SIMULATION OF THE 32-CHANNEL WDM-FSO SYSTEM IN DIFFERENT ATMOSPHERIC PHENOMENA

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Abstract
In this paper, the impact of atmospheric phenomena on the quality of signal transmission in the 32 channel WDM-FSO system at different link distances of the FSO link is investigated. WDM-FSO system operating in the third optical window is observed at clear weather, haze, fog and rain. Transmission quality was analyzed on the basis of Q factor and Bit Error Rate (BER), whose comparisons are given graphically and tabularly. Eye diagrams are also given. The results were obtained using simulation in the OptiSystem 7.4 software, in which the WDM-FSO system for different conditions was investigated.

Keywords: Wavelength Division Multiplexing - WDM, Free Space Optical - FSO, Bit Error Rate - BER, Q factor, atmospheric turbulence.

INTRODUCTION

Free Space Optical (FSO) communication, also termed as optical wireless, is an optical communication technology that uses Line of Sight (LOS) communication system and tries to fulfill the need for high bandwidth over short distances [1]. This system is suitable for circumstances where fiber optic cables cannot be laid [2]. The FSO communication system has the advantages of unrestricted spectrum and high-speed transmission over other wireless communication systems [3].

FSO channel affects the quality of signal due to atmospheric turbulence present, as FSO links are highly dependent on weather conditions [4]. Atmospheric effects like scintillation, fog, haze, rain, absorption by water vapors, scattering of beam, fading, etc., have to be considered while designing an FSO network. They play a major role in determining the link length, i.e., the distance up to which successful communication can take place [5]. The majority of the scattering occurred on the laser beam is Mie scattering. This scattering is due to the fog and haze aerosols at the atmosphere and can be calculated through visibility. FSO attenuation at heavy fog can reach values of hundreds dB. Heavy fog reduces the visibility range to less than 50 m, and it can affect on the performance of FSO link for distances. The rain scattering (non-selective scattering) is independent on wavelength, and it does not introduce significant attenuation in wireless infrared links, but it affects mainly on microwave and radio systems that transmit energy at longer wavelengths [6, 7].

Wavelength Division Multiplexing (WDM) refers to the technique in which more than one signals are multiplexed together and transmitted as one signal [5]. WDM technique started a revolution in optical communication network due to the fact that capacity of system can be increased simply by increasing the number of channels and tightening the channel spacing without using more than one FSO link [4]. So, in WDM-FSO, multiple modulating signals modulate different optical carriers (channels) which are then multiplexed and sent through a single laser beam. These systems are flexible as channels can be added or removed at any point in the link using add/drop multiplexers. However, they also suffer from weather effects and atmospheric turbulences [5].

The use of the WDM technology in the FSO communication system is a new research field. WDM is a natural approach to enhance the link capacity. In recent years WDM over FSO communication system has become very efficient communication system in wireless communication system due to its high data rate, security, and minimum Bit Error Rate (BER) [4, 8]. As a measure of quality, the Q factor and BER were used. BER is the probability that the impulse is interpreted incorrectly (i.e. a logical '1' is detected as '0' and vice versa). Thus, a BER of 10^{-6} corresponds to an average of one error per million bits. The BER value depends on the characteristics of the laser source and the transmission route. The criteria used in optical receivers is that BER is less than 10^{-9} [9]. A favorable BER performance and a clear eye map over a 100 m free-space optical can be achieved through appropriate channel spacing [3]. The application of WDM to the next-generation FSO access network has a focus on high bit rate, scalability, and flexibility [4].

SYSTEM MODEL

The 32 channel WDM-FSO system model, given in Fig. 1, is simulated in the software OptiSystem 7.4 [10]. It consists of an WDM Transmitter, generators, modulator, WDM multiplexer and demultiplexer, FSO channel optical receiver and filter.

At the input of the observed system are Pseudo-Random Bit Sequence (PRBS) and NRZ (Non-Return to Zero) Pulse Generator that are fed together to the Mach-Zehnder Modulator. The binary sequence of pseudo-random bits generated in the PRBS Generator passes through the NRZ Pulse Generator where that bit sequence is converted into electrical pulses. The pulse thus obtained and the multiplexed signal from the source are modulated in a Mach-Zehnder Modulator. The optical source is a WDM Transmitter which is connected to the WDM Multiplexer. A modulated optical signal is fed to the input of the component representing the FSO channel, whose parameter values are given in Fig. 2. The signal is further transmitted to the demultiplexer and then to the receiver.

