ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2015.0174

INVESTIGATION ON HYBRID WDM (DWDM+CWDM) FREE SPACE OPTICAL COMMUNICATION SYSTEM

S. Robinson[1], S. Jasmine[2] and R. Pavithra[3]
[1,2,3]Department of Electronics and Communication Engineering, Mount Zion College of Engineering and Technology, India
E-mail: [1]mail2robinson@gmail.com, [2]jasminesasthar@gmail.com, [3]pavikutti10@gmail.com

Abstract

Free Space Optical (FSO) communication is being realized as an effective solution for future accessing networks, offering light passed through air. The performance of FSO can be primarily degraded by various atmospheric attenuation namely, rain, fog, haze and snow. At present, hybridization of Dense Wavelength Division Multiplexing (DWDM) with Coarse Wavelength Division Multiplexing (CWDM) becomes necessary to scale the speed and high bandwidth of the services. In this paper, hybrid WDM system is proposed, designed and the network parameters such as Bit Error Rate (BER), Quality Factor and receiver sensitivity are analyzed with respect to link distance for various weather conditions. For investigation, 4 CWDM and 8 DWDM channels are considered whose corresponding channel spacing is 20nm and 0.8nm, respectively. From the simulation, it is investigated that the average link distance of proposed hybrid WDM-FSO system for DWDM and CWDM system at very clear condition are around 810km and 780km. The proposed hybrid WDM based FSO system is designed to handle the quality of transmission for 12 users, each at a data rate of 2.5Gbps.

Keywords:

FSO, Hybrid WDM, CWDM, DWDM, BER

1. INTRODUCTION

Free Space Optical (FSO) communication is a promising communication technique for various types of communication networks. FSO system is similar to conventional fiber optical system, however, no laying of fiber optical cable is needed, and no expensive roof top installations are required [1]. In addition to a aforementioned advantages, FSO can able to transfer the data rate around 2.5Gbps, unlike the smaller maximum data rate of 10-622 Mbps offered by RF communication systems [2, 3]. FSO has good prospects for widespread implementation and continuously ready to utilization as satellite link, terrestrial links and mobile links with the use of new compact laser communication terminal [4]. Although the FSO system having significant benefits, it is essential to consider internal parameters such as lasing power, transmission wavelength, transmission bandwidth, receiver sensitivity and external parameters like dislocation due to climatology conditions, atmospheric attenuation, window loss, scintillation, in order to attain higher quality of service [5]. The wide spread deployment of conventional Wavelength Divison Multiplexing based FSO system severely limited by adverse effects of atmospheric environment structure such as haze, rain, fog and snow [6]. Typically, the laser beam propagation affected by three factors are absorption, turbulence induced scintillation and multiple scattering effects or geometric losses. Atmospheric trace gas carbon dioxide and water vapor lead to strong broad absorption band [4, 7]. However, atmospheric turbulence produces fluctuations in the irradiance of the transmitted optical beam, which is known as atmospheric scintillation, severely degrading the link performance [8]. Attenuation due to rain fall rate, snow rate is also called non-selective scattering that are made of larger molecules. Generally, geometrical scattering affects wavelength and altitude those results in high bit error rate or signal loss at receiver end [9]. Signal Quality always inversely proportional to attenuation factor and BER [10].

WDM is used to simultaneously transmit the different wireless service signals independently over the FSO link [11]. There are two types of WDM implementation, coarse wavelength division multiplexing (CWDM) and Dense Wavelength division multiplexing (DWDM). In conventional fiber optical communication system, DWDM (ITU-T G.694.1) channels with the channel spacing of 1.6nm/0.8nm/0.4nm (200GHz/100GHz/50GHz) and CWDM (ITU-T G.694.2) channels with the channel spacing of 20nm are utilized for reliable communication [12]. The wavelength range of CWDM system is 1260nm-1625nm whereas DWDM spans from 1470nm-1625nm. Recently, combination of CWDM and DWDM system (Hybrid WDM) is proposed in order to enhance the quality and utilization of the network. In hybrid WDM system, the DWDM channels and CWDM channels are multiplexed and transferred through optical fiber and the receiver separated the multiplexed signals using demultiplexer and sent to its corresponding destination. In hybrid WDM-FSO system, the DWDM and CWDM signals are combined and transmitted through free space and it’s collected by the receiver. In general, DWDM is the best choice for applications where channel density/bandwidth is of high priority. At the same time, CWDM remains an excellent option for applications where deployment costs are to be considered [13]. Conventional FSO systems operate near the 850nm spectral range. Unfortunately, optical devices using the 850nm spectral range cannot operate above 2.5Gbps because of the power limitations imposed for eye safety. In order to overcome the power limitations, 1550nm wavelength is selected for new ultra high speed FSO systems and its advantages apart from being eye safety include reduced solar background radiation and compatibility with existing optical fiber technology infrastructure [14]-[20]. By using 1550nm wavelength, Mbps wireless transmission can be achieved by leveraging the technology developed for long haul optical communication.

WDM technique is one of the primary multiplexing technique in optical communication in order to enhance the bandwidth utilization for high demand broadband applications, where many number of signals with its designated wavelength are multiplexed with single medium and it’s separated at its destination. The hybrid WDM-FSO is a new research area which is proposed to overcome the limited received power, limited distance and limited scalability which are occurred in normal FSO system [21].

