Investigation of the range of signal under different atmospheric conditions in FSO communication employing spatial diversity

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Transmission speed of free space optical communication (FSO) is in Giga bits per second with low complexity of the system. As these links depends on the atmospheric conditions only, so the signals get suffered from weather conditions. Moreover, when fading of the signal increases under weather conditions, then the efficiency gets reduced. In this work FSO communication under different atmospheric situations has been investigated using spatial diversity for communicating multi channels on FSO. Maximum communication ranges with 10dB/km, 20dB/km, 40dB/km, and 70dB/km attenuation of signal at 1550nm wavelength having data rate 10Gbps has been investigated at high input power of order of 10 W. We have analyzed the results in terms of Q-factor, BER and eye diagram. Results obtained indicate high Q-factor, minimum BER and clear eye diagrams. Results indicate at 1550 nm wavelength, the fading of signal is less through the atmospheric channel. In addition, absorption and scattering, the two main factors responsible for fading of signal, have been mitigated using the spatial diversity technique.

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1. Introduction

In the recent years FSO has drawn significant attention of researchers worldwide due to its high data rate, low set up complexity, security and license-free transmission [1-3]. FSO communication is the new generation technology [4-5] used for wireless communication and it is a very good replacement of radio frequency. Although RF wireless networks have data rates of up to some hundred Mbps, high increase in users' traffic, range limitations and little available bandwidth, so RF technology won't full fill the necessity of the most recent technology [6]. FSO is a full duplex optical transmission using free space medium and depends primarily on ASK modulation [4]. The importance of FSO can be well gauged from it by the National Aeronautics and Space Administration (NASA) for deep space applications in NASA's Mars Laser Transmission Demonstration (MLCD) program [7]. European space agency also used the FSO communication for space communications in the Semiconductor Laser Inter-satellite Link Experiment .Though FSO communication system is designed to provide higher bandwidth, faster and secure transmission over the conventional systems, it is limited to the short range communications [7-8]. This is largely because of its extreme dependence on transmission conditions including the atmospheric turbulence, winds, weather extremities and also presence of high rise buildings in the surroundings [1,3]. Any conditions responsible for causing the deformation in the amplitude of the signal leads to the deteriorated FSO performance. Primarily the atmospheric conditions responsible for signal fading have been identified as rain, snow, haze and fog. Due to this atmospheric fading transmitted signal is absorbed and scattered in atmosphere that results loss of data signal before receiving at receiver end [7].To overcome fading within the signal, an amplifier will be accustomed to amplify the signal for long distance transmission. Many programs have been introduced to increase range of the signal, but this adds significantly to the complexity of the system one such modulation technique can be used to increase the performance of the system [6]. Over the years number of techniques have been explored to mitigate the effects of atmospheric conditions on FSO transmission and get enhanced performance over longer distances [1,3,9]. To mitigate the effects of atmospheric extremities aperture averaging [10] or employing diversity [11] at the receiver have been explored. Spectrum slicing wavelength division multiplexing (SS-WDM)-based FSO systems have been proposed to improve link range, high capacity, and efficiency of the system [12]. Spatial-mode multiplexing (SMM) for practical free-space optical communication (FSO) systems using direct detection assuming mutually coherent channels achieving significant in outage probability [13]. Hybrid Channel coding for OFDM –FSO 16 QAM based system has shown increase of 5 dB in SNR as compared to solo LDPC(low density parity check) and 7 dB as compared to TCM(transmission control module) alone [14]. Khajwal et al. [15] analyze the performance of

FSO-SISO (Single Input Single Output) and FSO-WDM systems under various conditions of atmosphere. The quality of the received signal has been studied as a function of beam divergence, transmission-range and transmitted-power for Clear Air, Haze, Moderate Fog and Heavy Fog conditions.

Of the most recent works performance of spatial diversity for FSO in the presence of pointing errors has been investigated [16]. Since FSO is affected by atmospheric conditions a lot of current work in research has been motivated to enhance the transmission speed and distance under varied weather conditions either as FSO [17] or FSO hybrid system [18]. The results are encouraging and serve as the platform for our research. In the proposed work the focus is on using spatial diversity to communicate 4 transmission channels using FSO in an IM/DD system

2. Proposed set up

To investigate the performance of FSO under different atmospheric conditions following simulation set up comprising of 4 transmitter and 4 receiver channels has been used as shown in Fig. 1.

