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Impact of Beam Divergence on the Performance of Free Space Optical System

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Abstract- Free space optical communication system (FSO) is a potential solution for increasing bandwidth demands. The FSO has a capability to provide high speed data communication, economic and quick deployable. With recent advances and interest in Free Space Optics (FSO) for commercial deployments, a proper understanding of optical signal propagation in different atmospheric conditions has become essential. Although FSO has several advantages, but at the same time FSO faces a major challenge from scintillation introduced by atmospheric turbulence but improvement in performance of FSO Link has been observed with the use of small beam divergence angles. In this paper, the simulation performance investigation of varying beam divergence angle for FSO system is carried out. The performances are analyzed in terms of bit error rate (BER), Quality factor (Q) and eye diagrams.

Index Terms- Divergence, FSO, RZ, Turbulence, Scintillation

I. Introduction

Free space optics (FSO), also known as wireless optics, is a cost-effective and high bandwidth access technique [1] and has received growing attention with recent commercialization success. With the potential high data-rate capacity, low cost, convenient re-configurability and scalability, high-security and particularly wide bandwidth on unregulated spectrum (as opposed to the limited bandwidth radio frequency (RF) counterpart), FSO systems [1-4] have emerged as an attractive means for deep-space and inter-satellite communication and other applications, e.g., search and rescue operations in remote areas. As the demand for high data rate connectivity continuously increases, and the cost of deploying Fiber-to-home remains prohibitive due to the associated high initial infrastructure costs, wireless technologies remain the most attractive approaches. Free-space optics communications offer an enormous unregulated bandwidth with a high reuse factor, making it a suitable candidate for future wireless broadband access. In examining FSO performance, it is important to take several system parameters into consideration. In general, these parameters can be divided into two different categories: internal parameters and external parameters. Internal parameters are related to the design of a FSO system and include optical power, wavelength, transmission bandwidth, divergence angle, and optical loss on the transmit side and receiver sensitivity, bit-error rate (BER), receive lens diameter, and receiver field of view (FOV) on the receive side. External parameters, or non-system-specific parameters, are related to the environment in which the system must operate and include visibility and atmospheric attenuation, scintillation, deployment distance. In our work the impact of Internal design parameter like divergence angle on the performance of the link will be studied. The RF channel model is based on an integrated set of four link attenuation models that estimates margin losses due to rain, fog [6] [9], and atmospheric (water vapor and oxygen) attenuation [6] and multipath effects. Due to the fact that the FSO link wavelength used in our simulation is 1550nm, gaseous attenuation can be neglected [8]. The rest of the paper is organized as follows: Sections 2 discusses channel model, Sections 3 Briefs about the performance metrics used for evaluation of the FSO link and section 4 gives system description used for simulation, section 5 discuss results and Section 6 concludes the paper.

II. FREE SPACE CHANNEL MODEL [1],[2],[4]

Observing power at the receiver and calculating the link margin, one can determine factors that affect quality of the link. Link Margin (LM),[4] usually expressed in decibels, is a ratio of the received power P_R and receiver threshold (*s*), or amount of power received above minimum detectable power:

$$LM = 10Log\frac{P_R}{S} \tag{1}$$

In order for signal to be recovered at the receiver's side, its power must be higher than receiver sensibility or receiver threshold. Receiver threshold is usually given by manufacturer and it ranges from -20 to -40 dBm. Power at the receiver [1] [2] ,[4] can be expressed as:

$$P_R = P_T * \frac{A_{RX}}{(\theta L)^2} * e^{-\alpha L} \tag{2}$$

where: P_R and P_T are power at the receiver and transmitter respectively, A_{RX} is receiver aperture area, θ divergence angle, α atmospheric attenuation and L distance between transmitter and receiver. As shown in the equation (2), [4] power at the receiver is directly proportional to the transmit power and receiver

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aperture area, but inversely proportional to the link range and divergence angle. Exponential part of the equation is related to atmospheric attenuation and it has the strongest influence on the link quality. Another factor that adds to attenuation of the signal is beam divergence. The received power can be increased by increasing the transmitter power, the receiver area, or by reducing the beam divergence of the transmitter beam, which is diffraction limited. In our simulation work we investigated that as divergence angle is decreased the performance is improved considerably and the reliability of the link increases.

