172. Performance Prediction of Free Space Optical Link in Presence of the Rain using Bit Error Rate Parameter

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Abstract

The demand of the bandwidth is dramatically increasing with the evolution of the technology and to accommodate the user with such demands Free Space Optics (FSO) is one of the most suitable options. It not only provides the data rates in hundreds of gigabits per second but also have some advantages in contrast of radio frequency or microwave communication. The most attractive features of the FSO technology are limited electromagnetic compatibility issues, free licensing, and easy installation. The performance is similar to the fiber optic communication system with more flexibility and robustness. FSO technology is point to point communication and uses the atmospheric channel to transmit the laser signal hence the light signal is used for transferring the information from one point to another. It works on very low power therefore, saves huge energy in comparison to the existing systems. Since this technology uses the atmospheric channel hence the FSO links are susceptible to atmospheric conditions, which include fog, rain, snow and scintillations. Amongst all, Fog effect the link significantly and degrades the performance at a very great extent. In absence of fog, rain is the parameter that limits the performance of FSO links. In this work losses due to rain at different rain intensities and data rates are simulated on wireless optical link and the performance is measured in terms of Bit Error Rate (BER). The model available in literature is modified to include the effect of rain in overall attenuation from transmitter to receiver.

Keywords: *Free Space Optics, Bit Error Rate, Rain, Opti-system*

1. Introduction

In the world of wireless communication, the signal is very sensitive to the atmospheric effects which include fog, rain, snow, scintillation. When the frequency of the signal is greater than 10GHz, the effect of rain is severely affects the strength of the signal. There are several applications which are working above the 10GHz band like Satellite communication, free space optical (FSO) communication and the future of mobile communication (5G technology) is also relying on it. Many researchers have suggested that for the 5G mobile communication, millimeter wave frequency band can be one of the bands [1]. The purpose of 5G mobile communication will be to provide the multi-gigabit per second range and this is only possible by using the millimeter wave band [2].

During recent years, there has been growing interest in free-space optical (FSO) communications. FSO is a technology which provides enormous advantages in comparison to existing wireless networks, i.e. microwave and RF systems. In communications, free space optical links provide a solution for high capacity data transmission through free atmosphere. The performance of FSO is similar to the fiber optics communication system with few additional features that provides the flexibility of providing the high data rates and fiber free communication. The key advantages are: free licensing, significantly higher transmission capacity, limited electromagnetic compatibility issues, and easy to install [3-4,15].

The FSO system uses the laser beam in order to achieve the communication between any two points. Since it uses free space path hence the laser beam is affected by the different atmospheric conditions which include fog, rain, scintillation and snow [5-6]. Depending on the environment and range over which an FSO link operates, it is subject to different impairments. Long-range links use directed laser beams to transmit data. Such links may operate over ranges of several kilometers or longer, and often their primary impairment is atmospheric turbulence, which causes phase and intensity fluctuations in the received signal [7]. There are various different weather conditions that attenuate the signal but amongst all, fog is the parameter that introduce the maximum attenuation and limit the signal up to few tens of meters [8]. But those regions where fog is not the dominant weather condition, rain affect the signal and attenuate it in order to limit the distance [9]. Different authors have contributed their work in the field of FSO. In [10], the authors have calculated the effect of rain on FSO links and introducing the concept of multiple beam transmission and reception. They have considered the Malaysia weather and used the 07 months' rain data. In [11], the authors have achieved the long distance FSO links, comprises of 10km, by keeping the beam width as minimum as 0.25 mrad. In this work, we aim to provide the minimum distance for the FSO link in presence of different intensities of rain in order to achieve the desired performance. The FSO link is simulated using opti-system 7.0 and the performance of the under different rain rates is analyzed using BER parameter.

The remainder of the paper is organized as follows: Section 2 describes the rain attenuation models used in this work. Section 3 explains the modeling of the FSO system. The important results are mentioned in Section 4. Finally, Section 5 draws some conclusions.