The observed WDM-FSO system operating in the third optical window with a transmitter power of 15 dBm. The analysis was performed for different FSO link distances of 500 m, 1000 m, 1500 m and 2000 m, as well as for attenuations from 0 dB/km to 40 dB/km. Beside the range and attenuation in the component for the FSO channel, parameters representing certain losses are defined, as well as transmitter and receiver aperture diameter.

Disp	Name	Value	Units	Mode
☐	Range	1	km	Normal
☐	Attenuation	15	dB/km	Normal
☐	Geometrical loss	☑		Normal
☐	Transmitter aperture dia	5	cm	Normal
☐	Receiver aperture diamet	10	cm	Normal
☐	Beam divergence	2	mrad	Normal
☐	Transmitter loss	1.2	dB	Normal
☐	Receiver loss	1.2	dB	Normal
☐	Additional losses	5	dB	Normal
☐	Propagation delay	0	ps/km	Normal

Fig. 2. *FSO channel parameter values.*

Attenuation in this range is caused by the impact of various atmospheric phenomena such as clear weather, haze, rain, fog whose attenuations are given in Table 1 [6]. Attenuations in case of clear weather or light haze can be classified as weak turbulence, fog, light rain and very light fog in the category of moderate turbulence, while moderate to heavy rain and fog belong to the category of strong turbulence.

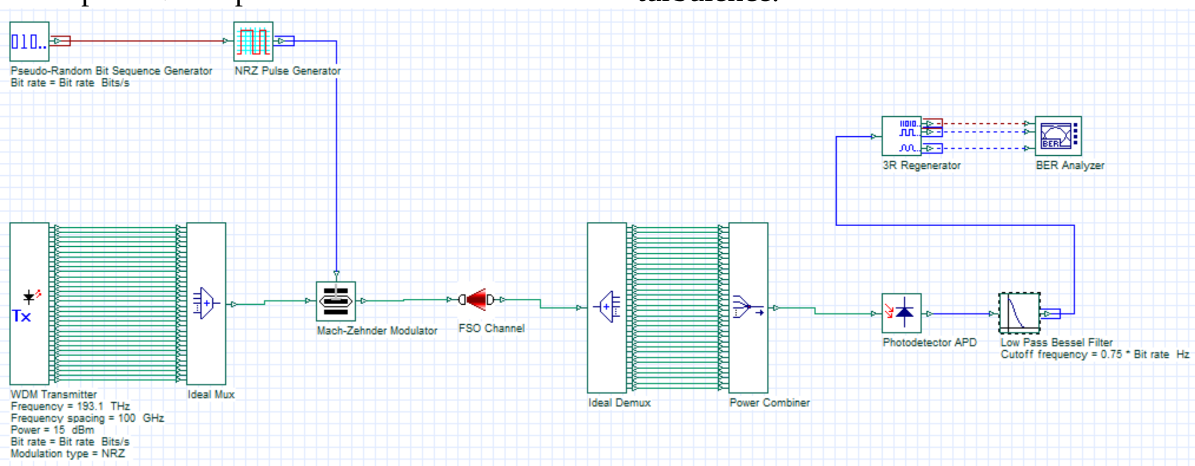


Fig. 1. *Scheme of WDM-FSO system.*

Table 1. Attenuation at different atmospheric phenomena.

Atmospheric phenomena	**Attenuation [dB/km]**
Very clear	0.19-0.47
Clear	0.54-0.6
Light haze	1.1-2
Haze	3.1-4.6
Light rain	6.27
Moderate rain	9.64
Heavy rain	19.28
Light fog	6.6-18.3
Moderate fog	28.9
Heavy fog	75

SIMULATION RESULTS - Q FACTOR

Fig. 3 shows the Q factor values obtained by simulation. A comparison of the Q factor for the WDM-FSO system in different weather conditions, i.e. for attenuations caused by various atmospheric phenomena, and for link distances of 500 m, 1000 m, 1500 m and 2000 m is given. Since the value of Q>5.5 is necessary for quality transmission, from Fig. 3 it can be seen that the transmission is of high quality at 500 m in all weather conditions. This is possible in this case since the distance is short. As the distance is larger, the transmission quality is poorer in case of heavy rain or fog. In clear weather, haze and light rain, the transmission is of good quality at all observed distances. At a distance of 1000 m, the transmission is of poor quality only in heavy fog. For attenuations higher than 5 dB/km or 10 dB/km, the Q factor decreases sharply at distances of 2000 m and 1000 m, respectively. It can be seen that in this case the transmission will only not be good for heavy rain and moderate and heavy fog.

