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Comparative Analysis of Point to Point FSO System Under Clear and Haze Weather Conditions

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Abstract Free space optics (FSO) is an optical mean of communication where free space acts as a medium between transmitter and receiver and both should be in the line of sight for successful transmission of signal. Free space can be air, outer space, or vacuum. This system is economically beneficial than other systems and deployed in a matter of hours. This system poses great advantages like high bandwidth. There are some factors which can affect the transmission in FSO. Presence of foreign elements like rain, fog, and haze, physical obstruction, scattering and atmospheric turbulence are some of these factors. In this paper, two FSO links are designed and compared using WDM to study under clear and haze weather conditions. The present system supports the transmission up to longer link distances of 350 and 47 km under clear weather and haze conditions respectively.

Keywords Free space optics (FSO) · Wavelength division multiplexing (WDM) · Bit error rate (BER) · Link distance · Attenuation · Laser power

1 Introduction

Free space optics (FSO) system grows as studies continue on its applications [1]. The transmission is done in air rather than glass so speed of transmission is more. Hence, FSO is classified as optical communication at the speed of light [2]. This technology delivers communication in less economy as it requires one fifth of the cost normally required in the ground base optical fibre system. The system can be set up in a matter of days [3]. Line of sight (LOS) is needed to establish a seamless communication link in an FSO system [4]. It offers many advantages like, high data rate, no RF license, no security upgrades, immune to RF interference, low power, increase in system bandwidth and much more [4–7]. Optical links in which FSO communication can be employed are: building to building, ship to ship, aircraft

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to ground and satellite to ground [1]. FSO benefits in wide area space networks. It not only serves as a backbone network for high speed Trunking but also supports the mobile users and high speed data services for small satellite terminals [8]. FSO system also has some limitations which caused system degradation [9]. Link availability is a key issue in FSO system deployment [10]. The line of sight of optical trans-receiver can comprise link availability but there are other factors also like atmospheric attenuation, scattering phenomena [2], multipath fading [8], absorption, turbulence along with link distance, laser wavelength and data rates [9]. Due to these factors the signal deteriorates at receiver and link performance is also deteriorating [5]. The attenuation effect can be the combination of geometric losses as well as atmospheric attenuation. Geometric loss or scattering is due to the raindrops and snow which are having large molecules. This impact is same as that of Raleigh scattering. Atmospheric attenuation is normally the resultant of fog and haze mostly but it also depends upon dust and rain [9]. Carbon dioxide (CO2) and water vapour (H2O) in the air can cause absorption along the transmission [11]. Turbulence is another factor to be considered in FSO system transmission [12]. Differential heating produces random fluctuations in refractive index of the air. These fluctuations cause the effect of intensity fluctuations in the received signal, the refocusing of beam, and the spreading of transmitting beam at the end [9]. The bit error rate (BER) and maximum quality factor (Q) of any system help in realizing the quality of transmission [2]. A BER of receiving data increases with the increase in attenuation and a decrease in transmission power [11,13]. The noise in the signal can also be determined by analysing the performance of the FSO link which can be analysed in terms of receiving power, BER and eye diagrams [4].

A WDM system is designed to overcome the challenge of FSO signal degradation due to atmospheric turbulence to achieve high data rate and longer link distance [9]. The proposed system is an improvement over the existing system. It is based on optimization of different parameters to increase the system performance under clear weather condition and haze weather condition. The block diagram of the unidirectional WDM system is shown in Fig. 1.

The wavelength-division multiplexing (WDM) is a technology where a number of optical carrier signals are multiplied having different wavelengths of optical beam of laser.WDM offers bidirectional communications, as well as the multiplication of capacity. WDM makes complex communication system flexible in addition to the increase in the transmission capacity. Moreover, number of channels can be introduced and extracted at different locations. The further sections included in this paper are: Sect. 2 discusses the design issues of a 32 channel WDM based FSO system and attenuation factor characteristics due to haze under Malaysia's

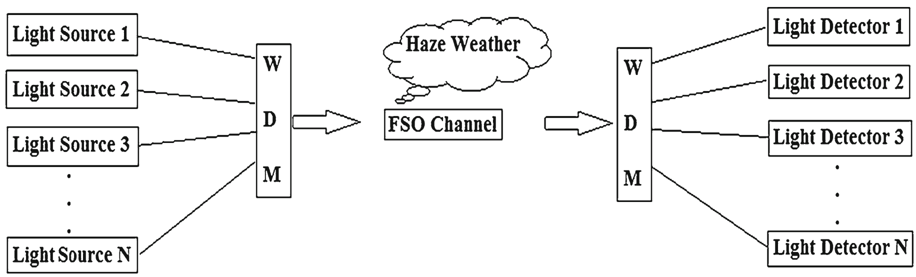

Fig. 1 FSO WDM system

weather condition. In Sect. 3, the simulation results and discussion of both systems are presented. The conclusion is given in Sect. 4.

