Investigation on Free Space Optical Communication for Various Atmospheric Conditions

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Abstract - Free space optical communication (FSO) provides high data rate by allowing light passed through the atmosphere. In Free Space Optical (FSO) Communication, the atmospheric conditions cause variations in the intensity and phase of the received signal which significantly reduces the performance of the system. In this paper, the effect of transmission distance with respect to the various atmospheric conditions such as air, haze, rain, fog and snow with different levels are investigated. Then, the Bit Error Rate (BER) while varying the link distance for various atmospheric conditions is analyzed. The transmission wavelength and date rate are 1550 nm and 2.5 Gbps is considered for investigation. Obviously, from the simulation it is noticed that the link distance is reduced while increasing the attenuation. This attempt will be useful for researchers and industries to select the optimum device for FSO with respect to the transmission distance.

Keywords: **Free space optical communication, atmospheric conditions, haze, rain, fog, snow, bit error rate, transmission distance**

I.*INTRODUCTION*

The exponentially increasing bandwidth requirement for multimedia and internet application is pushing Free Space Optical (FSO) communication ever closer to end user. FSO communication offers potentially wide bandwidth and high data rate, which makes this type of communication system highly attractive in meeting the exponential increasing demand. FSO system is similar to conventional fiber optical system however; it is fiber free, line of sight communication, no security and not required expensive rooftop installations. FSO is an optical communication technology that uses light propagating in free space to transmit data between two or more points. This technology is useful where a fiber optic cable is impractical. In FSO data is transmitted by modulated LASER light [1]. Free space optics (FSO) is a cost effective and attractive solution for high data rate and voice transmission. It is an alternative solution to more conventional RF/Microwave links [2].

Free space optics system suffers from various limitations. However, Quality of service of a FSO link in the atmosphere is strongly influenced by various weather conditions [3]. Atmospheric attenuation is dependent upon rain, haze, fog and snow. The total attenuation is a combination of atmospheric attenuation and geometric losses. In the FSO link two 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, 5].

Conventional FSO systems operate near the 850 nm spectral range and before transmission through the space, the optical signal is converted to electrical signal by the optical transmitter. The electrical signal amplified by a laser driver and the modulated light from the laser diode is directed through space. At the receiver, the optical signal is focused to a photodetector then converted back to optical signal for transmission through optical fiber [4].

Unfortunately, optical devices using the 850 nm spectral range cannot operate above 2.5 Gbps because of the power limitations imposed for eye safety. In order to overcome the power limitations, 1550 nm wavelength is selected for new ultra high speed FSO systems and its advantages apart from being eye safety include reduced solar background radiation and compatibility with existing optical fiber technology infrastructure. By using 1550 nm wavelength, Mbps wireless transmission can be achieved by leveraging the technology developed for long haul optical communication [4].

In the literature, there are several attempts are made to arrive the link distance for various atmospheric conditions [6-9], however they have not considered all the atmospheric conditions. In this paper, the effect of transmission distance for various atmospheric conditions namely, air, fog, snow and haze, is primarily analyzed. And the effects of Bit Error Rate with respect to the atmospheric conditions while varying the distance are investigated.

The paper is organized as follows; the introduction about FSO and present status of work through literature survey is given in Section I. The design of FSO system and the attenuation of various atmospheric conditions are discussed in Section II. The effect of link distance and Bit Error Rate with respect to atmospheric conditions is reported in Section III. Finally, Section IV concludes the paper.

II. *FREE SPACE OPTICAL COMMUNICATION SYSTEM MODEL*

The FSO system model is illustrated in Fig.1 which is comprised of three parts namely, transmitter, receiver and FSO link or atmospheric conditions. The transmitter consists of CW laser, Mach-Zehnder modulator, Pseudo-Random Bit Sequence (PRBS) Generator and NRZ Pulse Generator. Where as in receiver part is used to detect the optical signal which consists of APD photodiode, low pass Bessel filter. The space between transmitter and receiver is considered as FSO link distance or atmospheric distance. FSO system has been designed and simulated using optisystem7.0. The simulation parameters are listed in Table 1.