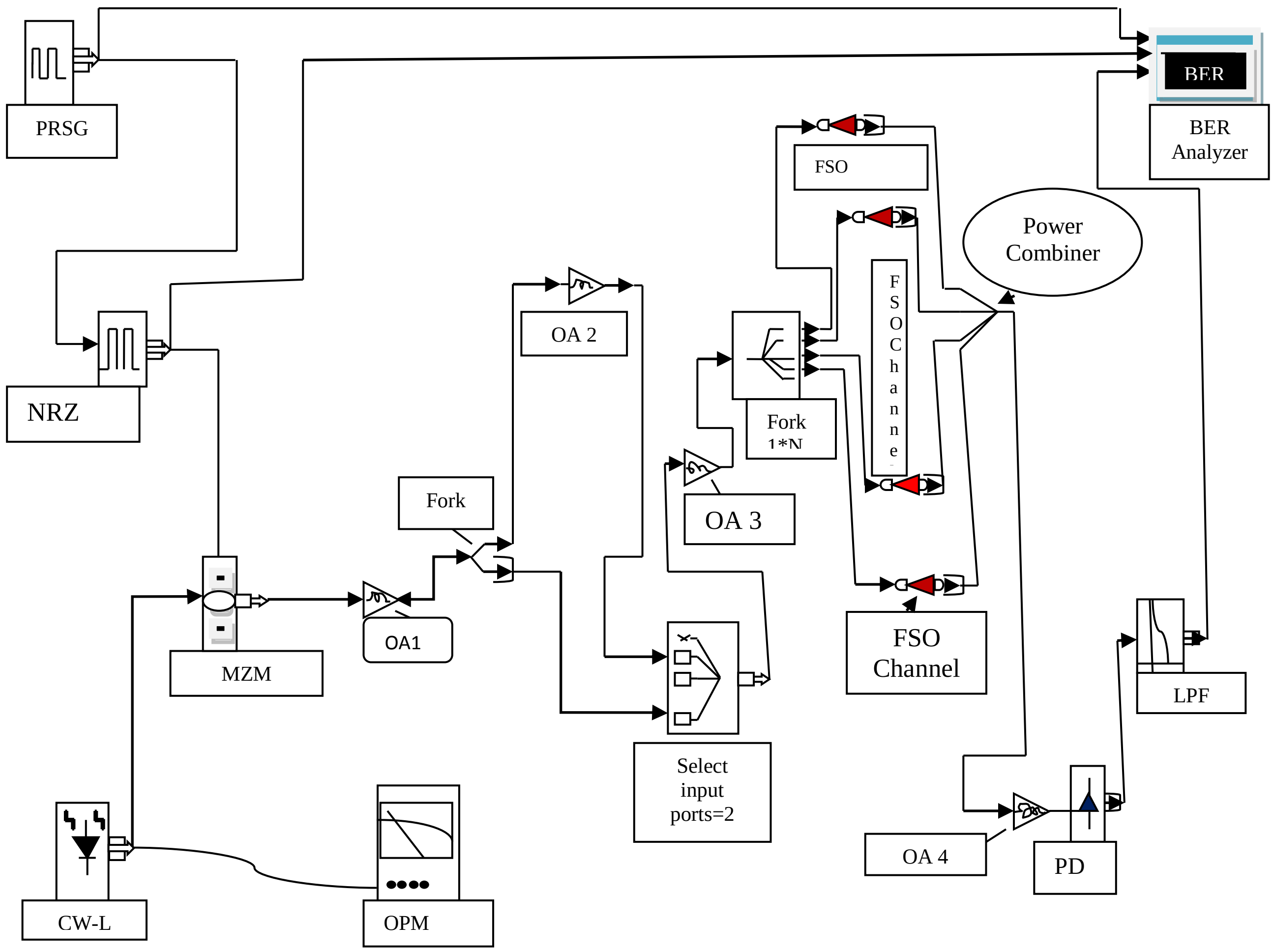

Fig. 1. Set up for analysis of FSO; PRSG-pseudo random bit sequence generator, MZM: Mach Zender modulator, OA-optical amplifier, PD-photo detector, LPF-low pass filter, CW-L continuous wave laser, OPM-Optical Power Meter

The main components used in transmitter side are a pulse generator, a bit sequence generator, MZM modulator, a CW Laser, a power meter, a spectrum analyzer, a select switching system, and EDFA optical amplifiers. The gain of the OA used is 20 dB with noise figure of around 4 dB. The Pseudo random bit sequence generator is used to produce a bit sequence of pseudo random bits at the rate 10 Gbps. The bit sequence is linked to a binary sequence visualizer in order to see the output bit sequence. This bit sequence is then fed to Non-Return to Zero(NRZ) pulse generator and output is obtained in the form of coded electrical signals.

