Improving Performance of Free Space Optics Link Using Array of Receivers in Terrible Weather Conditions of Plain and Hilly Areas

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***Abstract*—Free-space optical (FSO) communication is a cost effective and high data rate access technique, which has been proving itself a best alternative to radio frequency technology. FSO link provides high bandwidth solution to the last mile access bottleneck. However, for terrestrial communication systems, the performance of these links is severely degraded from atmospheric loss mainly due to fog, rain and snow. So, a continuous availability of the link is always a concern. This paper investigates the dreadful weather effects such as rain, fog, snow, and other losses on the transmission performance of FSO systems. The technique of using an array of receivers for improving the performance of FSO links is explored in this paper. It involves the deployment of multiple photo detectors at the receiver end to mitigate effects of various weather conditions. The performance of the proposed system is evaluated in terms of bit error rate, received signal power, Q- factor and height of eye diagram. The influence of various weather conditions of plain and hilly areas are taken into consideration and results are compared with conventional FSO links.**

Keywords—Free space optics (FSO) communication; Array of photo detectors; Bit Error Rate (BER); Eye diagram; Quality factor (Q factor); Bad weather effects

I. INTRODUCTION

The optical wireless communication (OWC) systems have attracted a lot of interest of the users because they can solve the last mile problem in urban environments. OWC, also recognized as free space optical (FSO) communication, has emerged as a commercially feasible alternative to radio frequency (RF) and millimetre waves wireless communication for reliable and rapid deployment of data and voice networks. FSO communication using high bandwidth transmission links has enormous potential to serve for requirements of high data rate transmissions. License free bandwidth, high carrier frequency (range 20 THz- 375Thz), easy deployment, appreciable security of data, avoiding electromagnetic pollution, low power consumption enables FSO links to provide high data rates communications[1]. Its various advantages over existing Radio Frequency (RF) technologies like wider bandwidth that can support a large number of users without any delay or interference in communication, have increased its demand in the market.

Despite of being on the list of most desirable technologies of the next generation, its deployment is highly dependent on atmospheric variations thus related to its reliability and availability issues. Fog, snow and clouds scatter or absorb the optical signal, which causes transmission errors. Maintaining a clear line of sight (LOS) between transmitter and receiver is also one of the major challenges in establishing optical wireless links in the free space [6]. The LOS is disturbed due to atmospheric influences like fog, rain, snow, dust, sleet, clouds or temporary physical obstructions like birds and airplanes. Various researchers have come up with the results that optical attenuation can reach up to 128dB/km in heavy fog and snow conditions in different areas [7]. The scattering, absorption and refraction of light signals reduce the link capacity and availability in different weather conditions.

To lessen these effects, techniques like using multiple transmit lasers and multiple receive apertures can be applied [8-9]. The performance of FSO links in the presence of atmospheric turbulence had been analyzed using spatial diversity [10-11]. To calculate the error rate performance, outage probability and diversity gain for multi-input multi-output FSO links, the combined effect of atmospheric turbulence and misalignment was also considered [12-13]. Then the effect of weather conditions was taken into account using array of receivers [14-16].

But the effect of weather conditions of hilly areas like heavy fog, wet snow, dry snow etc was not discussed by researchers in previous literature. The consideration of these parameters cannot be ignored while installation of FSO link especially in hilly areas. In this paper a comprehensive analysis of FSO link in all weather conditions has been performed using one of the most important approaches of array of photo detectors to reduce the effects of attenuation on received signal. At an ideal case, the only cause of signal attenuation is distance of transmission. So, the additional losses we have taken into account are due to weather conditions only and other losses are considered to be 0 dB/km. The study of bit error rate, height of eye diagram, Q factor and maximum received power is taken into account for studying the performance of FSO link.

The paper is organized as: After the introduction of FSO systems, system analysis of proposed FSO model is provided and various parameters that affect the quality of the signal in the link are discussed in section II. In Section III, the results obtained after simulations are evaluated for both hilly and plain areas using array of receivers. Finally, conclusions are drawn in Section IV.

II. System Analysis

A synoptic diagram of the considered system model is depicted in Figure 1 below. The block diagram shows the three key function elements of FSO system that are the transmitter, the atmospheric channel and the receiver. The transmitter which is used for converting electrical signal into optical signal consists of a modulator, a laser driver, a laser and a power meter.