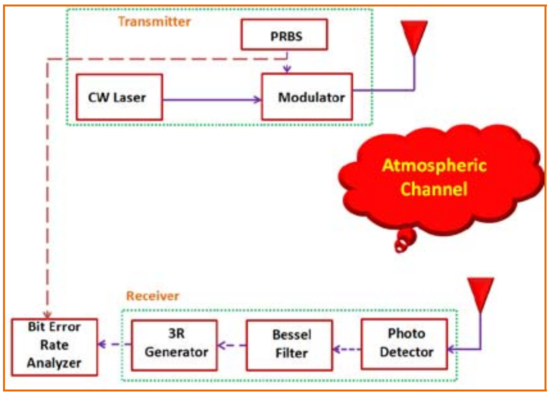

Fig.1.Block diagram of free space optical communication system

TABLE I SIMULATION PARAMETERS OF FREE SPACE OPTICAL COMMUNICATION SYSTEM

Parameters	Values
Data rate	2.5Gbps
Power	25dBm
Transmitted wavelength	1550nm
Link range	1- 475km
Transmitter's & Receiver's Apertures	30cm

Attenuation is one of the primary parameters that are limiting the performance of the FSO systems. Typically, the attenuation is varying with respect to the atmospheric conditions. The attenuation is the reduction of signal power at the receiver point. The attenuation of an optical beam as it propagates through the air is given by the Beers-Lambert law [1,6]

$$P_R = P_T \exp(-\alpha Z) \quad (1)$$

where, P_T and P_R are the transmitted and the received power and α is atmospheric attenuation coefficient and Z is the link range. The coefficient of atmospheric attenuation depends on the type of scattering and signal wavelength, size of the particles of the atmosphere and the link visibility. The Attenuation of the atmosphere can be caused by several factors, absorption and scattering of optical beam by gas molecules and aerosol present in the air. The primary atmospheric conditions that are affecting the system performance are air, haze, fog, rain and snow.

Free space optics (FSO) links significantly depends upon different visibility ranges and atmospheric conditions. The signal attenuation for air, haze and fog is based on the visibility range estimation is computed by employing Kim and Kurse model [6, 7, 8, 10].

$$\alpha = 3.91/V\ (\lambda/550nm)^{-q} \quad (2)$$

where,
α = attenuation coefficient
V= visibility in kilometers
λ = Wavelength in nanometers
q = The size distribution of the scattering particles
The visibility range and its attenuation are listed in Table 2.

TABLE II THE VISIBILITY AND ATTENUATION OF VARIOUS ATMOSPHERIC CONDITIONS

Weather condition	Visibility in Km	Attenuation in dB/km
Very clear	50	0.065
Clear	20	0.233
Light haze	10	0.55
Heavy haze	4	2.37
Light fog	0.8	15.5
Thick fog	0.6	25.5

Rain is the highest attenuation factor in atmosphere for laser beam compared to haze intensity factor. In general, rain intensity factors could reduce the visibility and also affect the FSO performance [7]. The scattering coefficient can be calculated using stroke law [3].

$$\alpha_{rain\ scat} = \pi a^2 Na\ Q_{scat}\ (a/\lambda) \quad (3)$$

where
a= Radius of rain drop (0.001-0.1cm)
Na= Rain drop distribution,
Q_{scat} = Scattering efficiency
λ= Wavelength.

The rain drop distribution, Na can be calculated using

$$Na=Za/[4/3(\pi a^3)Va]. \quad (4)$$

Za is rainfall rate (cm/s),
For 26mm/hr Za = 7.22×10^{-4}
For 40mm/hr Za is 1.11×10^{-3}
For 80mm/hr Za is 2.22×10^{-3}
Va = limit speed precipitation

$$Va=(2a^2\rho g)/9\eta \quad (5)$$

ρ is water density($1 g/cm^2$)
g is gravitational constant($980 cm/s^2$)
η is viscosity of air (1.8×10^{-4}(g/cm)s)

From the above equation the attenuation for different rain rate is calculate and it is depicted in Fig. 3.

