Improved Performance Analysis of FSO Communication Link under the effect of Moderate Haze Phenomena and Heavy Haze Phenomena in SDM based on EDFA Pre-amplifier

Mohammed Nasih Ismael
Geography Department, College of Arts, Kirkuk University, Iraq.
E-mail: mohammednasih82@gmail.com

Received September 23, 2021; Accepted December 18, 2021
ISSN: 1735-188X
DOI: 10.14704/WEB/V19I1/WEB19275

Abstract

Free Space Optics is of high bandwidth medium, having extreme rate of data. The need for enormous capacity of data speed has exponentially risen up because of the immense internet services widely reached. Thus, by means of the increasing rate of transmission and necessity in the area communication that is optical has turned into costing too much. The primary limitation of the system FSO is environment phenomena which probably indicate to maximum bit error rate (BER) of the system and makes the communication link impractical. However, the environment phenomena such as (moderate haze phenomena and heavy haze phenomena) cause attenuation thus will decrease the distance of communication system. In this paper, different combinations have been apply to improves the strength of weak signal in the free space optics (FSO) communication link under the effect of environment phenomena in spatial division multiplexing (SDM) based on erbium-doped fiber amplifiers (EDFA) Pre-amplifier.

Keywords

Free Space Optics, EDFA Pre-amplifier, Heavy Haze Phenomena, Moderate Haze Phenomena, Spatial Division Multiplexing.

Introduction

The system of (FSO free space optical) communication gives the probability of uploading huge amounts of data in a secure way by means of free space without enduring costs of laying fiber-optic cable (Ismael & Fakhrudeen, 2019). The communication of FSO is a technology known as (LOS line of sight) which whereby modified ray of visible or infrared light (IR) is transferred through FSO for the purpose of telecommunications or computer networking. It supports transmitting voice optically as well as data and communication using a video up to 2.5 Gbps without positioning the fiber cable of optical

(A. Ghazi, S. Aljunid, S. Z. S. Idrus, A. Fareed, et al., 2021; A. Ghazi, S. Aljunid, S. Z. S. Idrus, C. Rashidi, et al., 2021; Hossain & Afroze, 2013). FSO is of several benefits for new and modern communications such as huge bandwidth, spectrum free license, rate of maximum data, little power, extreme safety of transmission because of contracted optical rays or beams etc.

The major restriction of the system FSO is environment phenomena which could indicate system rate which is extreme bit error (BER) in addition to causing the communication link to be impractical (Koshy & Babu, 2016). The raising necessity meant for extreme-capacity telecommunication link sand the speed restriction of links that are single-wavelengthed has led to a significant raising in using different multiplexer in advanced light wave networks (Koshy & Babu, 2016). Atmospheric attenuations highly affect the quality of FSO system. Attenuation is considered as a major parameter which restricts the FSO performance. (Mahajan, Parkash, & Singh, 2020). It reduces the signal strength once promulgates through atmosphere because of various weather conditions. Thus, it has been essential for the system of FSO to take into accounts the weather conditions like rain, fog, haze, etc (Alshwani, Fakhrudeen, Ismael, Al-Dawoodi, & Ghazi, 2019; S. A. A. Ghazi et al., 2021; Ismael & Fakhrudeen, 2019; Maraha, Ameen, Mahmood, & Al-dawoodi, 2020).

Several researchers provided various techniques for completing the system of FSO in weather attenuation in addition to raised rate of data transmitted as well as the channel capacity system. For enhancing the act of FSO links, numerous techniques like adaptive optics, averaging aperture, control coding error etc. was suggested to make up for effects of environment phenomena because of various atmospheric conditions characterized by turbulence. (Singh & Malhotra, 2020). Losing information signal power for the reason of environment phenomena can be addressed by employing a laser at the transmitter with extreme power. However, the laser power can’t be risen up for particular constraints taking into accounts the mind, the safety of eye concerns. Likewise, the techniques of error control coding is possibly a tool that can lower the efficiency of bandwidth and causing processing delays (Amphawan, Nedniyom, & Al Samman, 2013; Singh & Malhotra, 2020).