2 System Design and Analysis

2.1 System Considerations

There are three basic sections of an FSO system i.e. Transmitter, FSO channel, and Receiver. The transmitter section included: Pseudo-Random Bit Generator, NRZ Pulse Generator, CW Laser, and Mach-Zehnder Modulator. The APD photo detector and Low Pass Gaussian Filter are used at the receiver end [9]. BER analyser and optical power meter is used to visualize the simulation value. The power of transmission is to be selected carefully because it can affect the health (eye sight) of human beings [8].

2.2 Link Analysis

The received power at the receiver end guarantees the reliability of transmission because receiver minimum sensitivity depends upon it at a given data rate. It needed to make sure that power level should remain above the minimum sensitivity. The received power is an important FSO link parameter and loss in the air due to weather conditions like haze between transmitter and receiver can vary it.

2.2.1 Haze

Attenuation present in a system can affect its performance. Atmospheric attenuation and geometric losses constitute all attenuation. Geometric losses are not considered in this article as it is assumed that there is no beam spread. Atmospheric attenuation is the effect of particles present in the air for e.g. haze. Haze particles can stay longer time in the atmosphere. So, attenuation values depend upon the visibility level at that time. There are two ways to gather information about attenuation for checking the performance of FSO system. Firstly, by installing system temporary at the site and check its performance. Secondly, by using Kim & Kruse Model to do mathematical analysis [9].

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550\,\text{nm}}\right)^{-q}$$

where, β is haze attenuation, λ is wavelength (in nm), V is visibility (in km), and q is the size distribution of the scattering particles. The size distribution of the scattering particles as referred from the literature is given below in Table 1.

Table 1 Size distribution of scattering particles [9]

q	Type of visibility	Length of visibility (in km)
0.585	Low	$V < 6$
1.3	Average	$6 < V < 50$
1.6	Very high	$V > 50$

2.3 WDM System Design

The WDM systems are designed in OptiSystem v7.0. The working wavelengths are 850 and 1,550 nm. The power level of 1,550 nm is more than 850 nm and system performance is found much better with 1,550 nm wavelength [9]. The aperture of the lenses is kept 15 cm. Laser power changes according to the attenuation value. The system has been optimized at 2.5 Gbps data rate for all weather conditions. Under very clear weather condition, attenuation is 0.065dB/km; laser power is set at −10 dBm. At heavy haze weather condition, attenuation is 2.37 dB/km; laser power is set at 40 dBm [9]. There are two systems designed in this paper: System I and System II.

2.3.1 System I

32 arrays of CW Laser are used in System I. 32 channel WDM MUX and De-MUX are used in transmitter and receiver end respectively. The Selector is used and the output is visualized in the BER analyser as shown in Fig. 2.

2.3.2 System II

A single CW Laser is used and the output is divided using fork. The Fork's output has the same value as the output of a previous component [4]. Later, the WDM MUX and modulation is used before transmission of signals in FSO channel. Power combiner is used next to the output of WDM De-MUX and BER analyser is used to analyse it. It is shown in Fig. 3.

3 Results and Discussion

Optimization of different parameters is needed to be done so that system performance does not degrade too low in the presence of different weather conditions. The parameters are