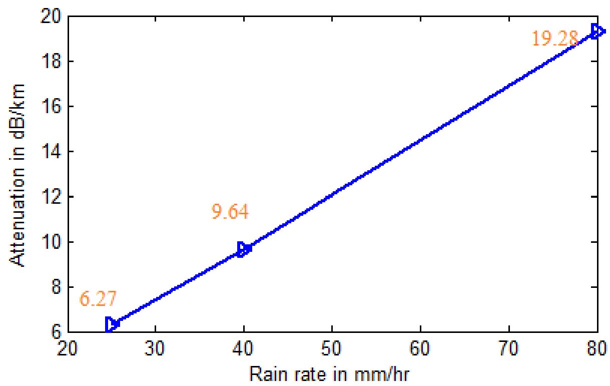

Fig.3 Attenuation versus rain rate

Snow is another important attenuation factor considered in FSO. The attenuation of the light not only depends on visibility ranges and it is proportional to size of snow particles. The snowflakes as large as 20mm have been reported [11] and large snow rate can cause link failure it is not ignorable. The FSO attenuation due to snow has been classified in to dry snow and wet snow attenuations. If 'S' is the snow rate in mm/hr then specific attenuation can be calculated by

$$\alpha_{snow} = a.s^{b} \qquad (6)$$

If λ is the wavelength, a and b are as follows for dry snow,

$$a=5.42 \times 10^{-5} \times \lambda + 5.4958776,\ b=1.38 \qquad (7)$$

The same parameters for wet snow are given as follows

$$a=1.023 \times 10^{-4} \times \lambda + 3.7855466,\ b=0.72 \qquad (8)$$

In dry snow for 1550nm, a=5.495and b=1.38. For wet snow, a=3.78and b=0.72 .The attenuation ranges for different snow rate is given in Fig. 4.

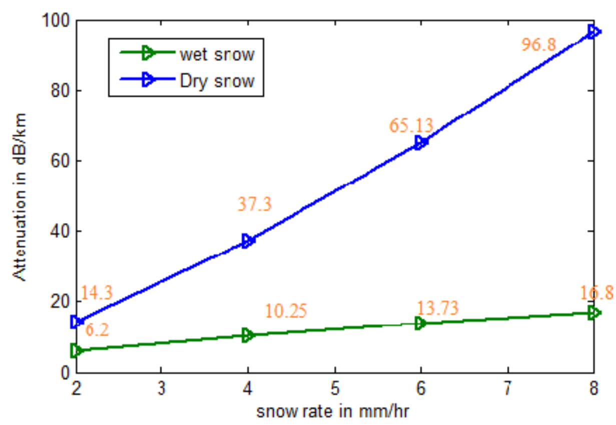

Fig.4 Attenuation versus snow rate.

III. SIMULATION RESULTS AND DISCUSSIONS

The performance of FSO system can be evaluated by Bit Error Rate with respect to the distance under different weather conditions. The effect of Bit error rate is calculated for different weather conditions for the data rate of 2.5 Gbps with respect to the transmission distance.

Fig. 5 shows the change in BER while varying the link distance. It is noticed that the BER starts to increase while increasing the transmission distance because of the increase in attenuation.

FSO link can be achieved up to 475Km with the bit error rate of 1.22×10^{-9} for very clear weather condition. In clear condition due to the precipitation of drizzle or mist travelling distance of FSO wavelength is decreased up to 172 Km. In this case BER rate is recorder as 5.8×10^{-9}.

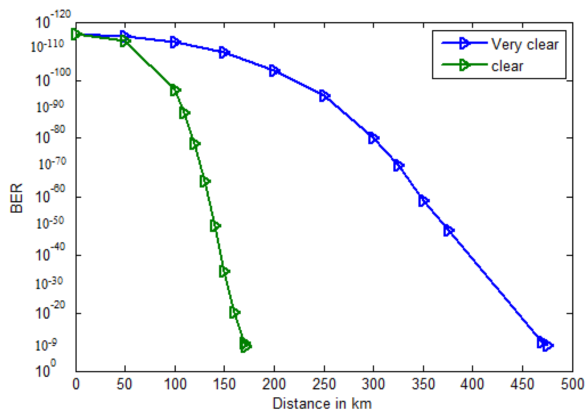

Fig.5. BER versus transmission distance for very clear and clear condition

At haze, rain and fog condition FSO wavelength is much affected with highest attenuation level. The result in BER, distance becomes 6.6×10^{-9} and 84 Km at light haze condition. At heave haze condition BER of 1.95×10^{-9} with the distance 24 Km achieved. The variation in BER, while increasing the transmission distance is shown in Fig. 6.