III. PERFORMANCE METRICS

The robustness of the design of any optical communication system can be effectively verified by critically applying performance checks on the system. The evaluation criteria should provide a precise determination and separation of dominant system limitations, making them crucial for the suppression of propagation disturbances and performance improvement. In our system we have applied simple and accurate methods viz BER, Q factor, and eye opening to estimate the behavior of the system. The Bit Error Rate (BER) of an optical link is the most important measure of the faithfulness of the link in transporting the binary data from transmitter to receiver. The BER quantifies the rate of errors and is defined as the probability of an error occurring per transported bit. The bit error rate takes the simple form

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right). \qquad (3)$$

Where Q is quality factor and 'erfc' denotes the complementary error function.

IV. SYSTEM DESCRIPTION

The block diagram of FSO link used for simulation is shown in the figure 1.

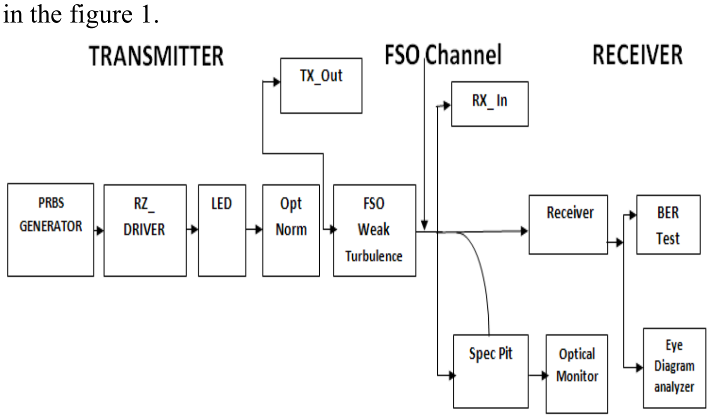

Figure 1: FSO link

The simulation study has been carried out using commercial simulation package OptSim. The FSO link wavelength used in our simulation is 1550nm. The transmitter consists of a PRBS generator and RZ Driver, and a directly modulated LED at 1550nm. Optical power out of the transmitter is 5 dBm. The FSO link has Data rate of 2.5 Gbps and length of link is 1000 meter. The receiver is a PIN diode and is followed by a BER Tester. There are also an Optical Power Meter, Spectrum, Eye Diagram, and Optical Waveform Analyzers. Q factor and BER and eye diagram are studied for the different divergence angles from 0.1mrad to 3mrad.

V. RESULTS AND DISCUSSIONS

The simulation is performed for several divergence angles from the range 0.1mrad to 3mrad. The simulation system performance is monitored using eye diagram analyzer, BER tester and Q factor. We examined the eye diagrams taken at divergence angle of 3mrad, 2mrad, 1mrad and 0.6mrad and observed that decreasing the beam divergence from 3mrad to 0.1mrad has significant effect on the improvement of the performance of the FSO link. The table 1 shows the BER and Q factor for the different values of divergence angle ranging from 0.1 mrad to 3mrad.The measurements are being taken at attenuation value of -8.48dB.It is observed from the table that low divergence angles can increase the link performance. It is clear from the table 1 that for the smallest possible value of 0.1mrad divergence angle the BER is 10^{-85} and Q factor is 25.8dB. Here we have used term Additional Attenuation in our various figures which refers to the attenuation caused by various atmospheric and weather conditions like fog, rain, haze.

Table 1: BER and Q factor for RZ Modulation Schemes at different divergence angles at attenuation of -8.48 dB

Divergence Angle (mrad)	BER	Q^2(dB)
1.0000e-004	6.1433e-085	2.5798e+001
2.0000e-004	4.1512e-083	2.5701e+001
3.0000e-004	4.5896e-080	2.5534e+001
4.0000e-004	1.7500e-075	2.5271e+001
5.0000e-004	1.0479e-069	2.4915e+001
6.0000e-004	2.5524e-063	2.4483e+001
7.0000e-004	1.2312e-056	2.3981e+001
8.0000e-004	2.3939e-049	2.3358e+001
9.0000e-004	2.5917e-042	2.2659e+001
1.0000e-003	7.5273e-036	2.1899e+001
1.1000e-003	4.8887e-030	2.1081e+001
1.2000e-003	5.6964e-025	2.0218e+001
1.3000e-003	9.1768e-021	1.9343e+001
1.4000e-003	2.6802e-017	1.8463e+001
1.5000e-003	1.7592e-014	1.7591e+001
1.6000e-003	3.3396e-012	1.6732e+001
1.7000e-003	2.3100e-010	1.5892e+001
1.8000e-003	7.0968e-009	1.5073e+001
1.9000e-003	1.1407e-007	1.4278e+001
2.0000e-003	1.0950e-006	1.3506e+001
2.1000e-003	6.9739e-006	1.2759e+001
2.2000e-003	3.2020e-005	1.2036e+001
2.3000e-003	1.1314e-004	1.1335e+001
2.4000e-003	3.0506e-004	1.0698e+001