2. Rain Attenuation Model

From the literature, it is analyzed that the areas where fog is not the dominant source, rain affect the performance of the FSO link. In order to model the FSO system, we have used the Carbonneau model to calculate the rain attenuation at different rain rates. The total attenuation (in dB) for any FSO link can be calculated as:

$$A = L_G - L_{atm} - L_{opt} - L_{mp} \quad (1)$$

Where,

L_{atm}: Atmospheric Losses
L_G: Geometrical Losses
L_{opt}: Optical Losses
L_{mp}: Bad Pointing Losses

The geometrical loss for the FSO link (in dB) can be calculated as:

$$L_g = 10\log\left[\frac{D_r}{d*\theta+D_t}\right]^2 \quad (2)$$

Where,

Dr: Diameter of receiver
Dt: Diameter of transmitter
d: Distance (km).
θ: Beam Divergence (mrad) [12]

L_{atm} is the loss due to different weather conditions. In this work, we have considered only the rain hence the losses due to atmosphere is the only loss which is produced due to rain. Using power law, the rain attenuation can be calculated as:

$$\alpha = x * R^{y} \quad (3)$$

Where:

R: Rainrate (mm/h)
α: attenuation due to rain (dB/Km)
x and y are the power law coefficients. Since we are using the Carbonneau Model so the value of coefficients of power law are, x=1.076 and y=0.67 [13].

Therefore, we can rewrite equation (3) as:

$$L_{atm} = \alpha * d \quad (4)$$

Fig. 1. shows the relationship between the rain rate (mm/h) and the attenuation (dB/km) using Carbonneau model. There are some other losses like miss pointing and optical losses which also attenuate the signal. The miss pointing loss is introduced due to imperfection between the transmitter and the receiver whereas, the optical loss is categories in to insertion and coupling loss. According to [9], the miss pointing loss is normally considered as 3 dB and the optical loss is considered as 9dB. Therefore, the equation (1) can be modified using Carbonneau model as:

$$A = 10\log\left[\frac{D_r}{D_t + d * \theta}\right]^2 - [1.076 * R^{0.67}] - 12 \quad (5)$$

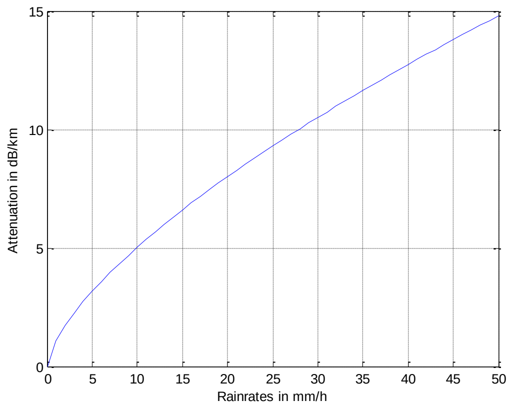

Fig. 1. Rainfall rate (mm/h) v/s Attenuation (dB/km)

3. System Modeling

As the Free Space Optics system is modelled in opti-system 7.0 tool hence the complete FSO model using opti-system tool is shown in fig. 2.

The parameters, their values and specifications which are used in this paper are shown in table. 1

Table 1. Parameter used for system modeling

S. No.	Parameters	Values
1.	Modulator Type	Mach-Zehnder
2.	Extinction Ratio	30dB
3.	Laser Type	CW
4.	Beam Divergence	Variable
5.	Attenuation	Variable
6.	Bit Rate	Variable
7.	Transmitter Aperture diameter	16cm
8.	Aperture diameter receiver	40cm
9.	Ionization Ratio	0.9
10.	Wavelength	780nm
11.	Dark current	10nA

4. Results

Table 2. Effects of input power on distance

No.	Weather Condition	Beam width (mrad)	Input Power (dBm)	Distance (Km)	Bit Error Rate (BER)
1.	Clear	2	25	2	4.9×10^{-4}
2.	Rain 5mm/h	2	25	2	1
3.	Rain 5mm/h	2	30	2	7.4×10^{-3}
4.	Rain 10mm/h	2	30	2	1

4.1. Effects of Input power on Distance in clear and rainy weather

The results of the simulations of the FSO system using opti-system is shown in table 2 and it can be observed from the results that when the input power is 25dBm and the weather is clear, i.e. there is no rain, the BER of the link goes up to 4.9x10-4 keeping the distance of 2km. And as the rain is initiated, the performance would get worst, i.e. the rain of 5mm/h corrupts all the bits and therefore the link is unavailable if the same parameters are used. In order to make the link available under this rain, 5mm/h, we have to increase the power or keep the link distance shorter. If we are keeping the distance constant, 2km, and increasing the power to 30dBm the link is again available with the BER of 7.4x10-3 now again if the rain rate is increased, i.e. 10mm/h, again the link is not available and all the bits are corrupted, keeping the distance constant. Hence it seems that as the rain rate is increased, the performance is decreasing, also mentioned in [8], but to overcome the effect of rain, the service provider has to increase the input power to get the desired performance.