Amplitude of the optical wave generated is modulated using an Mach-Zehnder modulator (MZM) with inputs from CW laser at 1550 nm with input power of 10 W and NRZ coded pulses from NRZ pulse generator at 10 Gbps.. Optical power meter measures the power of the optical signal used for transmission, the spectrum analyzer analyzes the spectrum of transmitted signal. The fork has been used to send the signals along two paths- one connected to the amplifier when the signal is to be sent over long distance while another without using additional amplifier for short distance transmission. The number of amplifiers used can vary in accordance with the transmission distance. If the receiver is near to the transmitter, then the selected path of the signal is without amplifiers because no amplification of the signal is required in short range transmission. As the transmission distance increases, the transmitted signal always chooses the amplifier path in order to maintain the good signal quality. As amplifiers are used to increase the distance of the transmission signal, the intensity of the signal is increased and helps overcome the loss in signal quality due to effects of atmosphere. Wireless channels have more signals fading relative to wired channels because environmental influences cause the signal to fade significantly.

The overall fading of the signal is calculated as [1],

$$\alpha_{Total} = \alpha_{Fogy}.\ \gamma+\alpha_{Snow}\gamma+\alpha_{Haze}\gamma+\alpha_{Rainy}\gamma+\ \alpha_{Mist}\gamma,\ \text{dB/km},\ (1)$$

where α is the fading constant and γ is the normal wavelength in micro meter.

On the receiver side the set up comprises of power combiner, optical amplifiers, image detector, LPF, PD, and BER analyzer. The photo diode used is APD(Avalanche photo diode) with responsivity of 0.8 A/W and the cut off frequency of LPF has been optimized at 0.6* bit rate. The Power combiner is used to combine all FSO channel signals. Similar to the transmitter side an optical amplifier is used to amplify the signal to increase the signal strength [19] before being fed to the PD.

The optical signal is converted into an electrical signal using the photo detector. The low pass filter has cutoff frequency set to stop the high frequency signal and allows only the low frequency signal. To increase the range of the signal optical amplifiers have been employed. The BER and Q-factor of signal will also improve as a result. FSO systems are affected by the atmospheric conditions causing some errors in the system which in turn render the system unusable for some time. In general the disappearance in the FSO communication signal is caused by aberrations caused by water vapor, water droplets (rain, snow, mist and fog) as well as due to the destruction of the environment such as flash and beam spreading. These atmospheric situations affect the quality factor and the bit error rate, as well as the range of the signal. The main damage on the FSO communication due to such turbulent atmospheric situations, causes the received signal to fluctuate, thereby reducing the performance of the FSO signal [20]. Nevertheless FSO communication systems have been designed to perform under the various atmospheric situations in many cities and rural areas which also have varying geographical location [21]. Atmospheric disturbance, such as fog and rain, affects transmission signal strength in a number of ways, including signal extraction and signal dispersion. Additionally some other factors responsible for the fading of the signal as geometric fading tend to further increase the error in the signal. For best results, the highly directional and narrow beam of light transmitted through the FSO communication system must be projected onto the telescope's receiver aperture on the receiver side of the transmission connection. Optical sources such as CW lasers transmit more than one beam of light which is usually scattered as the distance increases due to laser source bifurcation. The geometric fading as beam outspread separation increases with the range of the signal. As a result of which the transmitted light beam will not collect completely on the receiver's telescope, in which some of the light beam will be lost due to dispersion. So the narrow beam sources should be preferred. The quality factor of signal is defined by the diagnostic noisy pulse. The eye pattern oscilloscope will generates a report about the amount of Q factor. There are mainly two methods used to determine the quality factor of the sent signal.

The BER are going to be calculated from the SNR of the received signal [22-25].

$$\mathrm{BER} = \frac{2\times e^{\left(\frac{-\mathrm{SNR}}{8}\right)}}{\pi\times \mathrm{SNR}} \tag{2}$$

$$\text{I.}\ \mathrm{Pe} = \frac{1}{2}\,\mathrm{erfc}\left(\frac{Q}{\sqrt{2}}\right) \tag{2a}$$

$$\text{II.}\ X = \frac{|\mu 1-\mu 0|}{\sigma 1-\sigma 0} \tag{2b}$$

where Pe-probability of error, Erfc-complementary error function, Q-quality factor
$\mu 0$ - level 0 bit ; $\mu 1$- is level 1 bit; $\sigma 0$-standard deviation for bit'0' ;$\sigma 1$-is standard deviation for bit '1'.