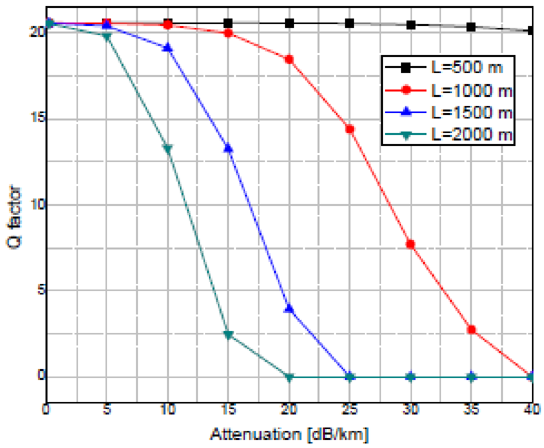


Fig. 3. *Comparison of Q factor for different FSO link distances.*

Q factor for link distances L = 1000 m and L = 2000 m and attenuation caused by clear weather and heavy rain/light fog are given in Fig. 4 and Fig. 5, respectively.

a)

b)

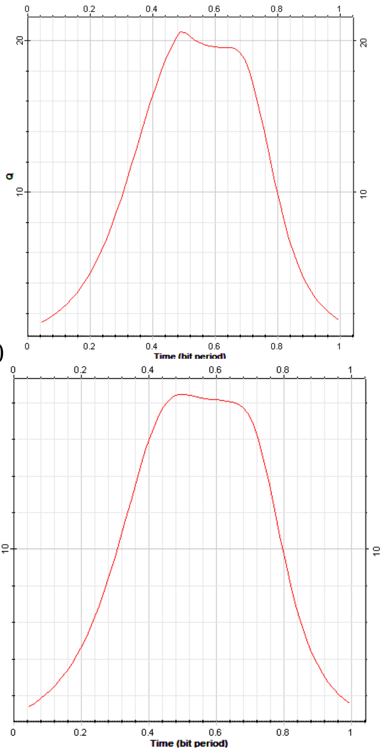


Fig. 4. *Q factor of the received signal for the FSO link distance L = 1000 m and attenuation caused by: a) clear weather, b) heavy rain/light fog.*

a)

b)