Moreover, for developing the capacity of transmission related to FSO links, multiplexing within the phase (Naila, Wakamori, & Matsumoto, 2011) code (Kanno et al., 2011), intensity (Singh & Malhotra, 2020), polarization (Tang, Ghassemlooy, Rajbhandari, Popoola, & Lee, 2012), and wavelength (Zhou, Mao, & Agrawal, 2014) is confirmed in preceding works. Spatial division multiplexing (MDM) is known as an evolving technology utilizing Eigenmode dimension to transfer multiple data signals at the same

time through separate modes of laser created employing optical signal processing (Ryf et al., 2011), fiber that is photonic crystal (Jung et al., 2013) and a fiber of single-mode (Amphawan et al., 2013). Hence (AL-DAWOODI et al., 2019; Alshwani et al., 2019; Amphawan, Ghazi, & Al-dawoodi, 2017; Chaudhary & Amphawan, 2018a, 2018b, 2018c; Ghazi et al., 2019; Ismael & Fakhrudeen, 2019) details regarding the SDM performance based FSO links undergoing the impact of various atmospheric conditions. Different Authors (Bayaki, Michalopoulos, & Schober, 2012; Khajwal, Mushtaq, & Kaur, 2020; Koshy & Babu, 2016; Kunzler & Lopes, 2020; Mathur, Saxena, & Bhatnagar; Singh, 2017) illustrated a preamplifier which is optical is utilized for enhancing the FSO link performance. The outcomes indicate using a preamplifier namely optical in such system to diminish the attenuation of weather in addition to achieve the extreme link.

The objective of this research paper intends for lessening the impacts of environment phenomena such as (moderate haze phenomena and heavy haze phenomena) causes attenuation thus will decrease the distance of on 16 channels SDM-FSO communication system and suggests a suitable method for lessening the environment phenomena by the adding Erbium amplifier which is of doped fiber. The other parts of this research is organized in this sequential arranging. Section 2 illustrates the system descriptions of FSO-SDM under environment phenomena such as (moderate haze phenomena and heavy haze phenomena) based on pre-optical amplifier. Section 2 the system description, in Section 3 results discusses, In Section 4 Comparison study, and finally, Section 4 concludes.

System Descriptions

The block diagram of the 16-channels in SDM over the FSO link under the effect of environment phenomena such as (moderate haze phenomena and heavy haze phenomena) which has been illustrated in Figure 1 and Figure 2. The system comprises of three parts: 1) transmitter; 2) FSO link; and 3) receiver. This study designed and simulated the system using opti-system (Guide, 2010; Release, 2013). The side optical transmitter includes 16-channels, where every single optical channel has: Data generator at 10 Gbps (total capacity is 160 Gbps), NRZ electrical pulse generator and leaser. The 16-channel consisted of 16 LG modes which are (LG 0 1, LG 0 2, LG 0 3, LG 0 4, LG 1 1, LG 1 2, LG 1 3, LG 1 4, LG 2 1, LG 2 2, LG 2 3, LG 2 4, LG 3 1, LG 3 2, LG 3 3, LG 3 4) based on wavelength 1550.12, and multiplexer, which will multiplex 16-channel.

Table 1 Simulation parameters of SDM over FSO under environment phenomena

Parameters	Values
Beam divergence	1 mrad
SDM wavelength	1550.12
Leaser power	1 dBm
Transmitter's Apertures	30 cm
Mode types	LG modes
Receiver's Apertures	20 cm
Moderate haze	6.80 dB/KM
Heavy haze	19.77 dB/KM
Data Rate	160 Gbps
Forward pump power of EDFA	100 mW
Maximum distance based on Moderate haze without optical pre amplifier	2.5 KM
Maximum distance based on Moderate haze with optical pre amplifier	3.4 KM
Maximum distance based on Heavy haze without optical pre amplifier	1.2 KM
Maximum distance based on Heavy haze with optical pre amplifier	1.5 KM

Moreover, the second part is FSO link. FSO link is evaluated under environment phenomena such as (moderate haze phenomena and heavy haze phenomena) weather. Tables 1 presentation of the parameters of the attenuation coefficients, maximum distance and the used parameters in the SDM over the FSO system based on Pre-optical amplifier erbium-doped fiber amplifiers (EDFA) the advancing power pump of EDFA is fixed to 100 mW. On the other hand, the receiver side consists of 16- Photo-detector: used to converts light into an electrical current, an electrical filter. Finally is the performance measurement is based on BER and Q-Factor.