3. Proposed work

In this paper the spatial diversity technique has been used to upgrade FSO communication to increase the range of signals in numerous atmospheric situations like fog, rain, snow and haze. The analysis of spatial diversity and its effect on BER has been done in recent work[11,16]. Execution of FSO communication depends on fading of the data due to atmospheric conditions. The proposed work has been investigated to see how the environmental effects will have an impact on the range and quality of the signal. Performance of the different weather conditions like rain, haze, snow and fog with NRZ modulation formats has been analyzed in this paper. Data rate of optical transmitter is 10 Gbps. CW laser with narrow bean has used as an optical source and the power of CW laser is set high at 10 W and wavelength of the CW laser is set as 1550 nm. The attenuation is set for different atmospheric conditions such as 70dB/km for Fog, 40dB/km for Snow, 20dB/km for Haze, 10dB/km for Rain. Accordingly as per to the atmospheric conditions, the communication range of system is optimized to get a good quality signal The Quality factor, BER, transmitted power and received power have been used for evaluation of the proposed system.

4. Investigation and results

Under the given system designed to investigate the performance of an FSO system the results have been tabulated in Table 1. As the attenuation increases the range increases which is as expected. But similar monotonous trend cannot be observed in the Q factor and BER with decreasing attenuation. This is primarily because apart from the losses quantitatively measured as attenuation the prevalence of the weather condition itself is critical to FSO performance. To achieve the lesser attenuation in our set up the optical amplifiers has been increased. By increasing the optical amplifiers the signal strength increases and signal is able to have a longer reach. In case of the 10 dB/km attenuation. The results after three more optical amplifiers have been added but still it does not guarantee the best Q factor. So adding amplifiers are neither a cost effective solution nor it gives the best performance. If for 10 dB/km the range of the signal is increased from 9 km to 15 km, the BER of the received signal is 1.196 X e^{-81} and Q-factor is 19 which is even lesser than 70 dB/km attenuation.

Table 1. Results achieved

Atmospheric conditions	**Attenuation(db/km)**	**Signal Range(km)**	**BER**	**Q factor**
Foggy	70	1.55	5.75 X e^{-109}	22.13
Snow	40	2.5	1.398 X e^{-213}	38
Haze	20	5	1.3 X e^{-71}	17.85
Rainy	10	9	3.013 X e^{-250}	33

4.1. Under fog atmospheric conditions

The optical signal is most affected by the foggy atmospheric condition. Due to this range of the signal will be shorter. In Fig. 2 the range of the signal is 1.55 km and fading is 70dB/km. This is the maximum distance achieved with proposed optical design in foggy conditions [26].

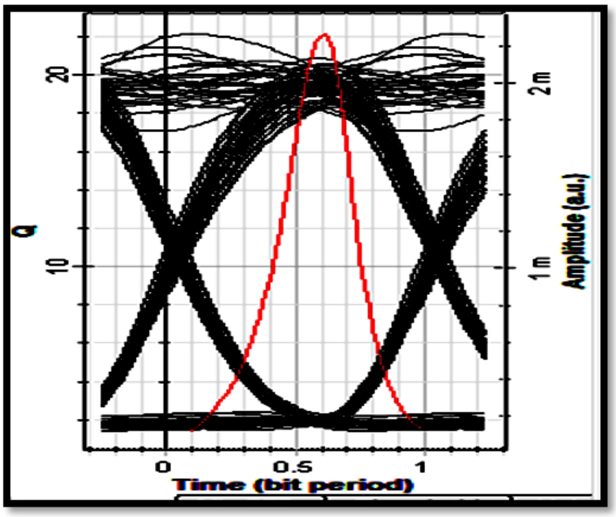

Fig. 2. Eye diagram under foggy conditions (color online)

4.2. Under snow atmospheric conditions

Snow in the environment has a greater effect on the signal than rain and haze but less than fog [27]. In Fig. 3 the fading of signal in the snowy condition is 40dB/km and the transmission range of the signal is 2.5km which is higher than the foggy condition. This is the maximum distance achieved with proposed optical design in the snowy conditions.