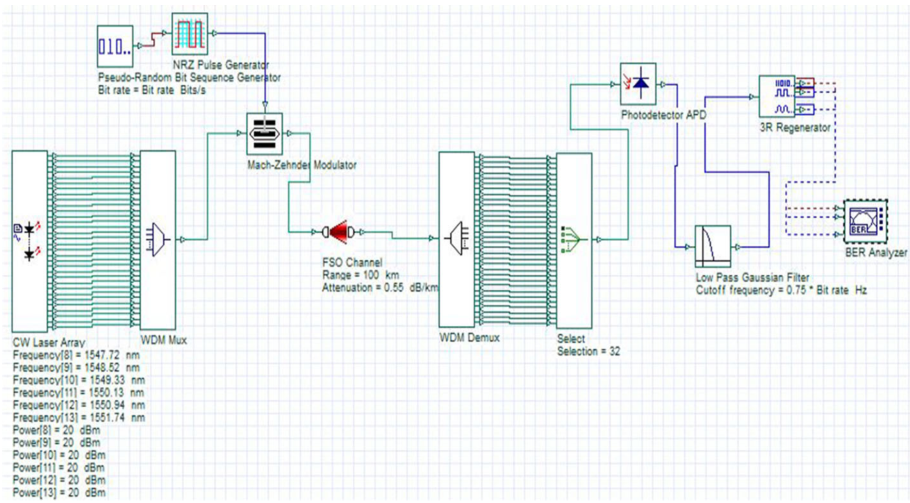

Fig. 2 System I OptiSystem layout

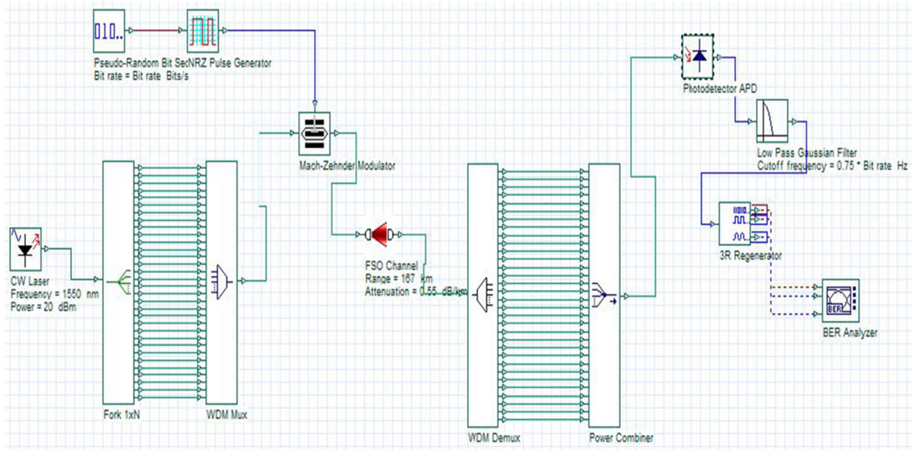

Fig. 3 System II OptiSystem layout

Table 2 Performance analysis of System I under various weather conditions

S. No.	Weather condition	Attenuation (dB/km)	Laser power (dBm)	Max. link distance (km)	Min BER	Max Q value
1.	Very clear	0.065	−10	388	7.15489 e^{-09}	5.6696
2.	Clear	0.233	10	193	1.04862 e^{-09}	5.99005
3.	Light haze	0.55	20	100	1.34421 e^{-09}	5.94953
4.	Heavy haze	2.37	40	31.7	3.6509 e^{-09}	5.78379

laser power, data rate, and aperture size of the transceiver and link distance. Simulations are carried out for the four weather conditions i.e. very clear, clear, light haze, and heavy haze conditions.

3.1 System I

32 CW Lasers are used in System I. The performance analysis of the System I under very clear, clear, light haze and heavy haze weather conditions are shown in Table 2 and BER has been analysed in Fig. 4. It can be seen from Table 2 that under optimized conditions of data rate and laser power, the increase in the attenuation (respective weather condition) causes the decrease in the maximum transmission distance with acceptable Q values. It is found that under very clear weather conditions the acceptable transmission can be carried out up to 388 km while it get reduced to 31.7 km under heavy haze conditions. It is also seen from Fig. 4 that the eye opening and BER value for the very clear weather conditions at 388 km is approximately same as that of heavy haze condition with 31.7 km.

3.2 System II

In this section, the system is designed using only one CW laser thus reducing the system complexity. Again the same optimal conditions of data rate (2.5 Gbps) and respective laser