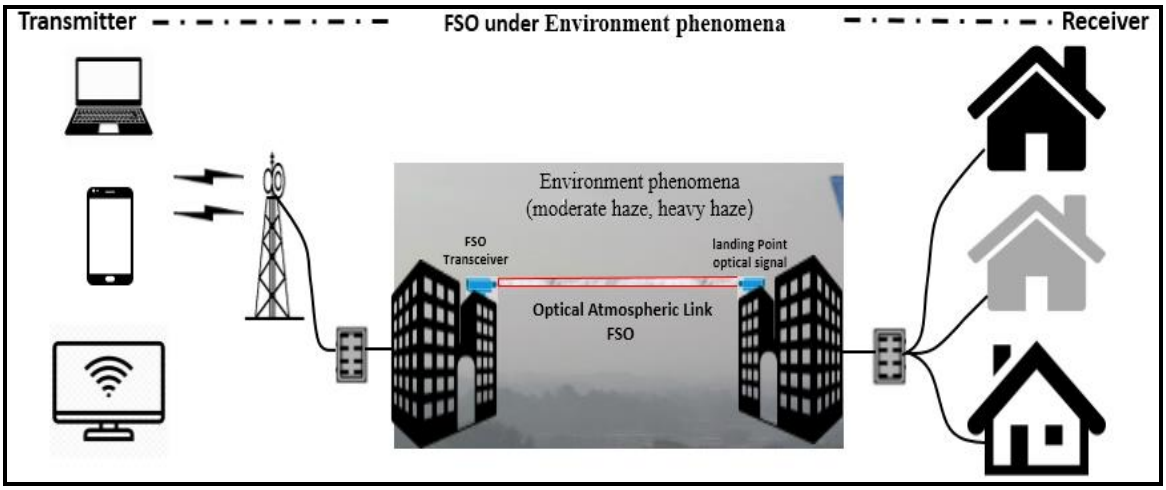

Figure 1 FSO based on SDM under environment phenomena (moderate haze, and heavy haze)

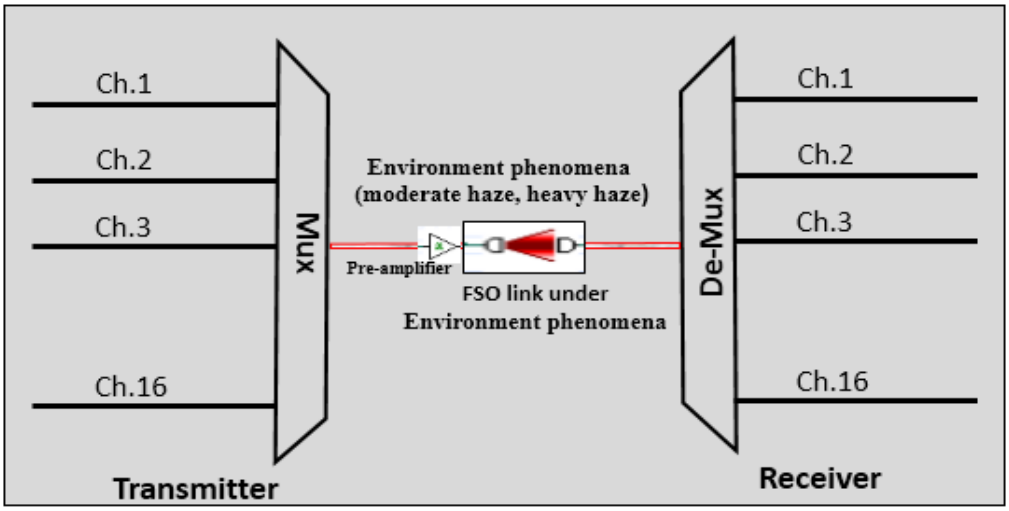

Figure 2 FSO based on SDM under environment phenomena (moderate haze, and heavy haze)

Results and Discussions

The performance measurement of 16-channels in FSO based on SDM under environment phenomena (moderate haze, and heavy haze) based on Bit Error Rate (BER) and Quality Factor (Q-Factor). Table 2 and Table 3 illustrate results of BER and Q-Factor of the 16-channels of FSO based on SDM system in the case of moderate haze phenomena with optical pre-amplifier from distance 0.6 KM to distance 3.8 KM. According to standard BER and Q-Factor, the results in the tables show acceptable results from the distance 0.6 KM to distance to 3.4 KM. However, at distance 3.8 KM the results is not acceptable.

Table 2 Results of 16-channels of FSO based on SDM moderate haze phenomena with optical amplifier and without optical amplifier from distance 0.6 KM to distance 3.8 KM based on BER measurement