2.5000e-003	7.3691e-004	1.0048e+001
2.6000e-003	1.5784e-003	9.4025e+000
2.7000e-003	2.9515e-003	8.7965e+000
2.8000e-003	5.4414e-003	8.1187e+000
2.9000e-003	8.5246e-003	7.5521e+000
3.0000e-003	1.2577e-002	7.0012e+000

Figure 2 gives the graph between Q factor and divergence angle at attenuation value of -8.48dB. Figure 3 shows graph between BER and divergence angle at attenuation value of -8.48dB. It is assumed that the minimum values of Q factor required to achieve satisfactory link performance is 17dB. It is observed from figure 2 that for divergence angle of 3mrad the Q factor is only 7dB and for divergence of 2 mrad the Q factor is 13.5dB and for divergence angle of 1 mrad the Q factor is near to 22 dB which is above the minimum desired Q value of 17dB, which shows that for optimum link performance the small angles of divergence gives satisfactory link performance.

Figure 4 shows the graph of BER vs. additional attenuation for divergence angle of 3 mrad and Figure 5 shows the graph between Q factor and additional attenuation for divergence angle of 3 mrad.

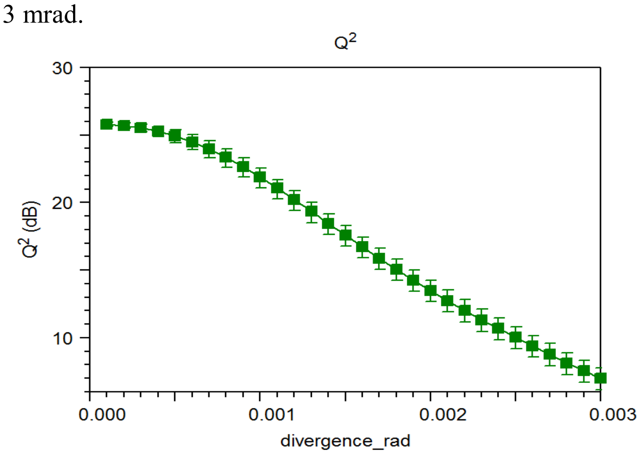

Figure 2: Q-factor vs. Divergence angle (milli radians) at attenuation value of -8.48dB

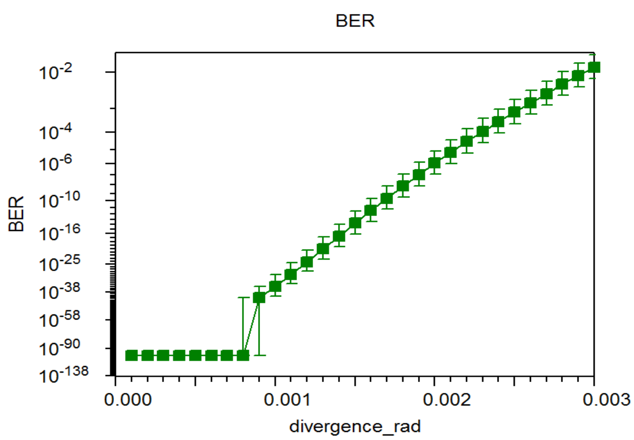

Figure 3: BER vs. Divergence angle (milli radians) at attenuation value of -8.48dB

Figure 4 shows the graph of BER vs. additional attenuation for divergence angle of 3 mrad and Figure 5 shows the graph between Q factor and additional attenuation for divergence angle of 3 mrad. Assuming That BER required for satisfactory link performance is less than or equal to 10^{-12}, it is observed from figure 4 that the link can tolerate maximum attenuation value of less than -3dB and the value of Q factor achieved from figure 5 is approximately 16.5dB. Figure 6 shows Eye Diagram for divergence angle of 3 mrad at attenuation value of -3dB.