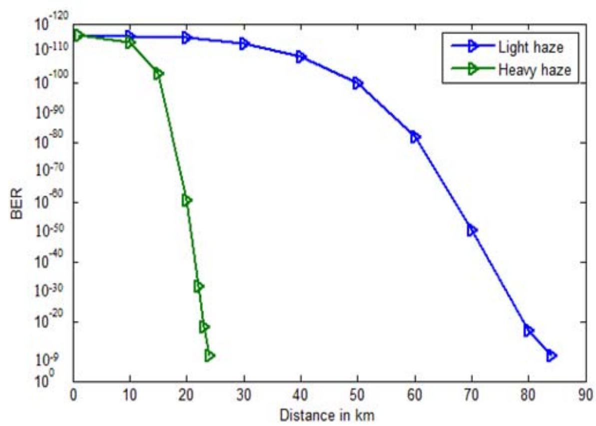

Fig.6. BER versus transmission distance for Haze condition

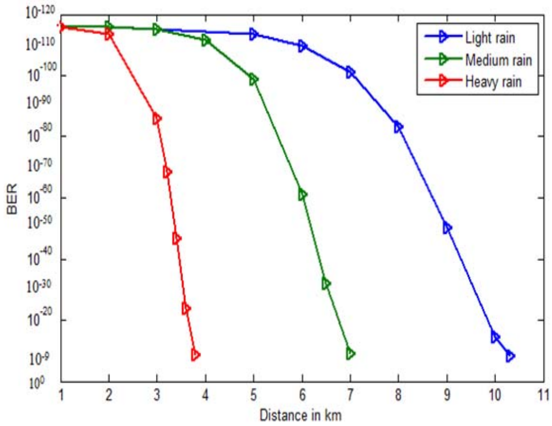

Fig.7. BER versus transmission distance for Rain condition

In light rain condition, the system could be achieved up to 10.25 Km with 2.99×10^{-9}. For the medium rain, the link range is fulfilled up to 7 Km with 1.027×10^{-9}. Finally, in heavy rain condition 3.8 Km with 1.83×10^{-9} is achieved as shown in Fig. 7.

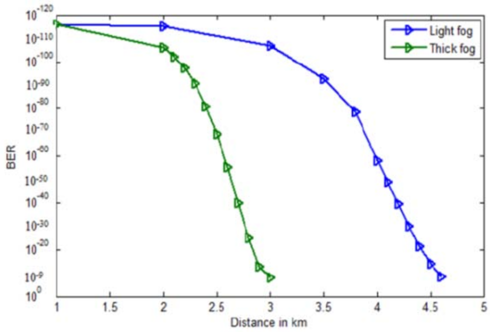

Fig.8. BER versus transmission distance for Fog condition

The BER rate of 3.03×10^{-9} is obtained for 1550nm at a distance about 4.6 Km for light fog. For thick fog the BER rate 1.95×10^{-9} is obtained for 3Km which is presented in Fig. 8.

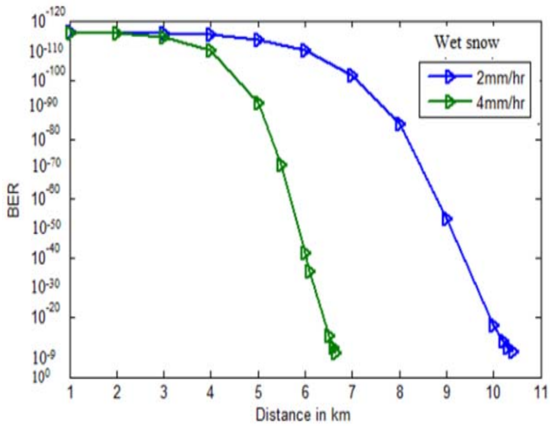

Fig.9. BER versus transmission distance for wetsnow

The Fig. 9 depicts the responce of BER $1.5\text{X}10^{-9}$ about the distance 10.4 Km for the snow rate of 2mm/hr.BERof 4.47×10^{-9} is achieved for the distance 6.7Km at snow rate of 4mm/hr.