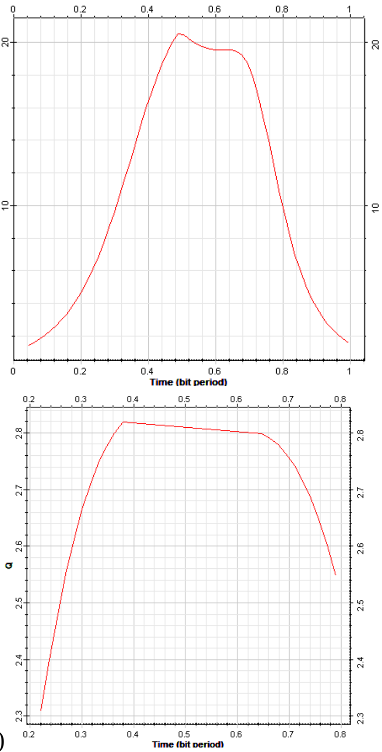


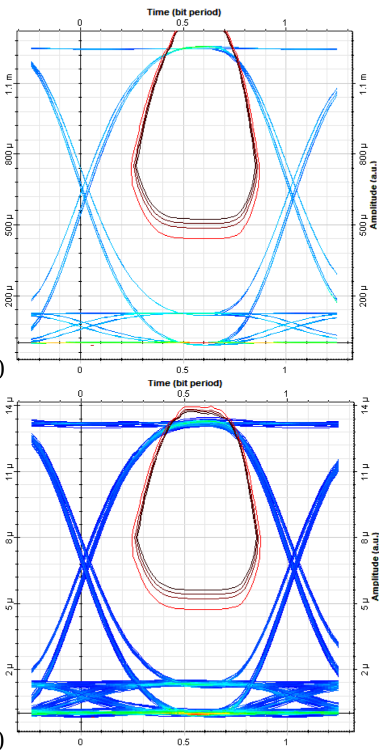
Fig. 5. *Q factor of the received signal for the FSO link distance L = 2000 m and attenuation caused by: a) clear weather, b) heavy rain/light fog.*

SIMULATION RESULTS - BER

Table 2 shows the BER values of the observed WDM-FSO system for different values of attenuation and link distances. The BER values correspond to the behavior of the Q factor shown in Fig. 3.

Table 2. *BER parameter values for different attenuations and link distances.*

Atten. [dB/km]	L = 500 m	L = 1000 m
0.23	1.741e-094	1.939e-094
5	1.774e-094	3.115e-094
10	1.867e-094	2.965e-093
15	2.101e-094	3.387e-089
20	2.718e-094	2.595e-076
25	4.742e-094	2.970e-047
30	1.578e-093	6.262e-015
35	1.990e-092	0.002
40	3.054e-090	1
Atten. [dB/km]	L = 1500 m	L = 2000 m
0.23	2.574e-094	4.309e-094
5	7.732e-093	9.310e-088
10	8.699e-082	1.373e-040
15	2.558e-040	0.006
20	3.670e-005	1
25	1	1
30	1	1
35	1	1
40	1	1

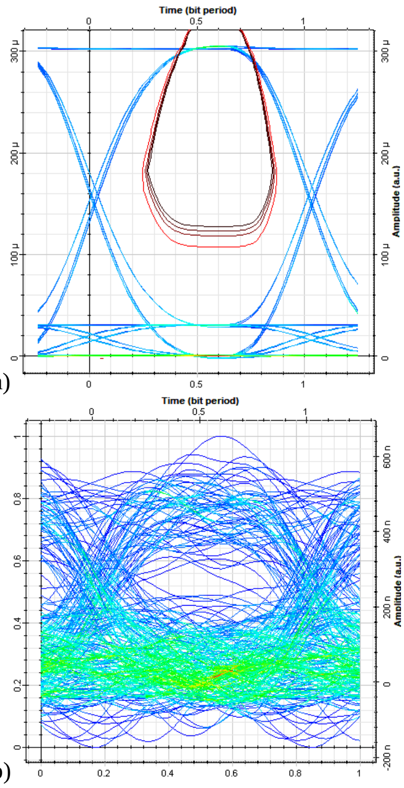


a)

b)

Fig. 6. *Eye diagram of the received signal for the FSO link distance L = 1000 m and attenuation caused by: a) clear weather, b) heavy rain/light fog.*

BER eye diagrams for link distances L = 1000 m and L = 2000 m and attenuation caused by clear weather and heavy rain/light fog are given in Fig. 6 and Fig. 7, respectively. Closed lines represent sectors with BER values of 10^{-8} to 10^{-12}. The eye opening corresponds to the change of the Q factor in Fig. 4 and Fig. 5.



a)

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Fig. 7. *Eye diagram of the received signal for the FSO link distance L = 2000 m and attenuation caused by: a) clear weather, b) heavy rain/light fog.*

CONCLUSION

Using the OptiSystem software package, in the paper is presented a simulation of a 32 channel WDM-FSO system operating in the third optical window. Based on the obtained values of Q factor and BER, it can be concluded that it is possible to achieve high quality transmission in all weather conditions at 500 m, while in the case of clear weather, haze and light rain transmission is of good quality at all observed distances. Heavy fog has the greatest impact on signal degradation, so in such cases an increase in transmitter power or some other parameter that would improve the performance of the WDM-FSO System is resorted to. The obtained results can be used in the design of optical FSO systems in different weather conditions, in order to obtain the highest quality signal reception.

ACKNOWLEDGEMENT

This work was done within the research project TR32023 and TR35026 of the Ministry of Science and Technological Development of Republic Serbia.

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