	0.6 KM	**1 KM**	**1.4 KM**	**1.8 KM**	**2.2 KM**	**2.6 KM**	**3 KM**	**3.4 KM**	**3.8 KM**
CH.1	0	0	0	0	0	7.11E-136	4.35E-39	3.87E-11	8.09E-04
CH.2	0	0	0	0	0	9.28E-171	3.71E-51	8.29E-15	7.17E-05
CH.3	0	0	0	0	0	9.43E-169	2.11E-50	4.16E-14	2.08E-04
CH.4	0	0	0	0	0	3.76E-145	8.32E-41	2.39E-11	8.78E-04
CH.5	0	0	0	0	0	1.55E-105	1.49E-31	8.95E-10	1.51E-03
CH.6	0	0	0	0	0	1.14E-130	3.67E-38	4.24E-11	7.51E-04
CH.7	0	0	0	0	0	1.71E-116	1.02E-32	2.19E-09	2.53E-03
CH.8	0	0	0	0	0	1.74E-116	1.16E-32	9.06E-10	1.35E-03
CH.9	0	0	0	0	0	1.47E-141	7.16E-43	3.30E-12	6.29E-04
CH.10	0	0	0	0	0	9.24E-141	1.14E-40	3.06E-11	1.20E-03
CH.11	0	0	0	0	0	9.26E-149	1.58E-44	7.83E-13	2.99E-04
CH.12	0	0	0	0	0	5.26E-125	7.82E-38	3.54E-11	8.85E-04
CH.13	0	0	0	0	0	5.90E-136	5.59E-40	2.11E-11	7.73E-04
CH.14	0	0	0	0	0	1.22E-119	5.47E-37	1.76E-11	4.64E-04
CH.15	0	0	0	0	0	1.22E-119	2.09E-40	7.29E-11	1.35E-03
CH.16	0	0	0	0	0	7.00E-136	2.94E-41	4.94E-12	5.99E-04

Table 3 Results of 16-channels of FSO based on SDM moderate haze phenomena with optical amplifier and without optical amplifier from distance 0.6 KM to distance 3.8 KM based on Q-Factor measurement

	0.6 KM	1 KM	1.4 KM	1.8 KM	2.2 KM	2.6 KM	3 KM	3.4 KM	3.8 KM
CH.1	252.073	192.087	126.357	77.0351	44.65	24.7795	13.0246	6.50468	3.15253
CH.2	241.663	188.446	129.163	81.5707	48.8976	27.8283	14.9976	7.67363	3.80169
CH.3	227.629	174.314	120.604	77.9463	47.8131	27.6618	14.8817	7.46435	3.53002
CH.4	250.513	196.932	131.989	80.5847	46.5949	25.626	13.3233	6.5763	3.12811
CH.5	230.09	171.045	111.505	67.3999	39.0655	21.7846	11.6264	6.01545	2.96521
CH.6	254.061	197.02	128.494	76.73	43.9365	24.2917	12.861	6.49154	3.17405
CH.7	243.035	185.553	122.177	73.9314	42.2286	22.9103	11.851	5.86548	2.79864
CH.8	226.708	173.067	116.865	72.4024	41.9516	22.9097	11.8415	6.01291	3.00003
CH.9	230.703	174.148	116.212	72.933	43.9711	25.3031	13.9731	6.86498	3.22472
CH.10	231.764	176.671	119.585	75.1855	44.7736	25.2282	13.2993	6.5397	3.03623
CH.11	261.196	198.028	129.037	78.4786	45.9847	25.9472	13.948	7.06708	3.43186
CH.12	227.091	168.718	112.18	69.9058	41.6829	23.7485	12.8011	6.51785	3.12616
CH.13	234.151	177.972	118.343	73.6668	43.8952	24.7859	13.1784	6.59356	3.16307
CH.14	226.798	172.767	115.929	71.2691	41.4489	23.2238	12.6487	6.62007	3.30955
CH.15	226.795	174.99	119.889	76.0697	45.533	25.5672	1.33E+01	6.40886	2.99948
CH.16	236.818	199.29	119.43	74.0289	43.7592	24.7801	13.4005	6.80743	3.24276

Table 4 and Table 5 shows the results of BER and Q-Factor of the 16-channels of FSO based on SDM system in the case of heavy haze phenomena with optical amplifier from distance, 0.8 KM to distance to 1.6 KM based on Q-Factor measurement. According to standard BER and Q-Factor, the results in the tables show acceptable results from the distance 0.8 KM to distance 1.5 KM. However, at a distance 1.6 KM the results are not acceptable.

Table 4 Results of 16-channels of FSO based on SDM heavy haze phenomena with optical amplifier and without optical amplifier from distance 0.8 KM to distance 1.6 KM based on BER measurement