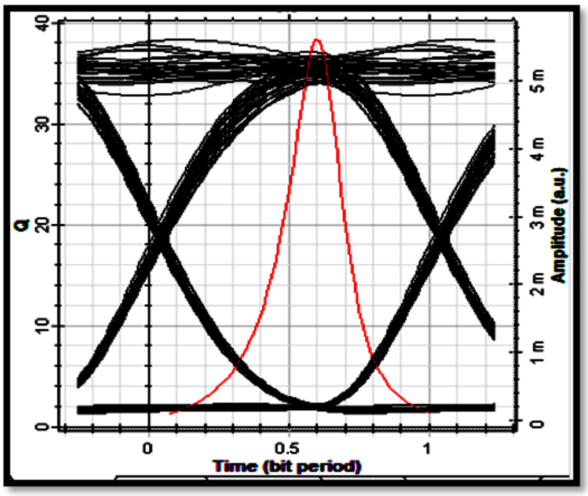

Fig. 3. Eye diagram under snowy conditions (color online)

4.3. Under haze atmospheric conditions

The hazy atmospheric situation affects the signal more than the rainy situations but less than the foggy and snowy condition. In Fig. 4 the fading of signal in the hazy condition is 20dB/km and the transmission range of the signal is 5km which is higher than the foggy and snowy condition [28].

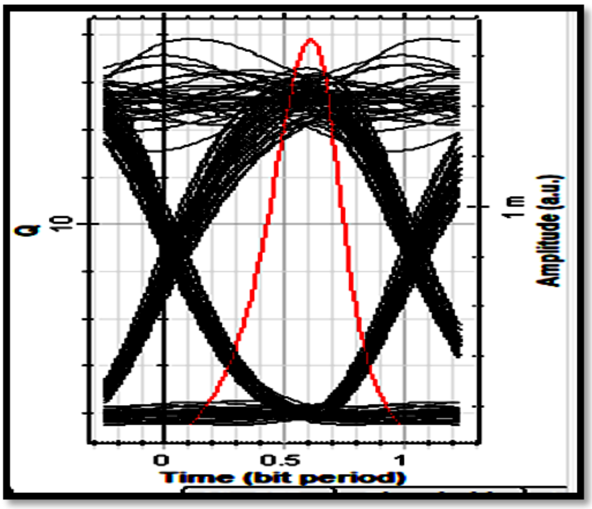

Fig. 4. Eye diagram under hazy condition (color online)

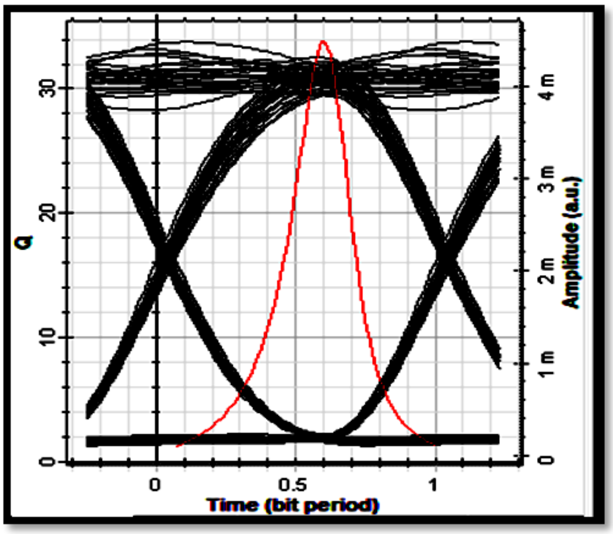

Fig. 5. Eye diagram under rainy condition (color online)

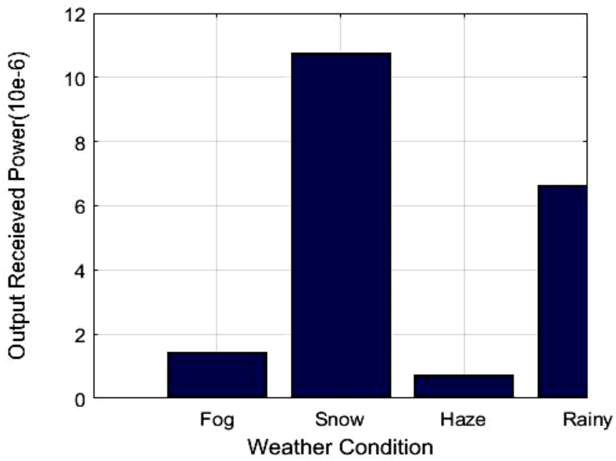

Fig. 6. Received power (W) under four different atmospheric conditions (color online)