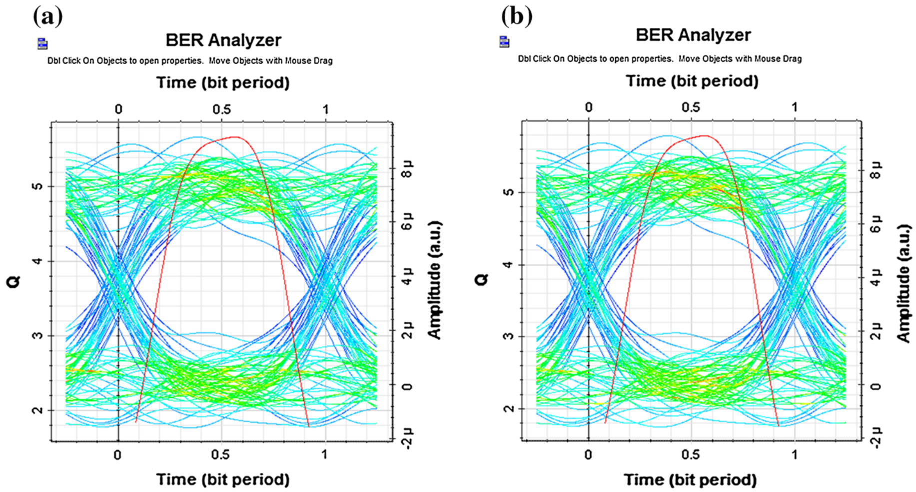

Fig. 4 Eye diagrams for system I: **a** BER on very clear weather, **b** BER on heavy haze weather

Table 3 Performance analysis of System II under various weather conditions

S. No.	Weather condition	Attenuation (dB/km)	Laser power (dBm)	Max. link distance (km)	Min BER	Max Q value
1.	Very clear	0.065	−10	950	2.44783 e^{-09}	5.85063
2.	Clear	0.233	10	350	4.89994 e^{-10}	6.11259
3.	Light haze	0.55	20	167	5.2062 e^{-09}	5.72381
4.	Heavy haze	2.37	40	47	1.22221 e^{-10}	6.33041

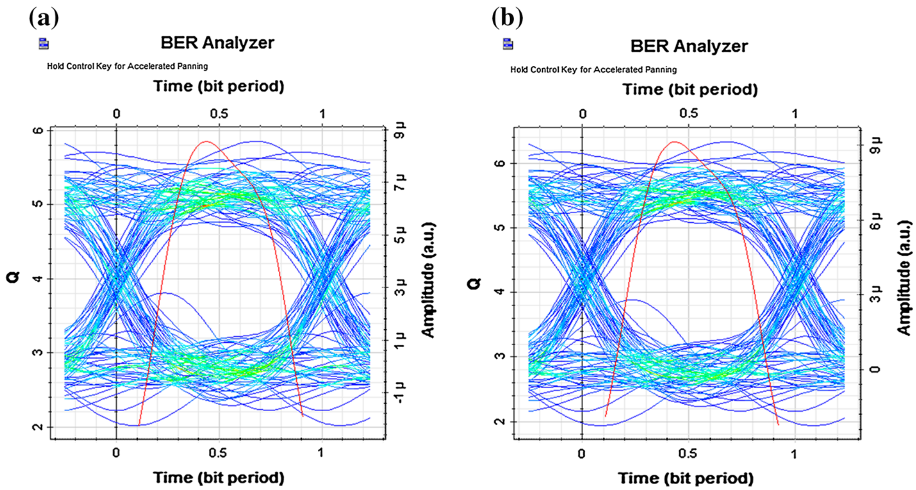

Fig. 5 Eye diagrams for system II: **a** BER on very clear weather, **b** BER on heavy haze weather

