providing us with an appropriate result. The difference of the power values between the respective theoretical result and simulated result is maximum 0.33%. This means that the components setup and connections are accurate and the system is ready to undergo the BER performance analysis.

By analyzing the eye diagram in the BER analyzer, the system performances can be measured and evaluated. Figure 4 shows the eye diagram for the 1TX/1RX, 2TX/2RX, 3TX/3RX and 4TX/4RX combinations with receiver aperture diameter 8 cm. Figure 5 shows the eye diagram for the 1TX/1RX, 2TX/2RX, 3TX/3RX and 4TX/4RX combinations with receiver aperture diameter 15 cm. The increment in the number of TX and RX reduces jitters in the signal and increases the size of the eye opening. The significance of a wider eye opening is that it will reduce the potential occurrence for data errors, so the wider the eye opening, the better the system performance.
Transmitted power, P_t = 7.348 dBm

Table 2 : Simulated received power for multiple TX-RX

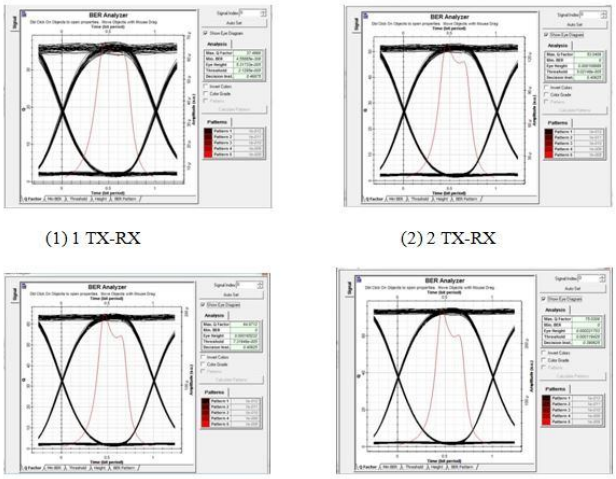
No of TX-RX	Received Power(dBm)
	Aperture diameter = 8 cm
1 TX- 1 RX	-24.819
2 TX-2 RX	-21.739
3 TX-3 RX	-19.978
4 TX-4 RX	-18.798
	Aperture diameter=15 cm
1 TX-1 RX	-19.359
2 TX-2 RX	-16.278
3 TX-3 RX	-14.518
4 TX-4RX	-13.338

In the BER analysis, the relationship between the average received power and BER is considered. The objective is to obtain minimum BER via simulation with various combinations of TX and RX. Theoretically, the received power will increase with the added number of TXs and RXs. With such addition, the BER for the system decreases due to the spatial diversity effect which has increased the total received power. A single TX and RX has the highest BER of 10-9, which means that there is 1 error bit for every 1Gbit of received data. The BER continues to decrease as the number of TX and RX increase. The lowest BER recorded is for 4TX/4RX combination which is 10-107. The low BER will enable the system to go a further distance i.e. more than 1 km, as long as the received power is above the receiver threshold.



(1) 1TX-RX (2) 2 TX-RX (3) 3 TX-RX (4) 4 TX-RX

FIG 4 : BER Diagrams for receiver aperture = 8 cm



(1) 1 TX-RX (2) 2 TX-RX (3) 3 TX-RX (4) 4 TX-RX

FIG 5 : BER Diagrams for receiver aperture = 15 cm

V.CONCLUSIONS

The aim of this work was to compare the performance of two turbulence reduction schemes implemented in FSO communication and also observe the combined effect of both of these. The simulation results are in sync with the theoretical calculations. Analysis of system performance is based on two parameters which are the received power and the BER.

From the theoretical and simulation modeling, it is seen that doubling the receiver aperture diameter as compared to the doubling the no of TX-RX provides a steep increase in the received power at the RX . Also the rise in Q-factor and the fall in BER is exponential when receiver aperture diameter is doubled.

So it is right to say that aperture averaging is a much more efficient method of reducing atmospheric turbulence as compared to employing multiple TX-RX. But there is a limit up to which we can increase the aperture diameter. So in practical cases it is advisable to combine both these techniques to obtain the desired results. This analysis will help in designing longer FSO links over large distances and enhance the usage of this technology in the future prospects.

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