SIMULATION OF FSO SYSTEM OPERATION IN DIFFERENT ATMOSPHERIC CONDITIONS

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Abstract:

In this paper, using simulation in the software OptiSystem 7.4, the FSO (Free Space Optical) system operating at wavelengths of 850 nm, 1315 nm and 1550 nm was observed. The influence of different levels of atmospheric turbulence and link distance on the signal transmission quality was investigated. The Q factor and BER (Bit Error Rate) were used as a measure of quality. The changes of the Q factor depending on the observed system parameters are graphically shown. Eye diagrams and signal spectrum are also given. The analysis of the results shows how the quality of the received signal changes due to different atmospheric phenomena at certain distances from the transmitter.

Keywords:

Free Space Optical - FSO, attenuation, atmospheric turbulence, Bit Error Rate - BER, Q factor.

INTRODUCTION

Wired optical networks are sometimes difficult to implement due to their complexity in installation and relatively expensive fiber technology. Therefore, they are not always a good solution, although they provide a wide range and high transmission speeds. FSO technology is a good alternative for short or medium distance transmission, especially for environments where wired optical network infrastructure is difficult to apply [1]. Compared to wired optical networks, the application of the FSO system is simpler, easier, faster and therefore cheaper. It also provides excellent data transmission security, high transmission speeds, as well as high bandwidth capability [2-5].

Beside to the various advantages provided by the FSO communication system, there are also various problems that lead to the degradation of the optical link and hinder its use. FSO systems are very vulnerable to atmospheric conditions. Since the signal propagates in free space, it is affected by atmospheric turbulence and pointing errors, which degrades system performance. Snow and rain have a significantly smaller impact on the transmission quality compared to atmospheric turbulence and fog [1,6-9].

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Atmospheric turbulence has a strong impact on the signal being transmitted and on the wavelengths of the system. Atmospheric turbulence is caused by both spatial and temporal random fluctuations of the refractive index due to changes in temperature, pressure and wind along the path of optical propagation through the channel [1,2]. Due to unfavorable atmospheric conditions, beam spreading, image dancing, beam wander, scintillation and intensity fluctuation and signal phase can occur [10,11]. This affects the FSO system performance and leads to high values of the Bit Error Rate (BER), i.e. to small values of the quality factor (Q factor) [3,12,13].

The deterioration in the FSO system performance is also greatly affected by small changes in the position of the transmitter and receiver. Many factors, such as building sway, wind loads or thermal expansion, can cause a misalignment, leading to pointing errors and signal fading at the receiver. All these factors are essential when planning a FSO system and therefore must be considered [6,14,15].

In this paper, the impact of weather conditions, i.e. atmospheric turbulence and link distance on the transmission quality in the FSO system is investigated. The Section 1 presents a system model that is analyzed in an OptiSystem environment. In the Section 2, the obtained simulation results for different wavelengths and distances between transmitter and receiver, as well as for attenuations caused by the impact of different atmospheric phenomena, are graphically presented and discussed. The Section 3 is the Conclusion.

1. SYSTEM MODEL

The system model used for the simulation in the software OptiSystem 7.4 [16] is given in Fig. 1. 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 signal from the source modeled by the CW (Continuous-wave) Laser are modulated in a Mach-Zehnder Modulator. The output thus obtained is an optical signal of variable intensity in accordance with the input electrical signal. A modulated optical signal is fed to the input of the component representing the FSO channel, where attenuation values due to atmospheric influences can be entered. The Optical Receiver with Cutoff Frequency = 0.75 * BitRate Hz is located on the receiving side, and a BER analyzer is connected to it, which is used to read the measured parameters.