The modulator used in the link converts the information into the desired signal and controls the amplitude of an optical signal. Laser driver provides the power to the laser for its proper functioning and helps to prevent aging and other environmental effects of laser. The range of the link for evaluating the performance is chosen as 500m and the transmission wavelength chosen for the working of laser is 1550 nm which is the 3rd optical window of wireless transmission. It is chosen to work on this wavelength as the functioning of FSO link is more robust and safe for human eye at this value [2-3].

The information signal is transmitted over FSO channel where it undergoes attenuation and power loss as a result of absorption, scattering and turbulence. At the receiver end, the signal is amplified and detected by an array of receivers which improve the overall efficiency and accuracy of the system. The filter and regenerator are used to preserve the wave shape of the signal. Power meter and BER analyser are used to measure the parameters of received signal. The data rates up to 100 Gb/s can be achieved using FSO technology [4-5].

Attenuation present in the atmosphere of the system can affect its performance. Atmospheric attenuation and geometric losses constitute all attenuation. It is the effect of particles present in the air for e.g. haze, rain, fog, snow etc. These particles can stay a longer time in the atmosphere. So, attenuation values depend upon the visibility level at that time. To reduce these effects, a system is proposed that can work properly under these conditions. The value of parameters on which the system is operating is mentioned in table 1.

The total attenuation of wireless medium communication system can be estimated [17] as:

$$\alpha = \alpha\mathrm{fog}_\gamma + \alpha\mathrm{snow}_\gamma + \alpha\mathrm{rain}_\gamma + \alpha\mathrm{scattering}_\gamma, \mathrm{dB/km} \quad (1)$$

where, α=attenuation and

γ=is transmission wavelength in μm

The main attenuation factor for optical wireless links is fog, but the attenuation caused by an effect of rain cannot be ignored, especially in environments where rain is more frequent than fog.

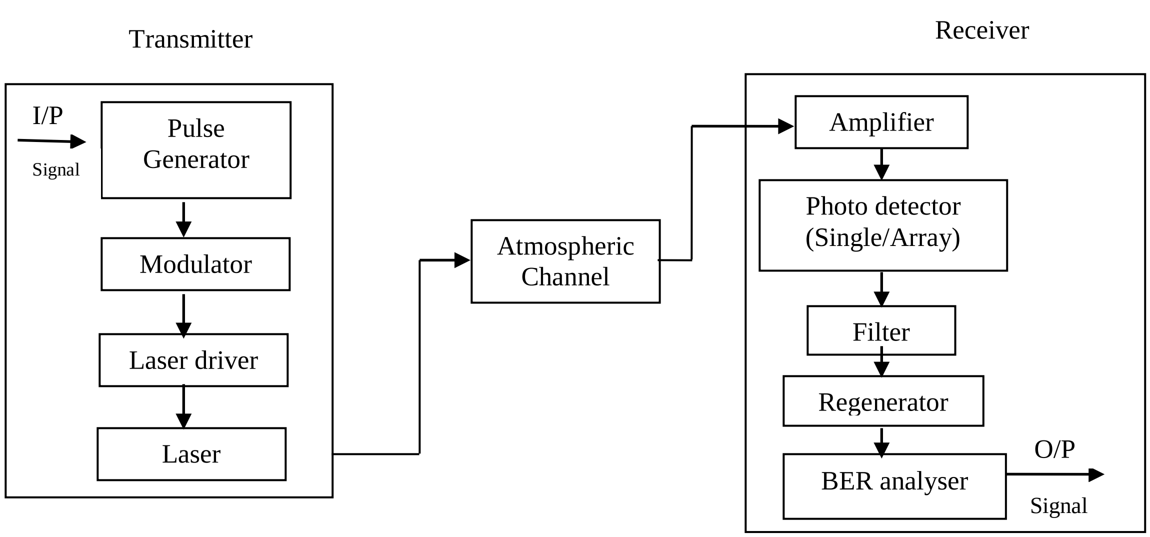


Fig. 1. Block diagram of FSO link

TABLE I. PROPOSED OPERATING PARAMETERS FOR FREE SPACE OPTICAL COMMUNICATION SYSTEMS

Operating parameters	Value
Signal transmitted power (plain areas)	1mW
Signal transmitted power (hilly areas)	20 W
Attenuation (plain areas)	0-43 dB
Attenuation (hilly areas)	110-128 dB
No. of photo detectors used	8
Range of Link	500 m
Operating signal wavelength,	1550 nm
Transmitter lens diameter	100 cm
Receiver aperture diameter	50 cm