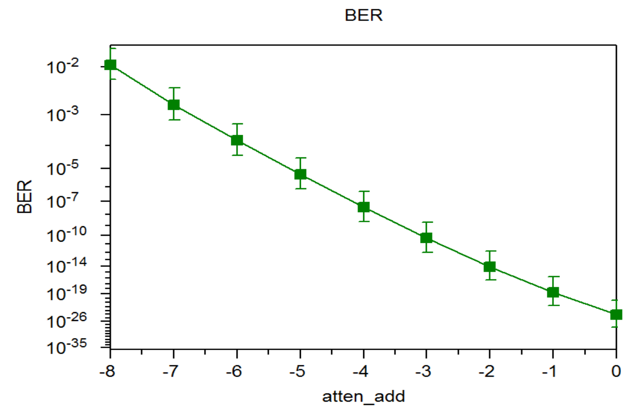

Figure 4: BER vs. additional attenuation [in dB] for divergence angle of 3 mrad

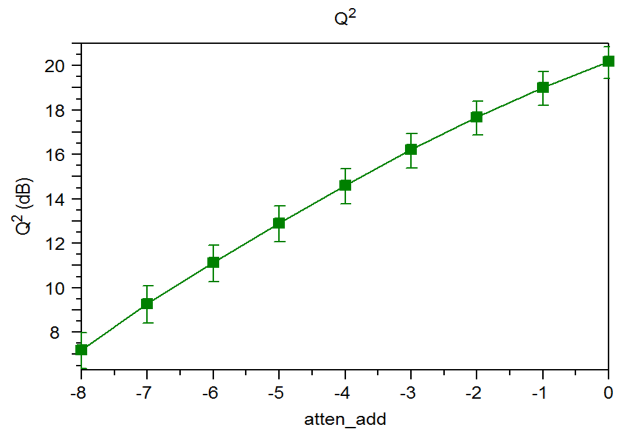

Figure 5: Q factor vs. additional attenuation [in dB] for divergence angle of 3 mrad

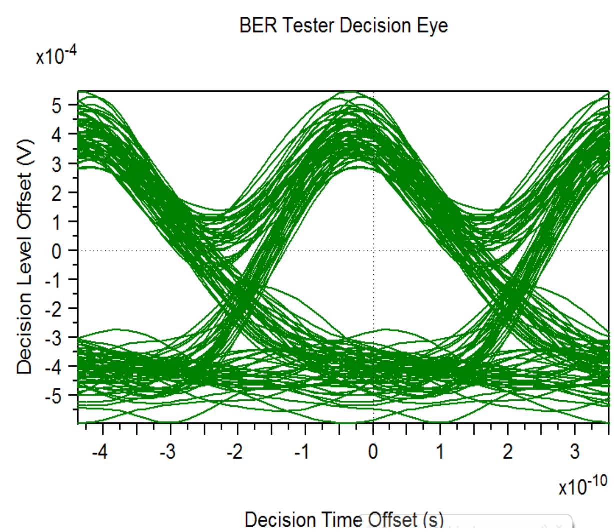

Figure 6: Eye Diagram for divergence angle of 3 mrad at attenuation value of -3dB

Figure 7 shows the graph of BER vs. additional attenuation for divergence angle of 2 mrad and Figure 8 shows the graph between Q factor and additional attenuation for divergence angle of 2 mrad. Assuming That BER required for satisfactory link performance is less than or equal to 10^{-12}, it is observed from figure 7 that the link can tolerate maximum attenuation of upto -6dB and the value of Q factor achieved from figure 8 is approximately 17dB. Figure 9 shows Eye Diagram for divergence angle of 2 mrad at attenuation value of -3dB. This shows that divergence angle of 2 mrad provide better performance as compared to 3mrad divergence angle.

Figure 10 shows the graph of BER vs. additional attenuation for divergence angle of 1 mrad and Figure 11 shows the graph between Q factor and additional attenuation for divergence angle of 1 mrad. Assuming That BER required for satisfactory link performance is less than or equal to 10^{-12} , it is observed from figure 10 that the link can tolerate maximum attenuation of upto -12dB and the value of Q factor achieved from figure 8 is approximately 17dB. Figure 12 shows Eye Diagram for divergence angle of 1 mrad at attenuation value of -3dB. This shows that divergence angle of 1 mrad can further improve the link performance as compared to 2mrad divergence angle.