4.2. Effect of Data Rate on Distance and BER

In this section, the effect of data rate is observed on distance and the BER. In this section, we have used input power of 25dBm, the weather is clear and the beamwidth is 2mrad. Initially the link is setup at the different distances and observed the BER at respective distances. From the fig. 3, it is observed that in order to achieve 99.99% performance at the data rate of 1.5Gbps, one has to keep the distance 1.9km considering the input power, beam divergence and weather as 25dBm, 2mrad and clear respectively. Now as we are increasing the data rate, as shown in fig. 4 for

2.5Gbps and fig. 5 for 3.5Gbps, keeping all parameter constant, the distance of the link has to be shorter in order to get the 99.99% performance.

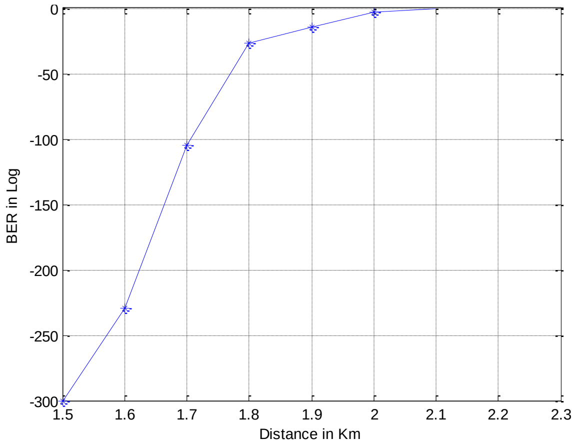

Fig. 3. BER v/s Distance at Data Rate 1.5Gbps

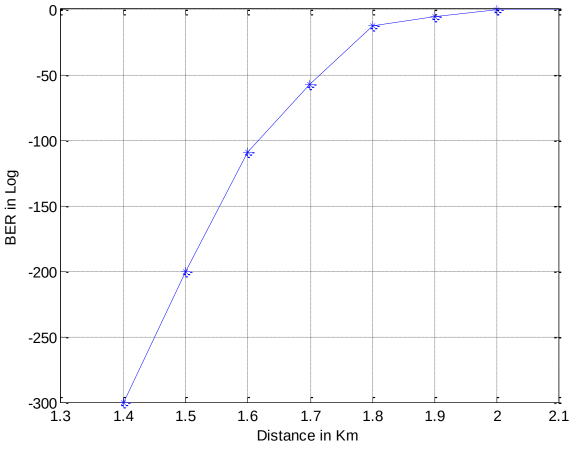

Fig. 4. BER v/s Distance at Data Rate 2.5Gbps

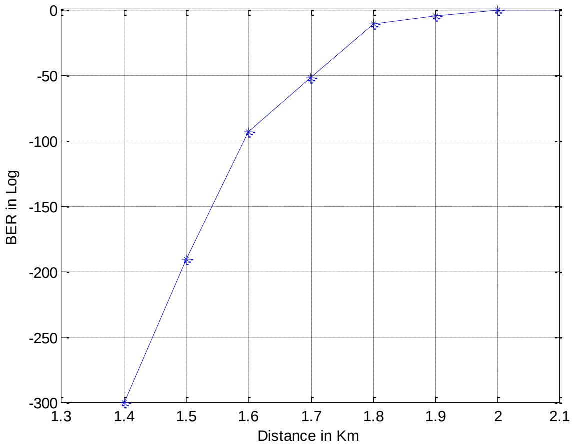

Fig. 5. BER v/s Distance at Data Rate 3.5Gbps

The data rates is directly propotional to the BER. As the datarate is increased, the BER also increases [14] and this is what we have analyzed in this section by using parameters as shown in table 1. It can be easily analyzed that as the datarate is increased, the link get shorter because the amount of bit corroption is increased by increasing the datarates keeping the all other parameters constant. It order to achieve 99.99% performance, the maximum distance using the 1.5 Gbps, 2.5 Gbps and 3.5 Gbps data rates can be 1.95km, 1.92km and 1.905km for the respectively.

4.3. Effect of Beam width on Distance in clear and rainy weather

In this section, we have discussed the effect of beam width on the distance of the FSO link at different rain rates. We have observed the signal at three different beamwidths, i.e. 2mrad, 3mrad and 4mrad.