Let R be the rain rate in mm/h, the specific attenuation of optical wireless link is given by [18]:

$$\alpha_{rain}=1.076\ R^{0.67}\ \ \text{dB/km} \qquad (2)$$

If S is the snow rate in mm/h then specific attenuation in dB/km is given by [19] as:

$$\alpha_{\text{dry snow}} = aS^{b}\ \text{dB/km} \qquad (3)$$

If λ is the wavelength, the parameters a and b for dry snow is given as the following:

$a = 5.42\times10-4\lambda+5.495876$, $b = 1.38$

The specific attenuation in the case of wet snow can be expressed as the following formula [20]:

$$\alpha_{\text{wet snow}} = h\ S^{g}\ \ \text{dB/km} \qquad (4)$$

The parameters h and g for wet snow are as, $h = 1.023\times10-4\lambda+3.7855466$, $g = 0.72$

The amount of received power is proportional to the amount of power transmitted and the area of the collection aperture but inversely proportional to the square of the beam divergence and the square of the link range. It is also inversely proportional to the exponential of the product of atmospheric attenuation coefficient times the link range [21-22].

$$P_{\text{received}} = P_{\text{received}} * \frac{d_2^2}{[d1+(D*R)]^2} * 10^{(-a*r/10)} \qquad (5)$$

Where, P = power,

d1 = transmit aperture diameter (m),

d2 = receive aperture diameter (m),

D = beam divergence (mrad), R = range (km),

a = atmospheric attenuation factor (dB/km).

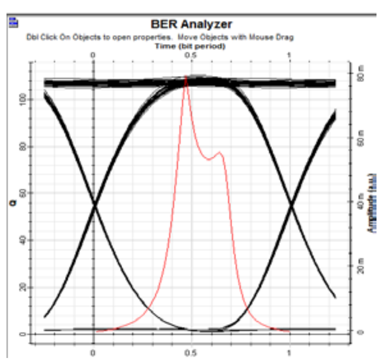
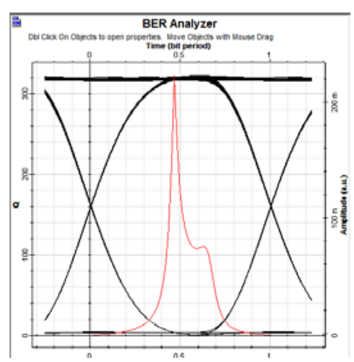
Also, the bit error rate can also be expressed in terms of signal to noise ratio (SNR) as:

$$\text{BER} = \frac{2}{\pi.\text{SNR}}.\exp\left(-\frac{\text{SNR}}{8}\right) \qquad (6)$$

III. RESULTS AND PERFORMANCE EVALUATION

The model has been investigated to show the weather effects on the transmission and overall performance on free space communication in hilly and plain areas by using single photo detector and an array of photodetectors. FSO system with link range 500m operating at a wavelength of 1550 nm is considered such that it can show useful results over a wide range of weather conditions. The values of attenuation effecting information signal considered in table 2 are taken from [6].

TABLE II. COMPARISON OF OUTPUTS OF BER ANALYSER IN PLAIN AREAS

Attenuation	Weather conditions	Output using single receiver	Output using array of receivers
0.43 dB	**Clear air**		