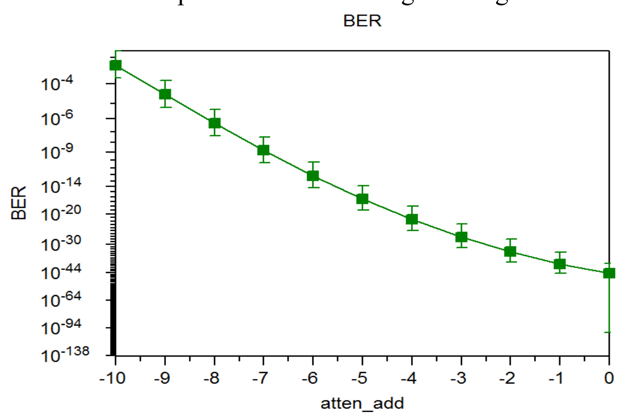

Figure 7: BER vs. additional attenuation [in dB] for divergence angle of 2 mrad

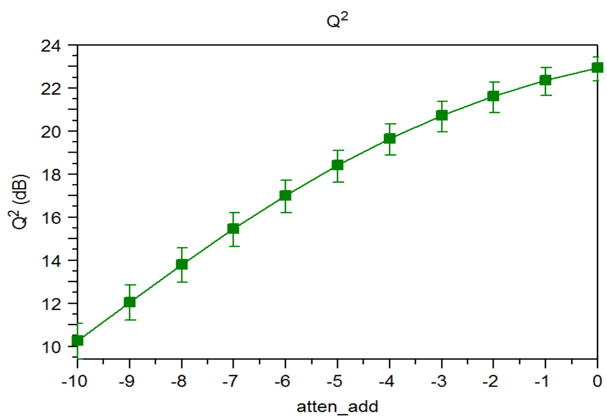

Figure 8: Q factor vs. additional attenuation [in dB] for divergence angle of 2 mrad

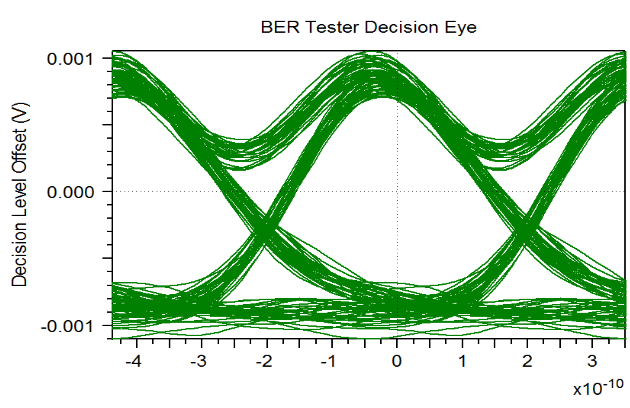

Figure 9: Eye Diagram for divergence angle of 2 mrad at attenuation value of -3dB

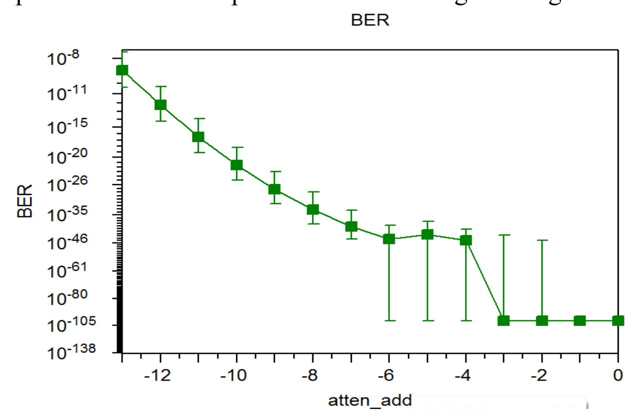

Figure 10: BER vs. additional attenuation [in dB] for divergence angle of 1 mrad

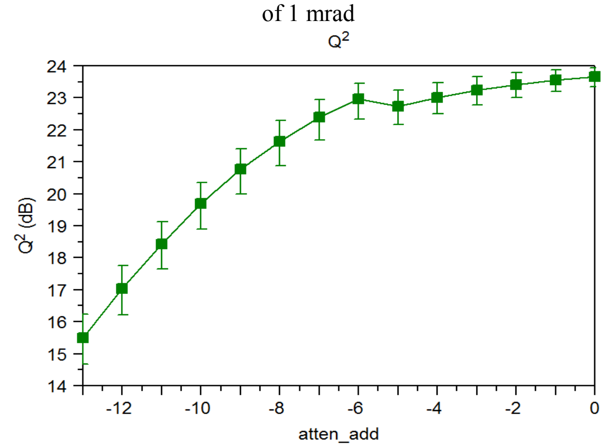

Figure 11: Q factor vs. additional attenuation [in dB] for divergence angle of 1 mrad