	0.8 KM	0.9 KM	1 KM	1.1 KM	1.2 KM	1.3 KM	1.4 KM	1.5 KM	1.6 KM
CH.1	0	0	0	2.25E-291	6.57E-135	1.06E-59	1.36E-25	4.50E-11	3.51E-05
CH.2	0	0	0	0	1.39E-169	3.57E-77	7.82E-34	1.01E-14	9.81E-07
CH.3	0	0	0	0	1.30E-167	1.93E-76	4.58E-33	5.07E-14	3.41E-06
CH.4	0	0	0	2.75e-315	4.24E-144	8.04E-63	1.57E-26	2.80E-11	3.56E-05
CH.5	0	0	0	7.00E-224	8.49E-105	4.67E-47	2.97E-21	1.01E-09	9.59E-05
CH.6	0	0	0	1.59E-280	9.62E-130	7.25E-58	3.52E-25	4.91E-11	3.31E-05
CH.7	0	0	0	1.32E-256	1.23E-115	3.33E-50	2.09E-21	2.48E-09	1.90E-04
CH.8	0	0	0	4.31E-255	1.24E-115	4.13E-50	1.38E-21	1.02E-09	8.96E-05
CH.9	0	0	0	7.43E-290	1.32E-140	1.29E-64	2.83E-28	3.91E-12	1.85E-05
CH.10	0	0	0	9.51E-297	8.92E-140	3.02E-62	1.78E-26	3.58E-11	4.91E-05
CH.11	0	0	0	1.729e-311	9.73E-148	3.62E-67	2.02E-29	9.33E-13	7.56E-06
CH.12	0	0	0	6.74E-259	3.74E-124	8.36E-57	3.51E-25	4.10E-11	3.57E-05
CH.13	0	0	0	1.99E-285	5.17E-135	1.04E-60	2.87E-26	2.46E-11	3.00E-05
CH.14	0	0	0	9.10E-252	8.03E-119	7.03E-55	5.52E-25	2.04E-11	1.72E-05
CH.15	0	0	0	1.58E-306	1.81E-143	1.15E-62	5.92E-26	8.49E-11	6.53E-05
CH.16	0	0	0	2.56E-283	5.98E-135	6.74E-62	2.06E-27	5.81E-12	1.82E-05

Table 5 Results of 16-channels of FSO based on SDM heavy haze phenomena with optical amplifier and without optical amplifier from distance 0.6 KM to distance 1.6 KM based on Q-Factor measurement

	0.8 KM	0.9 KM	1 KM	1.1 KM	1.2 KM	1.3 KM	1.4 KM	1.5 KM	1.6 KM
CH.1	1.01E+02	73.8251	52.47704	36.4594	24.6897	16.2512	10.3897	6.48218	3.97512
CH.2	1.05E+02	78.395	56.9426	40.3071	27.7309	18.5552	12.066	7.64787	4.75672
CH.3	9.92E+01	75.0618	55.3388	39.6822	27.5669	18.4643	11.9199	7.43817	4.49861
CH.4	1.06E+02	77.2232	54.8125	37.9391	25.5315	16.6863	10.5939	6.55306	3.97127
CH.5	8.89E+01	64.5682	45.8713	31.918	21.7065	14.3573	9.39014	5.99554	3.72958
CH.6	1.02E+02	73.4371	51.7921	35.7685	24.2041	15.9905	10.2991	6.46931	3.98975
CH.7	9.76E+01	70.7941	49.9013	34.1948	22.8241	14.8498	9.42436	5.84486	3.54995
CH.8	9.45E+01	69.432	49.4089	34.0926	22.824	14.8357	9.46951	5.99291	3.74628
CH.9	9.41E+01	70.1046	51.0869	36.3637	25.2145	16.9306	10.9627	6.84081	4.12427
CH.10	9.71E+01	72.2324	52.267	36.7986	25.1383	16.6068	10.5819	6.51615	3.89457
CH.11	1.03E+02	75.2395	53.811	37.7075	25.8565	17.273	11.1989	7.04279	4.32598
CH.12	9.06E+01	67.1396	48.5843	34.3481	23.666	15.8362	10.2983	6.49551	3.97085
CH.13	9.55E+01	70.7636	51.2128	36.0818	24.6983	16.3915	10.5355	6.57062	4.00431
CH.14	9.33E+01	68.3214	48.6981	33.8677	23.1427	15.5548	10.2537	6.59846	4.14058
CH.15	9.77E+01	73.1366	53.0667	37.4043	25.4746	16.6651	1.05E+01	6.38556	3.8251
CH.16	9.63E+01	71.0513	51.1755	35.9476	24.6935	16.5587	10.7823	6.78399	4.12913

Comparison Study

In this study compressions results of SDM over FSO link under the effect of environment phenomena such as (moderate haze phenomena and heavy haze phenomena) with optical amplifier and without optical amplifier based on eye diagram, BER, eye diagram and Q-Factor has been represented in Figure 3 and Figure 4. The performance results of the comparison of FSO based on SDM moderate haze phenomena at distance (1 KM, 1.8 KM, 2.6, and 3.4 KM) with optical amplifier and without optical amplifier based on eye diagram, BER, and Q-Factor has been illustrated in Figure 3. The results of BER, and Q-Factor based on pre-optical amplifier in the Figure 3 show acceptable results at distance 1 KM is (0 and 192.087), 1.8 KM is (0 and 77.035), 2.6 KM is (7.10683e-136 and 24.779), and 3.4 KM is (3.8725e-11 and 6.504). However, at more distance the results is not acceptable. Furthermore, The results of BER, and Q-Factor without pre-optical amplifier show in Figure 3 show acceptable results at distance 1 KM the result is (0 and 94.776), at distance 1.8 KM the result is (2.42039e-152 and 26.2628), at distance 2.6 Km the results is (6.6148e-10 and 6.0639). However, the results of BER and Q-Factor at distance 3.4 KM is (1 and 0) which is not acceptable.