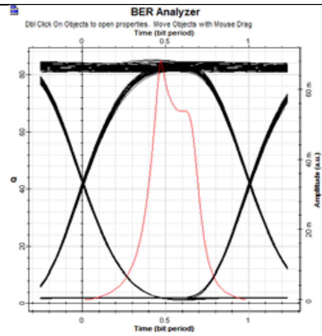
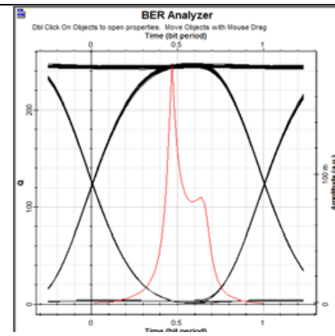
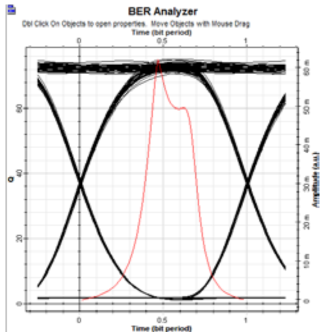
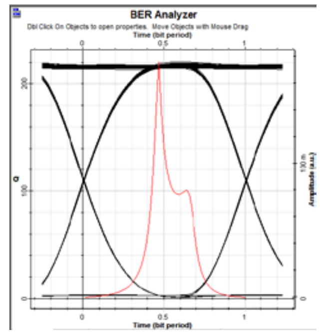
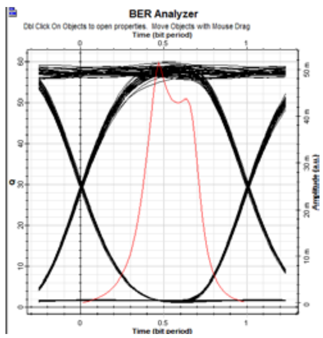
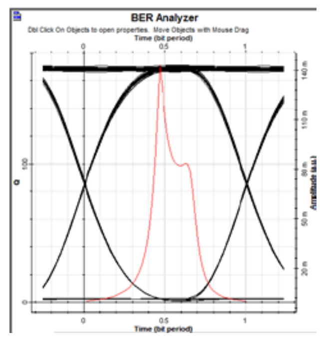
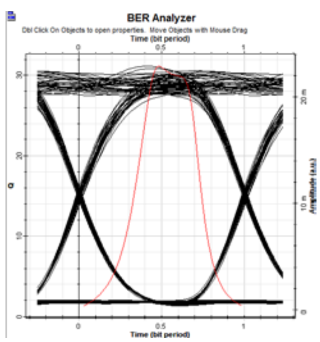
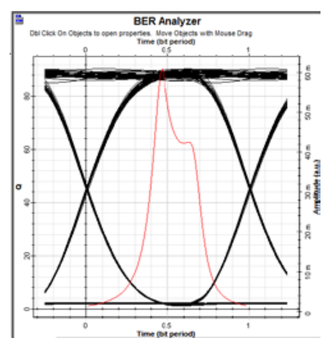
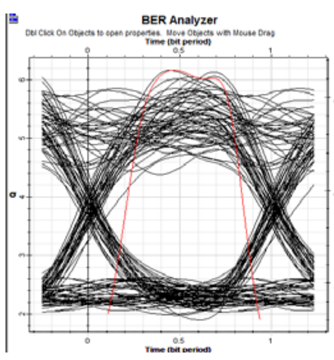
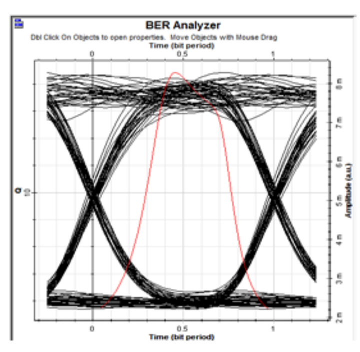
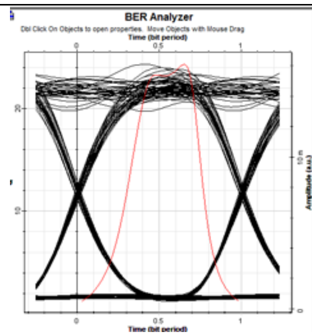
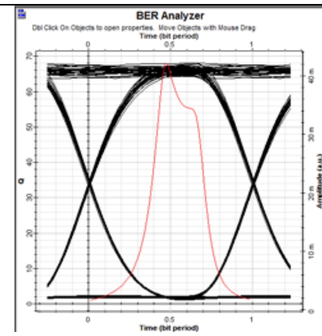
4.2 dB	**Haze**		
5.8 dB	**Moderate rain**		
9.2 dB	**Heavy rain**		
20 dB	**Light fog**		
42.2 dB	**Moderate fog**		

Table 2 shows the output of BER analyser for FSO link located in plain areas. The comparison is showing the improvement in the output when more than one receivers are inserted in the link. It can be seen than width and height of eye have increased and curve of Q factor has become sharp after using array of receivers at different values of attenuation. Figures in the table have proved that received signal power decreases with increasing atmospheric attenuation for in the presence of bad weather effects. But using an array of photo detectors has presented the highest received signal power compared to a single receiver. From the above discussion it is clear that array of receivers is giving better results in these weather conditions also. So, this technique can be further implied on the weather conditions of hilly areas too.