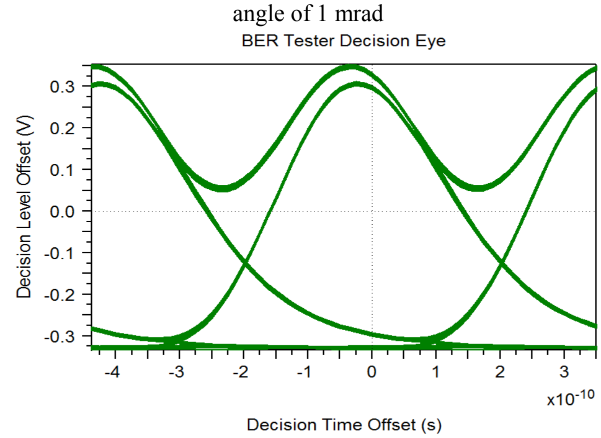

Figure 12: Eye Diagram for divergence angle of 1 mrad at attenuation value of -3dB

Figure 13 shows the Eye Diagram for divergence angle of 0.6 mrad at attenuation value of -3dB. Figure 13 demonstrates that considerable improvement in the link can further be achieved by decreasing the divergence angle to 0.6mrad from 3 mrad

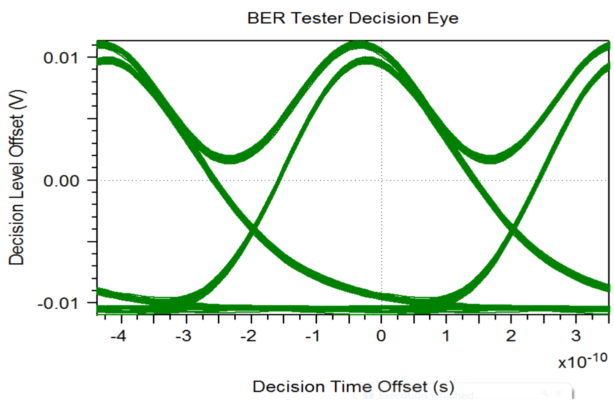

Figure 13: Eye Diagram for divergence angle of 0.6 mrad at attenuation value of -3dB

VI. CONCLUSION

The performance of varying divergence angle under controlled turbulence environment has been studied for FSO communication link. The Simulation results have shown that divergence 0.6mrad offer significantly performance improvement for the FSO link compared to 3mrad divergence. It is also concluded that the link can tolerate more attenuation by decreasing the divergence angle.

REFERENCES

[1] Heinz Willebrand, and Baksheesh S. Ghuman, " Fiber Optics without Fiber," IEEE, 2001.

[2] Scott Bloom, "Physics of free space optics," 2002.

[3] Bloom, Eric Korevaar, John Schuster, Heinz Willebrand, "Understanding the performance of free-space optics, "Journal of Optical Networking, 2003.

[4] S. Sheikh Muhammad, P. Köhldorfer, E. Leitgeb, " Channel Modeling for Terrestrial Free Space Optical Links", IEEE, 2005.

[5] Husagic Alma, Wajdi Al-Khateeb, "Effect of Weather Conditions on Quality of Free Space Optics Links," Proceedings of the International Conference on Computer and Communication Engineering, 2008.

[6] M. Saleem Awan, E. Leitgeb, S. Sheikh Muhammad, Marzuki, F. Nadeem, M. Saeed Khan, C. Capsoni, "Distribution Function For Continental and Maritime Fog Environments For Optical Wireless Communication", IEEE Proceedings, 2008.

[7] Ales Prokes, Vladislav Skorpil, "Estimation of Free Space Optics Systems Availability Based on Meteorological Visibility," IEEE 2009.

[8] Thomas Plank, Erich Leitgeb, Markus Loeschnigg, "Recent Developments on Free Space Optical Links and Wavelength Analysis", International conference on Space Optics and applications, 2011.

[9] S. Rajbhandari, Z. Ghassemlooy, J. Perez, H. Le Minh, M. Ijaz, E. Leitgeb, G. Kandus and V. Kvicera, " On The Study of the FSO Link Performance under Controlled Turbulence and Fog Atmospheric Conditions ", International conference on Telecommunications, 2011.

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