On the other hand, The performance results of the comparison of FSO based on SDM heavy haze phenomena at distance (1.2 KM, 1.3 KM, 1.4, and 1.5 KM) with optical amplifier and without optical amplifier based on eye diagram, BER, and Q-Factor has been illustrated in Figure 4. The results of BER, and Q-Factor based on pre-optical amplifier in the Figure 4 show acceptable results at distance 1.2 KM the result is (6.5697e-135 and 192.087), at distance 1.3 KM the result is (1.06444e-59 and 16.2512), at

distance 1.4 KM the results is (1.36307e-25 and 10.3897), and at distance 1.5 KM the result is (4.49708e-11 and 6.48248). However, at more distance the results is not acceptable. Furthermore, the results of BER and Q-Factor without pre-optical amplifier show in Figure 4 show acceptable results at distance 1.2 KM the result is (7.85122e-10 and 6.0363). However, the results of BER and Q-Factor at distance 1.3 KM the result is (0.000150175 and 3.61481), at distance 1.4 Km the results is (0.0157793 and 2.14995) and at distance 1.5 KM the result is (1 and 0) which is not acceptable.

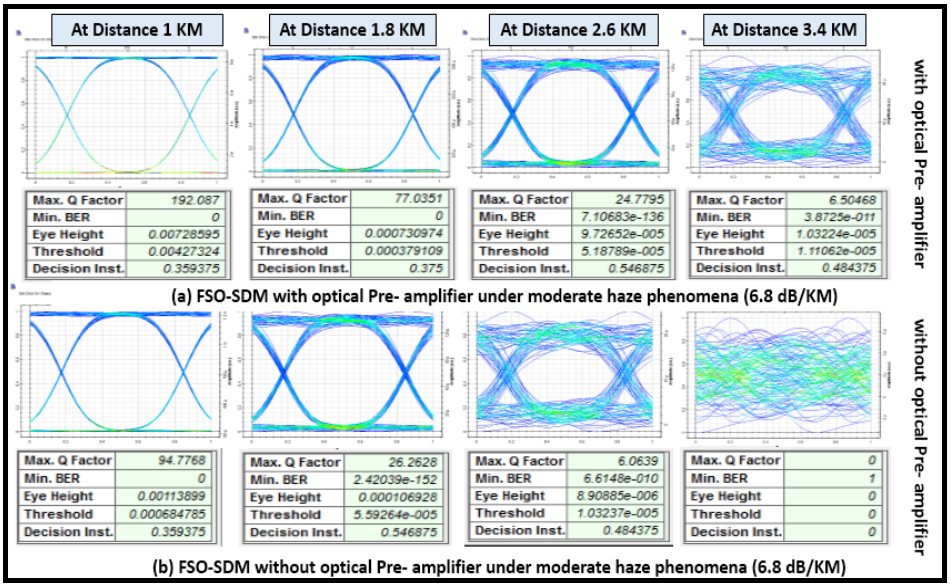

Figure 3 Results of the comparison of FSO based on SDM moderate haze phenomena with optical amplifier and without optical amplifier from distance (1 KM, 1.8 KM, 2.6, and 3.4 KM) based on eye diagram, BER, and Q-Factor