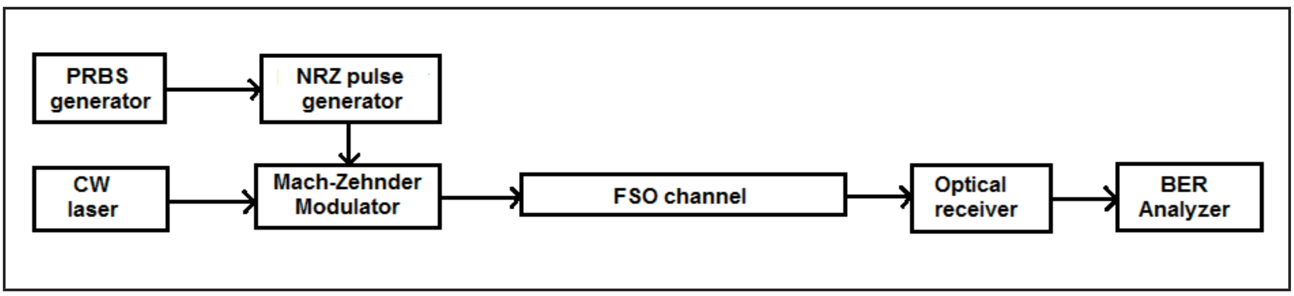

Fig. 1. Block diagram of the system model.

The system was simulated with a transmitter power of 10 mW and at wavelengths of 850 nm, 1315 nm and 1550 nm. The transmitter and receivers aperture diameter are 5 cm and 7.5 cm, respectively, while their losses are 1.8 dB each. The beam divergence is 2 mrad, while the other additional losses are 1 dB.

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. 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 [7,8]. 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.

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

2. SIMULATION RESULTS

Fig. 2, Fig. 3 and Fig. 4 show the behavior of the Q factor versus attenuations caused by different atmospheric phenomena and for different distance lengths between transmitter and receiver, at wavelengths of 850 nm, 1315 nm and 1550 nm, respectively.

From the given figures it can be seen that the transmission is of high quality in clear weather, as well as when the haze is weaker or somewhat stronger, since the value of Q > 5.5 is necessary for quality transmission. In light and moderate rain, as well as light fog, quality transmission can be achieved at a maximum distance of 1000 m at a wavelength of 850 nm. Under the same conditions at a wavelength of 1315 nm, the transmission will be correct even at slightly longer distances than 1000 m, while in the case when the wavelength is 1550 nm, the transmission quality will be good up to 2000 m.

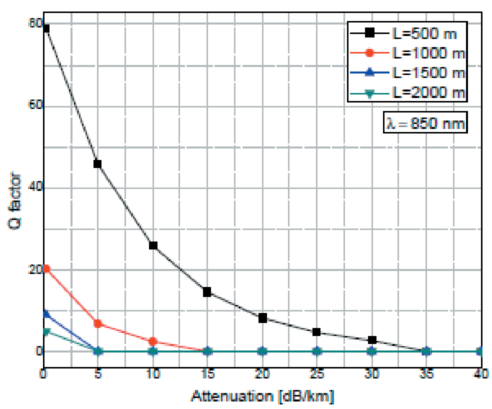

Fig. 2. Q factor for different FSO link distances at a wavelength of λ = 850 nm.

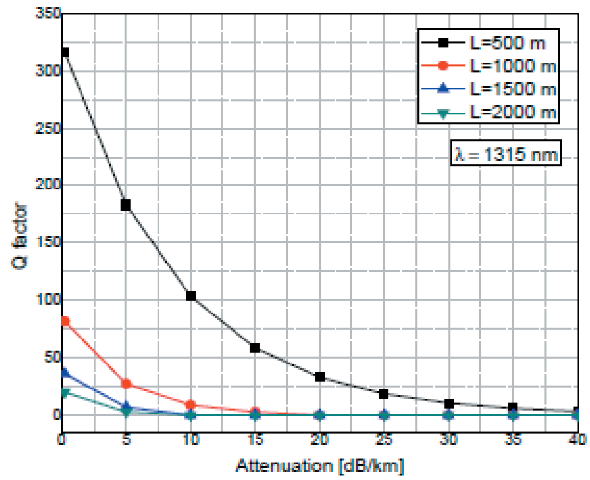

Fig. 3. Q factor for different FSO link distances at a wavelength of λ = 1315 nm.