TABLE III. COMPARISON OF OUTPUTS OF BER ANALYSER IN HILLY AREAS

<table>
<tr><th>Attenuation</th><th>Weather conditions</th><th>Output using single receiver</th><th>Output using array of receivers</th></tr>
<tr><td>110 dB</td><td>Wet snow</td><td>
</td><td>
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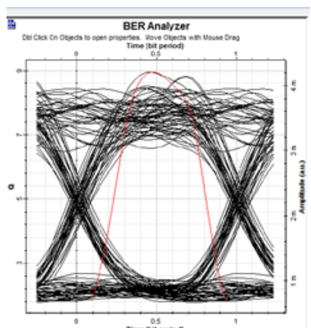
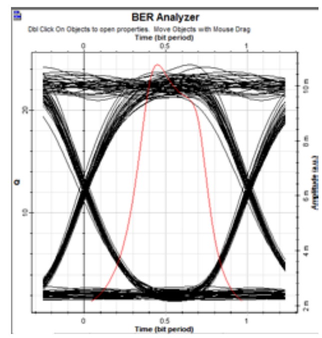
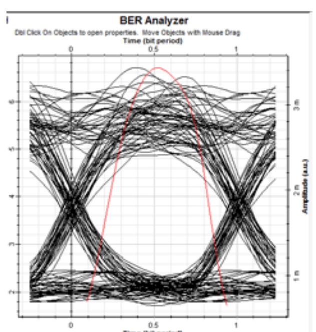
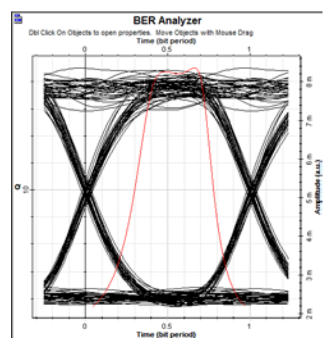
<tr><td>125 dB</td><td>Heavy fog</td><td>
</td><td>
</td></tr>
<tr><td>128 dB</td><td>Dry snow</td><td>
</td><td>
</td></tr>
</table>

Similarly, Table 3 is the comparison of the output of BER analyzer in hilly areas. The values of attenuation of the signal effecting communication considered in table 3 in taken from [7]. The value of attenuation in hilly areas is very large as compared to plain areas.

So using an array of receivers in hilly areas gives very effective results by improving values of simulation parameters far better than optimum values.

The figures show that even in high attenuation conditions FSO systems can be deployed reliably by slightly modifying the conventional FSO systems.

The system operation characteristics have been plotted under varying weather conditions using different simulation parameters. A brief comparison is made to show the improvement in all simulation parameters using more than one receiver for receiving the information signal.

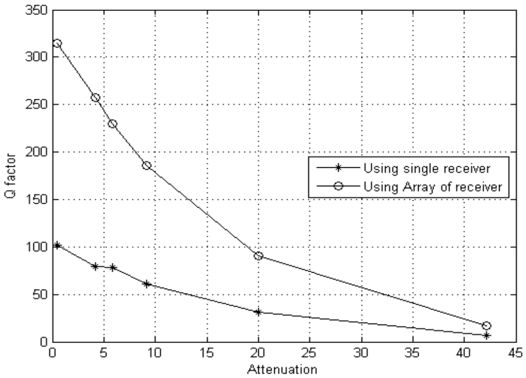


Fig. 2. Comparison of Q factor in weather conditions of plain areas using single and array of Photo detectors

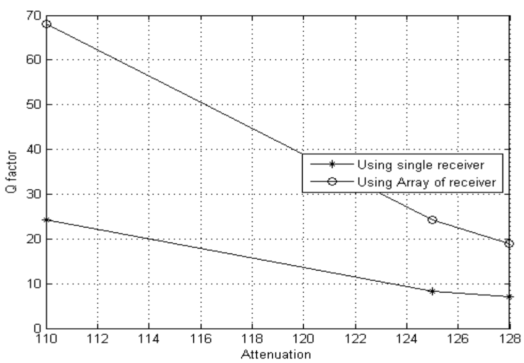


Fig. 3. Comparison of Q factor in weather conditions of hilly areas using single and array of Photo detectors