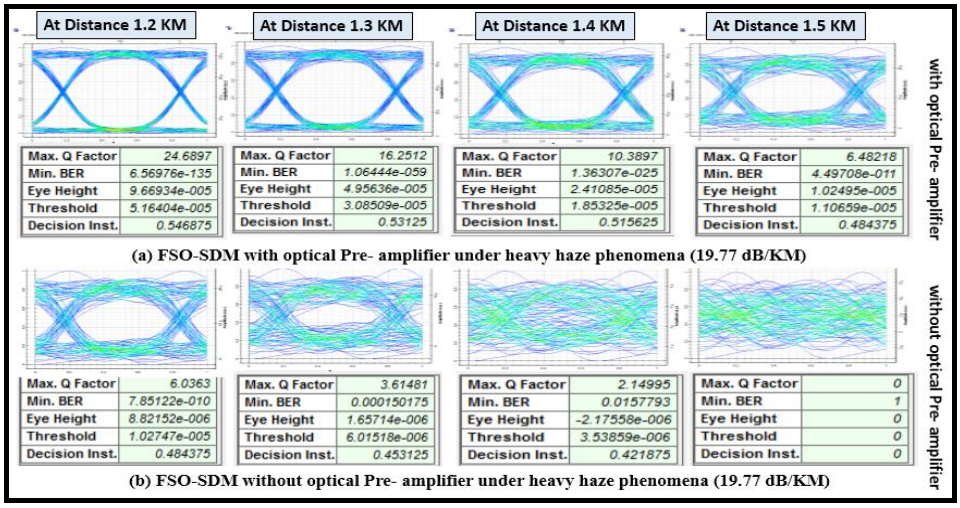

Figure 4 Results of the comparison of FSO based on SDM under heavy haze phenomena with optical amplifier and without optical amplifier from distance 1.2 KM to distance 1.5 KM based on eye diagram, BER, and Q-Factor

Conclusion

Optical Communication of Free Space runs extensive applications in entire areas. Faster installation, license-free spectrum, no necessity for bringing out in communications of FSO. This study successfully transmitted 160 GB/s SDM over the FSO communication system at the distances 1 Km to distance 3.4 KM for moderate haze phenomena with a pre-optical amplifier and without a pre-optical amplifier rich to distance 2.6 KM. Moreover, this study also successfully transmitted 160 GB/s SDM over the FSO communication system at the distances 1.2 Km to distance 1.5 KM for heavy haze phenomena with a pre-optical amplifier and without a pre-optical amplifier maximum distance until 1.2 KM. In this study, Opti-system simulation has been applied to evaluate and present the performance results of 16-channels in SDM over the FSO link with based on erbium-doped fiber amplifiers (EDFA) Pre-amplifier under the effect of environment phenomena such as (moderate haze phenomena and heavy haze phenomena) based on BER, and Q-Factor and eye diagram.

References

AL-Dawoodi, A., Maraha, H., Alshwani, S., Ghazi, A., Fakhrudeen, A.M., Aljunid, S., & Ameen, K.A. (2019). Investigation of 8 x 5 Gb/s mode division multiplexing-fso system under different weather condition. *Journal of Engineering Science and Technology, 14*(2), 674-681.

Alshwani, S., Fakhrudeen, A.M., Ismael, M.N., Al-Dawoodi, A., & Ghazi, A. (2019). Hermite-gaussian mode in spatial division multiplexing over FSO system under different weather condition based on linear gaussian filter. *International Journal of Mechanical Engineering and Technology, 10*(1), 1095-1105.

Amphawan, A., Ghazi, A., & Al-dawoodi, A. (2017). *Free-space optics mode-wavelength division multiplexing system using LG modes based on decision feedback equalization.* Paper presented at the EPJ Web of Conferences.

Amphawan, A., Nedniyom, B., & Al Samman, N.M. (2013). Selective excitation of LP01 mode in multimode fiber using solid-core photonic crystal fiber. *Journal of Modern Optics, 60*(20), 1675-1683.

Bayaki, E., Michalopoulos, D.S., & Schober, R. (2012). EDFA-based all-optical relaying in free-space optical systems. *IEEE Transactions on Communications, 60*(12), 3797-3807.

Chaudhary, S., & Amphawan, A. (2018a). High-speed MDM-Ro-FSO system by incorporating spiral-phased Hermite Gaussian modes. *Photonic Network Communications, 35*(3), 374-380.

Chaudhary, S., & Amphawan, A. (2018b). Selective excitation of LG 00, LG 01, and LG 02 modes by a solid core PCF based mode selector in MDM-Ro-FSO transmission systems. *Laser Physics, 28*(7), 075106.

Chaudhary, S., & Amphawan, A. (2018c). Solid core PCF-based mode selector for MDM-Ro-FSO transmission systems. *Photonic Network Communications, 36*(2), 263-271.

Ghazi, A., Aljunid, S., Idrus, S.Z.S., Fareed, A., Al-dawoodi, A., Hasan, Z., & Abdullah, S.S. (2021). Hybrid Dy-NFIS & RLS equalization for ZCC code in optical-CDMA over multi-mode optical fiber. *Periodicals of Engineering and Natural Sciences (PEN), 9*(1), 253-276.

Ghazi, A., Aljunid, S., Idrus, S.Z.S., Rashidi, C., Al-dawoodi, A., Mahmood, B.A., & Rafeeq, R.M. (2021). A Systematic review of Multi-Mode Fiber based on Dimensional Code in Optical-CDMA. *Paper presented at the Journal of Physics: Conference Series.*

Ghazi, A., Aljunid, S., Noori, A., Idrus, S.Z.S., Rashidi, C., & Al-Dawoodi, A. (2019). Design & investigation of 10x10 gbit/s MDM over hybrid FSO link under different weather conditions and fiber to the home. *Bulletin of Electrical Engineering and Informatics, 8*(1), 121-126.