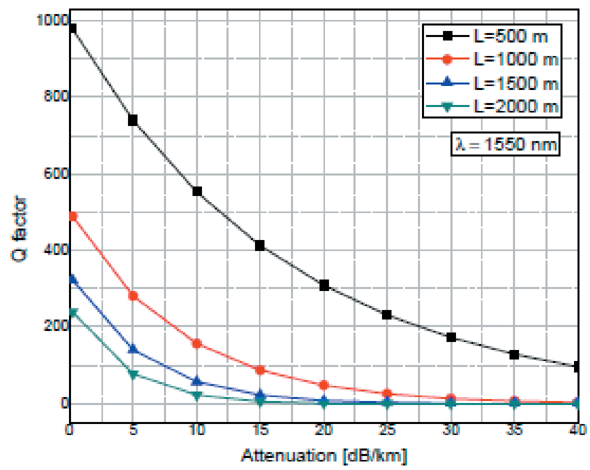

Fig. 4. Q factor for different FSO link distances at a wavelength of λ = 1550 nm.

From Fig. 2 and Fig. 3 it can be seen that in worse atmospheric phenomena, quality signal transmission is impossible to achieve at distances greater than 500 m. In order for this to be achieved, certain parameters of the system must be changed on the transmitting side, such as e.g. increasing the source power.

Based on the results shown in Fig. 4, it can be concluded that the FSO system has the best performance at a wavelength of 1550 nm, where it is possible to achieve quality transmission over longer distances, at 1000 m in almost all weather conditions, while at longer distances it is achievable for attenuations up to 20 dB/km. Also, the decrease in Q factor is more pronounced at shorter distances. As the link distance increases, the decrease in the Q factor is less pronounced.

Table 2 shows the BER values of the observed FSO system at wavelengths of 850 nm, 1315 nm and 1550 nm for different values of attenuation and link distances.

BER eye diagrams for link distances L = 1000 m and L = 2000 m and attenuation caused by moderate rain and moderate fog are given in Fig. 5 and Fig. 6, 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.

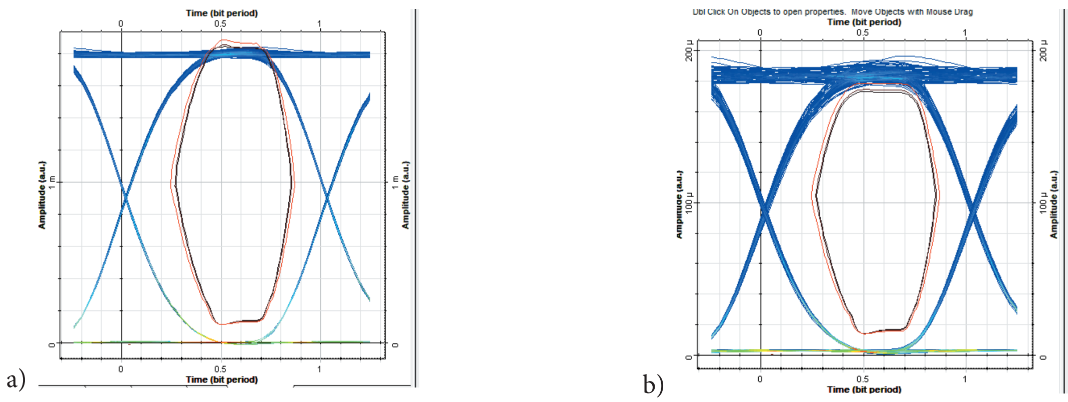

Fig. 5.Eye diagram of the received signal for the FSO link distance L = 1000 m and attenuation caused by: a) moderate rain, b) moderate fog.

Table 2. BER PARAMETER VALUES FOR DIFFERENT FSO SYSTEM CONDITIONS.