The graphs in figure 2 and 3 show the comparison of various values of Q factor of system model, as a result of using single receiver and array of receivers at different weather conditions of plain areas and hilly areas. The curve in figure 2 shows that, at transmitter power of 1mW there is a large difference in output signals of both the cases. Below 20 dB attenuation the technique employed is improving the quality of the received signal in huge ratio. After 20 dB the results start decreasing linearly with increasing attenuation and for the values above 40 dB there are not many variations in the results.

In figure 3 also, the results have assured that the Q factor of the system increases with increasing number of photo detectors in the link. It is observed that the quality of a signal received using an array of receivers is much better than the quality of the signal using single detector under different attenuation conditions. There is a significant difference in the value of Q factor at 128 dB, thus improving the reliability of the communication in bad weather conditions.

Figures 4 and 5 have demonstrated that the width of eye increases after the use of array of receivers in the link in both plain as well as hilly areas because the resultant signal is chosen such that it have maximum signal to noise ratio thus the opening of eye is more as compared to signal detected with single photo detector.

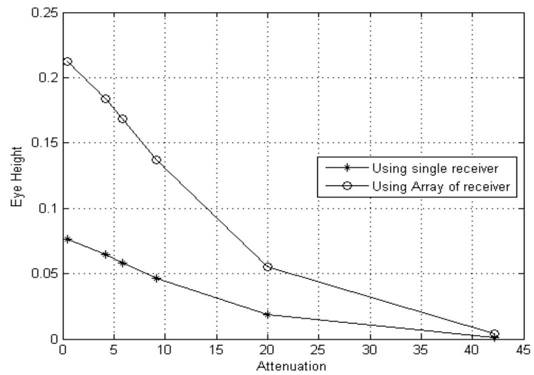


Fig. 4. Comparison of Eye height in weather conditions of plain areas using single and array of Photo detectors

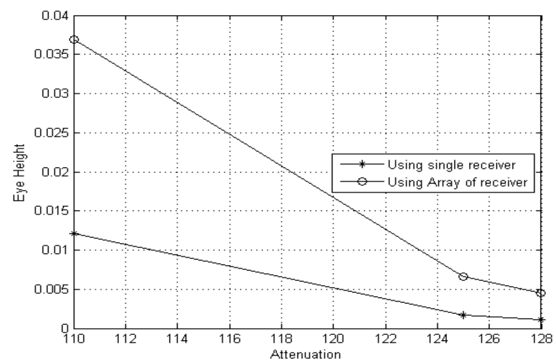


Fig. 5. Comparison of eye height in weather conditions of hilly areas using single and array of Photo detectors

In figure 4, there is a significant difference in the values before 20 dB attenuation but after 20 dB it is almost same. But figure 5 illustrates that in hilly areas using this technique is quite helpful in removing the noise and jitter from the signal.

At 128 dB, the value of eye height in the conventional system is 0.0012 which is improved to 0.0036 using array of receivers.

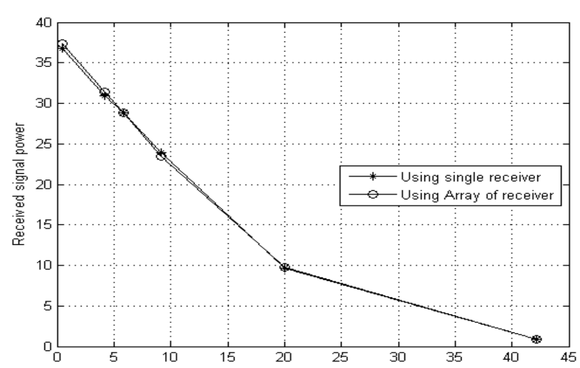


Fig. 6. Comparison of received signal power in weather conditions of plain areas using single and array of Photo detectors