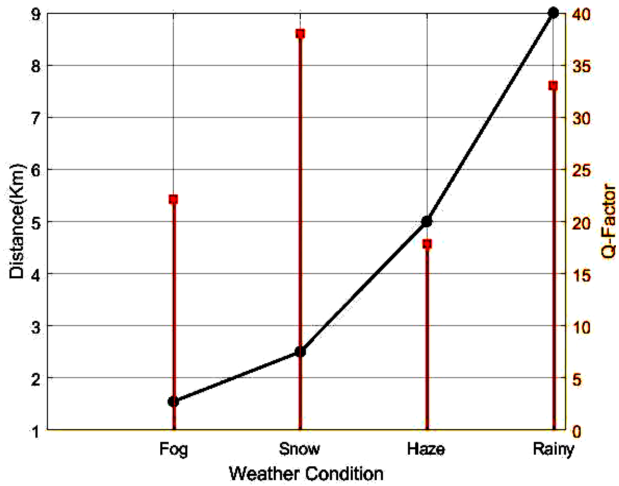

Fig. 7. Distance and Q-factor for different weather conditions (color online)

4.4. Under rain atmospheric conditions

Due to the water droplets present in the rain, some of the signals that fall on it are scattered and some observations are made [29]. This causes the signal fading to be less than at other atmospheric conditions. In Fig. 5 the fading of signal in the rain condition is 10dB/km and the transmission range of the signal is 9 km which is higher than the foggy, hazy and snowy condition.

The results in Fig. 6 represent the power as received under the four different atmospheric conditions. Fig. 7 shows distance and Q-factor plots for different weather conditions employing the proposed spatial diversity FSO channel. As can be seen the results in Figs. 6 and 7 show agreement with haze showing the minimum Q-factor as well as the minimum received power for uniform input power of 10 W for all the conditions. The use of Optical amplifiers plays a crucial role in increasing the transmission distance. Under the rainy conditions if three additional optical amplifiers(EDFA) with net gain of 20 GB are employed in cascade as pre-amplifiers the transmission distance increases from 9 km to 15 km with output received power also increasing from -21.213 dbm to -29.213 dBm. This can be well observed from Fig. 8.

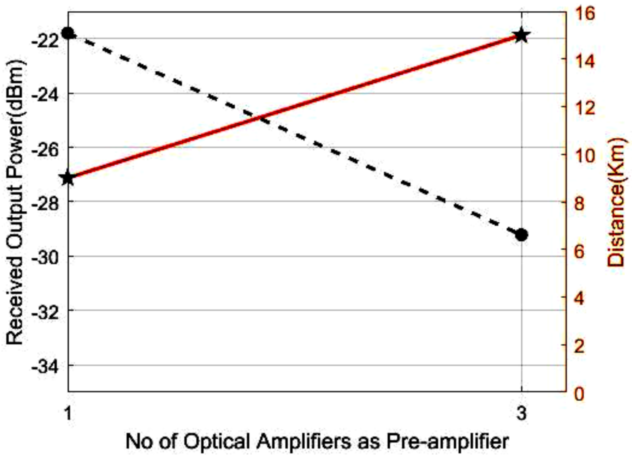

Fig. 8. Distance and output power for rainy weather for different number of optical amplifiers (color online)

But use of Optical amplifiers adds to cost of the system and also make it bulkier. So an optimum choice has to be made between distance and number of optical amplifiers.

5. Conclusion and future scope

Even if the FSO offers attractive features, its transmission range is mainly dependent on the weather situations, which weaken the transmitted signal. This article has proposed a sequential elevation algorithm and improved optical transmission link design to reduce atmospheric conditions. The improved optical connections enhance the potential of system due to this transmission range and Q-factor of the signal will be increases and BER will be minimized under discrete atmospheric situation like haze, fog, rain and snow. When fading of signal increases range will decrease, as explained earlier in this paper, if the fading decreases to 10 dB/km, the signal range increases to 9 km and if the fading is 70 dB/km, the signal range is reduced to 1.55 km. Results show the longer transmission range, with good higher Q-factor, and lower BER are a challenge for FSO system. FSO industry has good future, probably the best overall prospects are in the space, where progress is being made to improve acquisitions and tracking

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Authors' contributions

Anil Kumar Rao conceived the project and implemented and tested the set up. Dr. Hardeep Singh with support of Dr. Gaganpreet Kaur and Dr. Ravi Kumar supervised this overall project.

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