Attenuation	L = 1000 m			L = 1500 m			L = 2000 m		
	850 nm	1315 nm	1550 nm	850 nm	1315 nm	1550 nm	850 nm	1315 nm	1550 nm
0.23	1.659e-091	0	0	2.449e-019	5.905e-285	0	4.019e-007	1.344e-088	0
5	6.879e-012	7.712e-165	0	1	1.814e-012	0	1	0.00246	0
10	0.00840034	2.622e-018	0	1	1	0	1	1	3.030e-107
15	1	0.002908	0	1	1	3.289e-106	1	1	2.474e-007
20	1	1	0	1	1	4.156e-014	1	1	1
25	1	1	3.273e-136	1	1	0.007398	1	1	1
30	1	1	6.708e-036	1	1	1	1	1	1
35	1	1	2.582e-009	1	1	1	1	1	1
40	1	1	0.006945	1	1	1	1	1	1

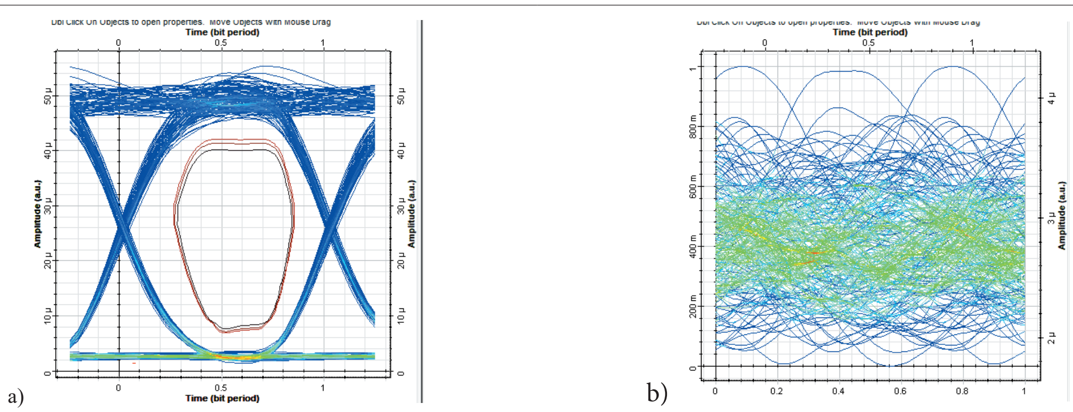

Fig. 6. Eye diagram of the received signal for the FSO link distance L = 2000 m and attenuation caused by: a) moderate rain, b) moderate fog.

Fig. 7 and Fig. 8 show a comparison of the signal spectrum before transmission and after transmission through the FSO channel at attenuation caused by light haze and light fog for link distances of 1000 m and 2000 m, respectively.