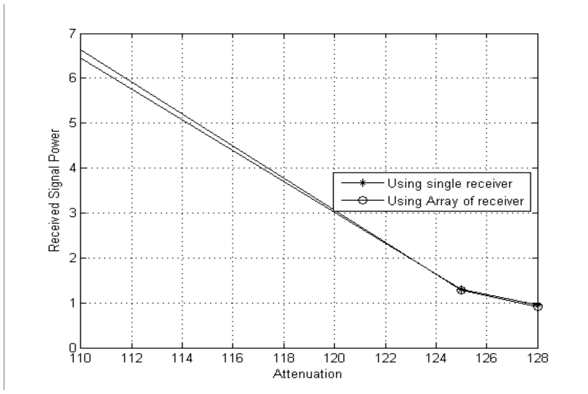


Fig. 7. Comparison of received signal power in weather conditions of hilly areas using single and array of Photo detectors

Figures 6 and 7 are indicating that with an increase in a number of photo detectors at the receiver end, there is a slight increase in received signal power because the multiple numbers of detectors are detecting the same signal independently. The final signal obtained is the maximum value of all detected signals.

Finally, a comprehensive comparison has been presented in an organized manner among the performances of links having single photo detector and multiple photo detectors in tabular form. Table 4 is illustrating the values of simulation parameters analyzed in plain areas with transmission power one mW. It can be clearly visualized that in the case of an array of photo detectors, there is a significance decrease in bit error rate. Also the values of Q factor, the height of eye and received signal power increases with the introduction of more than one photo detectors in the link.

TABLE IV. EVALUATION OF FSO LINK IN PLAIN AREAS WITH POWER 1 MW

		Max. Q factor	**Min. BER**	**Eye height**	**Received signal power(mW)**
Single photo detector	Clear air (0.43	102.192	0	0.076034	36.7936
	Haze (4.2dB)	79.0142	0	0.0647861	30.911234
	Moderate rain (5.8dB)	78.2872	0	0.0583843	28.845105
	Heavy rain (9.2dB)	60.5079	0	0.0461851	23.91591
	Light fog (20 dB)	30.7312	7.34165e-208	0.0184382	9.69035
	Moderate fog (42.2 dB)	6.93705	1.83037e-12	0.00107621	0.90622
Array of photo detectors	Clear air (0.43	314.806	0	0.21236	37.388885
	Haze (4.2dB)	257.198	0	0.183567	31.362605
	Moderate rain (5.8dB)	229.584	0	0.168624	28.845105
	Heavy rain (9.2dB)	186.242	0	0.136811	23.480854
	Light fog (20 dB)	90.6124	0	0.055339	9.8212256
	Moderate fog (42.2 dB)	17.0842	8.87462e-66	0.00437094	0.920583

TABLE V. EVALUATION OF FSO LINK IN HILLY AREAS WITH POWER 20W

		Max. Q factor	**Min. BER**	**Eye height**	**Received signal power(mW)**
Single photo detector	Wet snow (110 dB)	24.2834	1.12641e-130	0.0121424	6.4458854
	Heavy fog (125 dB)	8.19081	1.13342e-16	0.0017453	1.3038745
	Dry snow (128 dB)	7.04754	8.40774e-13	0.0011057	0.9438791
Array of photo detectors	Wet snow (110 dB)	68.0498	0	0.0369363	6.6352527
	Heavy fog (125 dB)	24.1941	2.00845e-104	0.0065796	1.2833537
	Dry snow (128 dB)	19.0077	8.40774e-13	0.0044685	0.9144441

The performance of link in hilly areas for different cases is summarized in Table 5. It shows the values of various parameters in hilly areas, where attenuation is very high as compared to plain areas. So, the power used for transmission of signal in hilly areas is 20W. The quality of received signal is improving as the values of simulation parameters are attaining optimum values.

It can be clearly visualized from the above results that as the number of photo detectors are increased at the receiver end; it is possible to obtain performance that may not be possible by using other techniques like increasing the transmitter power or aperture averaging.

IV. Conclusion

In this paper, the performance of the free space optical communication systems under the effects of bad weather conditions especially for heavy rain, fog, dry and wet snow has been analyzed. The performance of link is investigated for these conditions and is further improved by the technique of using an array of receivers. The results reveal that use of array of receivers is advantageous over that of a single receiver in FSO link for detecting the signal more accurately as the quality factor of received signal is improved by approximately 28% in all the cases under consideration. With further research and development, communication in FSO system can also be enhanced at higher data rate over a longer link range under all weather conditions and atmospheric turbulences to enhance the usage of free space optics technology.

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