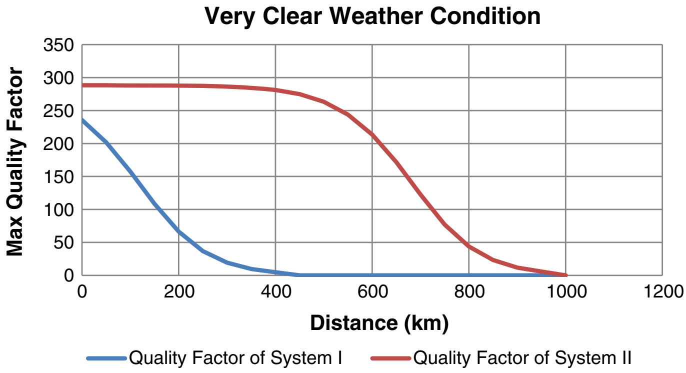

Fig. 6 Max. Q factor versus link distance under very clear weather condition

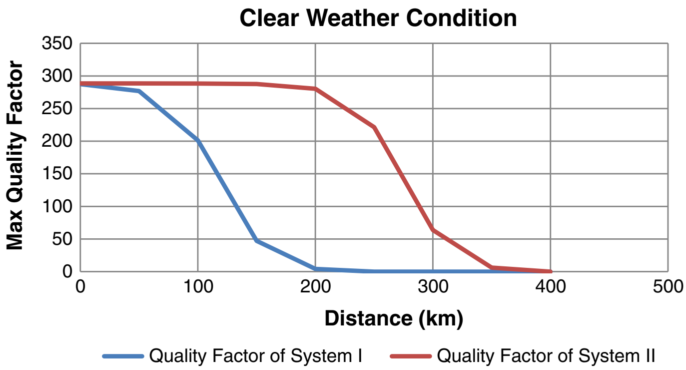

Fig. 7 Max. Q factor versus link distance under clear weather condition

powers (as tabulated) are used. The output is checked for varying link distances under different weather conditions. The performance analysis is shown in Table 3 and eye diagrams for BER analysis is shown in Fig. 5.

It can be seen from Table 3 that under very clear weather conditions the acceptable transmission can be carried out up to 950 km while it get reduced to 47 km under heavy haze conditions. It is also seen from Fig. 5 that the eye opening and BER value for the very clear weather conditions at 950 km is approximately same as that of heavy haze condition with 47 km is.

3.3 System I versus System II

It is well depicted in Tables 2 and 3, with the increase in distance max. Q factor value decreases and system performance also decreases. Also it can also be observed that with increase in attenuation (worse weather condition), Q factor decreases. For larger attenuation, max Q factor value became zero in a few km but for lesser it decreases after few hundred of km. System I and System II performance can be analysed and compared from graphs in Figs. 6, 7, 8 and 9 under very clear, clear, haze and heavy haze conditions. It can be observed from the graphs that System II supports the acceptable transmission for longer link distances

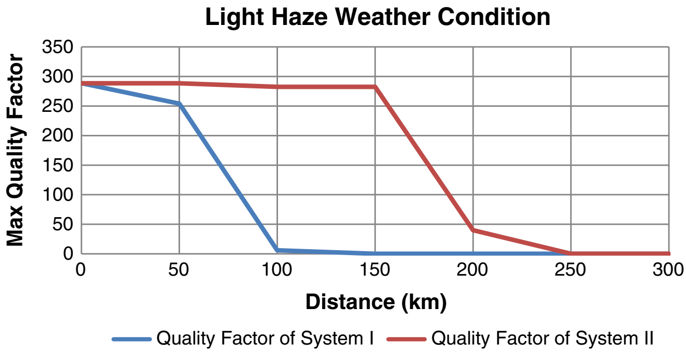

Fig. 8 Max. Q factor versus link distance under light haze weather condition

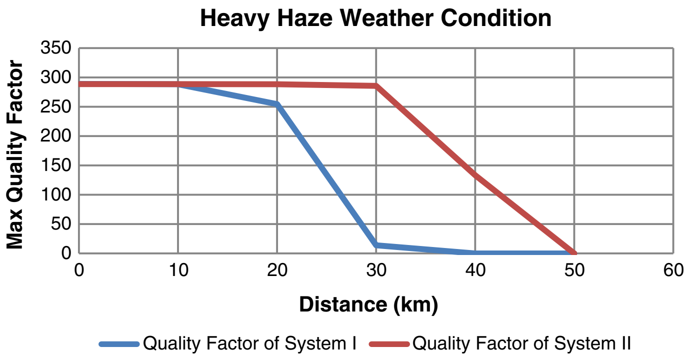

Fig. 9 Max. Q factor versus link distance under heavy haze weather condition

as compared to System I under all weather conditions. Also, very clear weather condition System I link distance is about half of the link distance of System II.

4 Conclusion

Free space optics is a new reach of communication where other systems are hard to reach because of cost, disadvantage or any other factor. Studies are going on improving the system performance in the worst weather conditions and other areas where FSO lacks. Different technologies are mixed up to generate the best result to solve a problem area. In this paper, simulation is done with two WDM FSO communication systems and performance is investigated under similar optimized parameters. It has been observed that under very clear weather conditions, System I give acceptable transmission up to 388 km while it has been extended to 950 km for System II. With heavy haze, System II proved to give better performance at longer link lengths i.e. up to 47 km while it was observed 31.7 km in System I. Similarly with clear and light haze conditions the performance in terms of distance is improved with System II. In System I, the number of LASER used is extremely high which increases the loss and hence reducing the received power. While in System II, system is designed using only one LASER and hence the performance in terms of quality factor is better as compared to System I. Thus it can be concluded that FSO system performance under several weather conditions is improved for system II in terms of link distance using lesser circuitry.

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