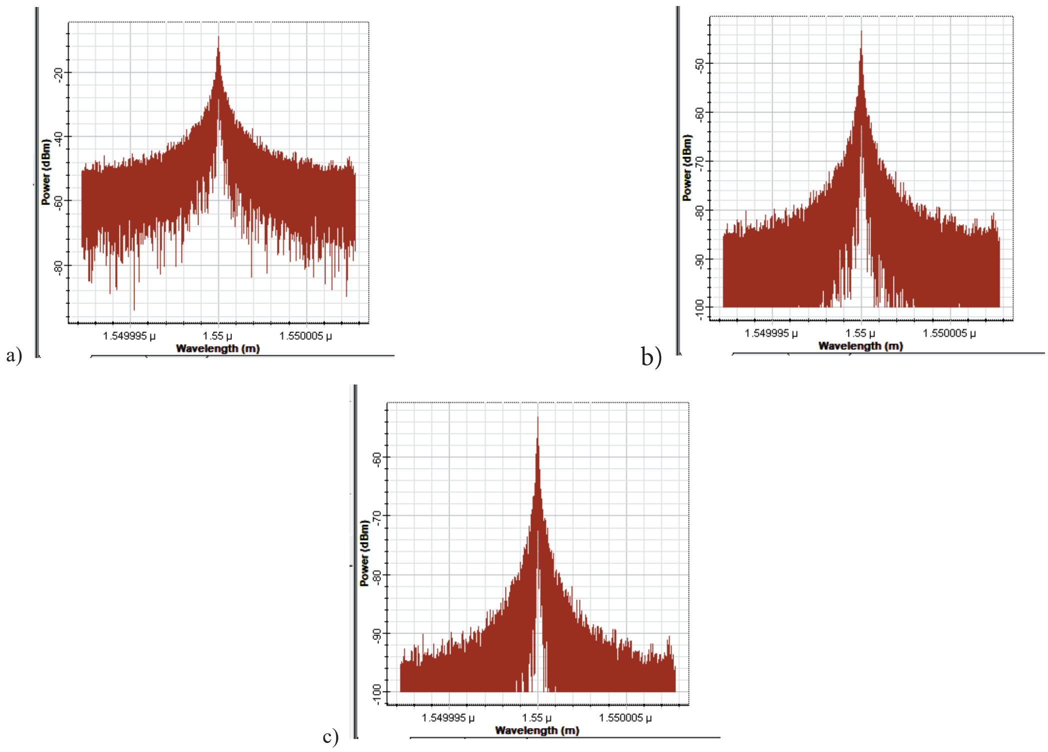

Fig. 7. Signal spectrum: a) before transmission, b) after transmission through FSO channel at 1000 m in light haze, c) after transmission through FSO channel at 1000 m in light fog.

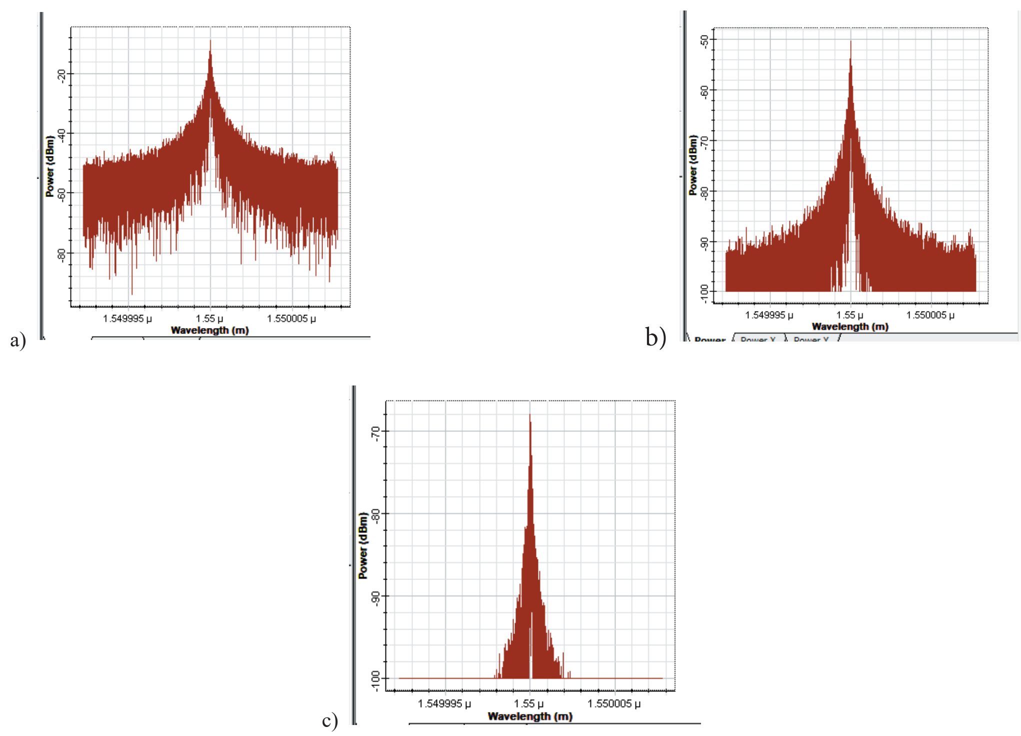

Fig. 8. Signal spectrum: a) before transmission, b) after transmission through FSO channel at 2000 m in light haze, c) after transmission through FSO channel at 2000 m in light fog.

3. CONCLUSION

By simulating the FSO system operating at wavelengths of 850 nm, 1315 nm and 1550 nm, the impact of different levels of atmospheric turbulence and link distance on the transmission quality using the BER parameter and Q factor is shown. The simulation results confirm the analytical results presented in the literature in terms of achieving transmission quality at different lengths of the transmission FSO link operating in different atmospheric phenomena. The FSO system has the best performance in the 3rd optical window (1550 nm), where it is possible to achieve quality transmission over long distances in almost all weather conditions. The decrease in the Q factor is significantly more pronounced at shorter FSO link lengths.

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