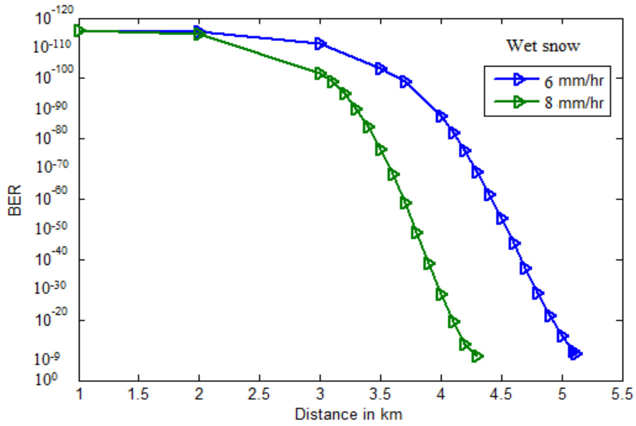

Fig.10.BER versus Distance for wet snow

The BER 1.9×10^{-9} is obtained for the distance 5.2 Km (6mm/hr) and 8.6×10^{-9} is obtained for 4.27 Km(8mm/hr) which is shown in Fig. 10.

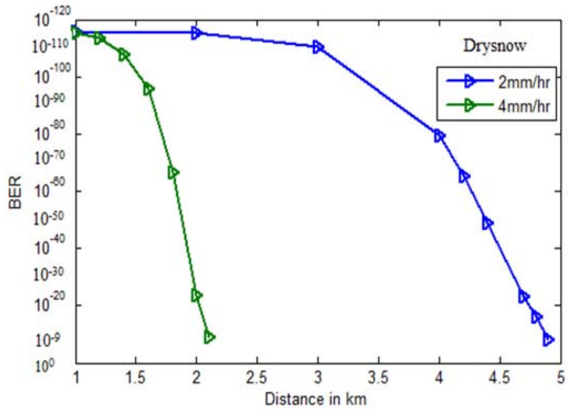

Fig.11. BER versus transmission distance for drysnow

In Fig.11, the effect of BER is calculated for dry snow at 2mm/hr and 4mm/hr. For snow rate 2mm/hr the BER value is 6.33×10^{-9} and distance is 4.9 Km.For snow rate 4mm/hr the BER,distance value becomes 1.12×10^{-9} and 2.1 Km

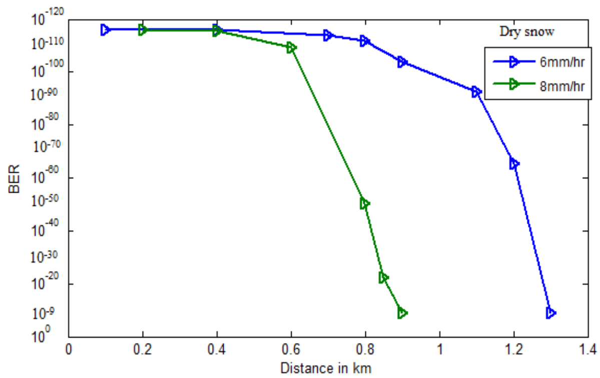

Fig.12. BER versus transmission distance for drysnow

Fig. 12 shows that the BER variation for dry snow at 6mm/hr and 8 mm/hr. The BER rate of 1.23×10^{-9} is obtained for 1550nm at a distance about 1.29Km for light fog. However, for thick fog the BER rate 1.93×10^{-9} is obtained for 0.9 Km. From the simulation it is investigated that the transmission distance varies for different atmospheric weather conditions because of attenuation.

IV. *CONCLUSION*

Free-space optical communication with various atmosphere conditions is now under active research area. In this paper, the performance of the system is analyzed for various atmospheric conditions such as air, haze, rain, fog and snow. The changes in bit error rate for different atmospheric condition while varying the transmission distance is investigated. It is observed that the link distance is decreased while increasing the attenuation. It is noticed that the snow is a highest attenuation factor in that dry snow significantly reduces the distance less than 1km.However in clear weather condition communication link of 475 km with 2.5 Gbps data rate has been successfully achieved.

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