Beamwidth has the significant importance on the FSO link. As the beamwidth of the signal is narrowed, the greater distance is achieved by the signal and this is what we have shown in this section. Fig. 6, 7 and 8 shows the relationship of the rain rate and the achievable distance at 4mrad, 3mrad and 2mrad beamwidth respectively. It is observed from fig. 6 that in order to achieve the 99.999% performance of the system using 4mrad beamwidth in the clear environment, the link distance must be 1.61km. And as the rain is introduced, the distance get significantly decreased keeping the performance of the system constant, i.e. 99.999%. From fig. 7 and 8, it is observed that as the beamwidth of the signal is decreased the link distance is increased keeping the system performance as 99.999%.

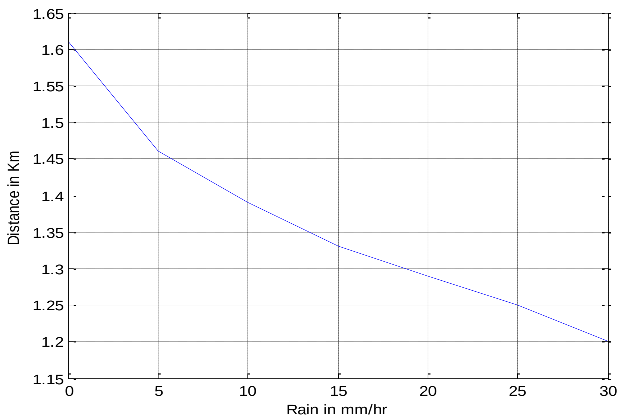

Fig. 6. Rain rate v/s distance with 99.999% link performance using 4mrad beam width.

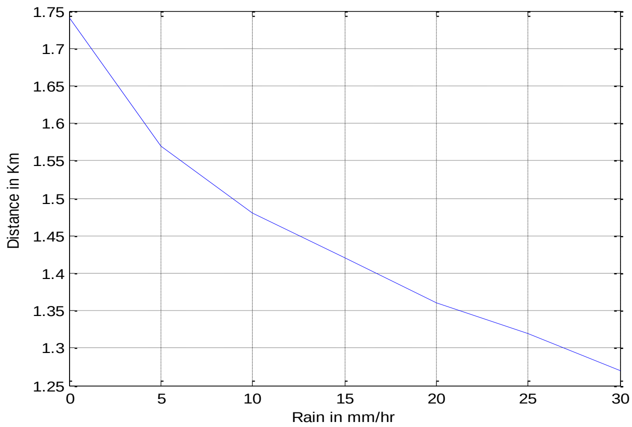

Fig. 7. Distance v/s Rain Rate with 99.999% link performance using 3mrad beam width

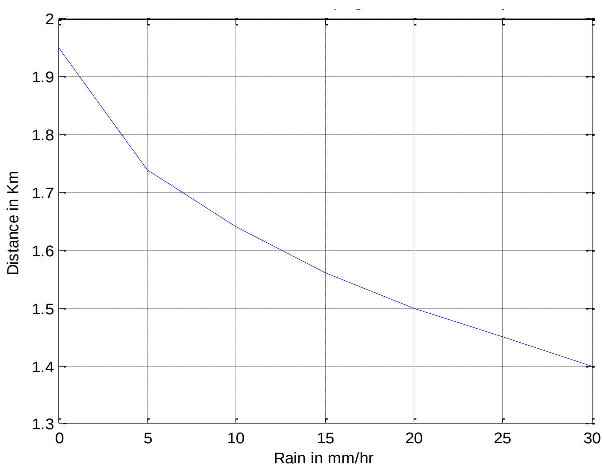

Fig. 8. Distance v/s Rain rate with 99.999% link performance using 2mrad beam width

5. Conclusion

The effects of data rate, beam width and its impact on the rain rate is analyzed. The results show the significant effect of the rain intensity on the FSO link can be mitigated by number of factors, like reduction of the beam width, increasing the input power for improving the performance of the system. The result shows the relationship between the data rate and BER, which is inversely proportional. It has been observed that in order to achieve 99.99% performance, the maximum FSO link distance using the 1.5 Gbps, 2.5 Gbps and 3.5 Gbps data rates can be 1.95km, 1.92km and 1.905km respectively. It has also been investigated that there is a direct relationship between the link distance and rainfall intensity keeping all the parameters constant. In order to increase the link distance, beam width plays a very important role. It has been observed that as the beam width is narrowed down, the FSO link distance is increased for the same rainfall rate. The result shows that for the rain rate of 30mm/h, the maximum attainable distance for the beam width of 4mrad, 3mrad and 2mrad is 1.2km, 1.28km and 1.4km respectively. For the future work, we will incorporate the effects of scintillation, turbulence and fog and design the model and calculate the minimum distance at which the link gives optimum performance under the above weather parameters.

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