Ghazi, S.A.A., Idrus, S., Fareed, A., Hamood, L., Endut, R., Ali, N., & Matem, R. (2021). Comparison of MD & ZCC one dimension code for optical-CDMA over multi-mode fiber based on Laguerre-Gaussian modes. *Journal of Engineering Science and Technology, 16*(4), 3588-3599.

Guide, O.U. (2010). RSOFT Design Group: Inc.

Hossain, F., & Afroze, Z. (2013). Eliminating the effect of fog attenuation on FSO link by multiple TX/RX system with travelling wave semiconductor optical amplifier. *In 2nd International Conference on Advances in Electrical Engineering (ICAEE)*, 267-272.

Ismael, M.N., & Fakhrudeen, A.M. (2019). SDM over hybrid FSO link under different weather conditions and FTTH based on electrical equalization. *International Journal of Civil Engineering and Technology (IJCIET), 10*(1), 1396-1406.

Jung, Y., Chen, R., Ismaeel, R., Brambilla, G., Alam, S.U., Giles, I., & Richardson, D. (2013). Dual mode fused optical fiber couplers suitable for mode division multiplexed transmission. *Optics Express, 21*(20), 24326-24331.

Kanno, A., Inagaki, K., Morohashi, I., Sakamoto, T., Kuri, T., Hosako, I., & Kitayama, K.I. (2011). 40 Gb/s W-band (75–110 GHz) 16-QAM radio-over-fiber signal generation and its wireless transmission. *Optics Express, 19*(26), B56-B63.

Khajwal, T.N., Mushtaq, A., & Kaur, S. (2020). Performance analysis of FSO-SISO and FSO-WDM systems under different atmospheric conditions. *In 7th International Conference on Signal Processing and Integrated Networks (SPIN)*, 312-316.

Koshy, A. S., & Babu, J. S. (2016). Impact of erbium doped fiber amplifier on WDM-FSO system under rain attenuations. *International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering, 5*, 867-872.

Kunzler, L.M., & Lopes, L.A. (2020). A novel algorithm for increased power balance in cascaded H-bridge multilevel cells in a hybrid power amplifier. *Electrical Engineering*, 1-12.

Mahajan, S., Parkash, D., & Singh, H. (2020). Design and Investigation of Multiple TX/RX FSO Systems Under Different Weather Conditions *Proceedings of ICRIC 2019*, 377-388.

Maraha, H., Ameen, K.A., Mahmood, O.A., & Al-dawoodi, A. (2020). DWDM over FSO under the effect of different atmospheric attenuations. *Indonesian Journal of Electrical Engineering and Computer Science, 18*(2), 1089-1095.

Mathur, A., Saxena, P., & Bhatnagar, M.R. Performance of Optically Pre-amplified FSO System under Gamma-Gamma Turbulence with Pointing Errors and ASE Noise.

Naila, C.B., Wakamori, K., & Matsumoto, M. (2011). Transmission analysis of M-ary phase shift keying multiple-subcarrier modulation signals over radio-on-free-space optical channel with aperture averaging. *Optical Engineering, 50*(10), 105006.

Release, M. (2013). The mathworks. *Inc., Natick, Massachusetts, United States, 488*.

Ryf, R., Randel, S., Gnauck, A.H., Bolle, C., Essiambre, R.J., Winzer, P.J., & Lingle, R. (2011). Space-division multiplexing over 10 km of three-mode fiber using coherent 6× 6 MIMO processing. *In National Fiber Optic Engineers Conference*, PDPB10.

Singh, M. (2017). Enhanced performance analysis of inter-aircraft optical wireless communication link (IaOWC) using EDFA Pre-amplifier. *Wireless Personal Communications, 97*(3), 4199-4209.

Singh, M., & Malhotra, J. (2020). Performance comparison of different modulation schemes in high-speed MDM based radio over FSO transmission link under the effect of atmospheric turbulence using aperture averaging. *Wireless Personal Communications, 111*(2), 825-842.

Tang, X., Ghassemlooy, Z., Rajbhandari, S., Popoola, W.O., & Lee, C.G. (2012). Coherent heterodyne multilevel polarization shift keying with spatial diversity in a free-space optical turbulence channel. *Journal of lightwave technology, 30*(16), 2689-2695.

Zhou, H., Mao, S., & Agrawal, P. (2014). Optical power allocation for adaptive WDM transmissions in free space optical networks. *In IEEE wireless communications and networking conference (WCNC)*, 2677-2682.