In the literature, so far there is no much attempt is made in hybrid WDM-FSO. However there are some attempts is made to for hybrid WDM using single beam [14]-[20] and multiband concept [21-23] where they have considered only DWDM channels with the channel spacing of 0.8nm over the wavelength range of around 850nm and 1550nm. Also, the authors did not accounted CWDM channels. In multibeam hybrid WDM-FSO, the source and detector is kept on increasing according to the number of incoming channels which in turn increases the cost of the network. In this paper, hybrid WDM-FSO system is proposed and designed and the network parameter such as BER, Q factor and Receiver sensitivity are analyzed for various atmospheric conditions. The hybrid WDM is carried out by considering DWDM and CWDM channels combinedly for signal transmission through free space.

The paper is organized as follows: the design of hybrid WDM-FSO system is discussed in section 2. The effect of link distance and Quality factor with respect to various atmospheric conditions for the proposed system is reported in section 3. Finally, section 4 concludes the paper.

2. HYBRID WDM-FSO SYSTEM

The proposed hybrid WDM based FSO system model is illustrated in Fig.1 which is comprised of three parts namely, transmitter, receiver and FSO link or atmospheric conditions. The transmitter consists of CW laser, Mach-Zehnder modulator, Pseudo-Random Bit Sequence (PRBS) Generator, NRZ Pulse Generator and Hybrid Wavelength Division Multiplexing (HWDM). HWDM comprising four CWDM channels spaced by 20nm, a set of eight DWDM channels spaced by 0.8nm) whereas in receiver part demultiplexer is used to separate the optical beam profile at a high rate of 2.5Gbps with different wavelengths. The designated wavelengths for DWDM channels are (1537.4nm, 1538.2nm, 1539nm, 1539.8nm, 1540.6nm, 1541.4nm, 1542.2nm, 1543nm) and CWDM channels (1510nm, 1530nm, 1550nm, 1570nm). APD photodiode is utilized to convert optical signal in to electrical signal, followed by low pass Bessel filter to filter the unwanted signal. We considered aperture size and transmitted power keep constant an entire attempt from lesser to larger attenuations. The space between transmitter and receiver is considered as FSO link distance or atmospheric distance. FSO system has been designed and simulated using optisystem7.0. The simulation parameters are listed in Table.1.

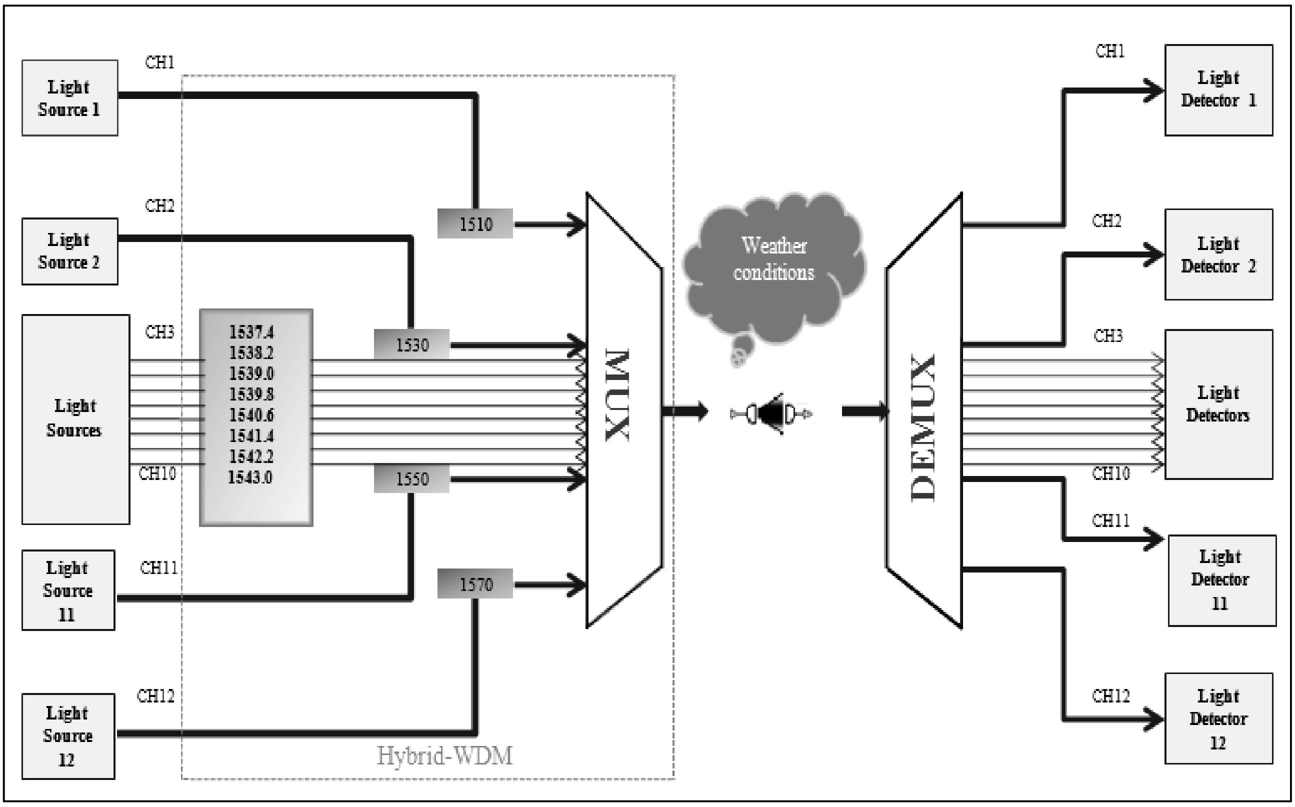


Fig.1. Schematic representation of Hybrid WDM-FSO system

Table.1. Simulation Parameters of Free Space Optical Communication System

Parameters	Values
Data Rate	2.5Gbps
Launch Power	20dBm
Channel Spacing: CWDM/DWDM Laser linewidth: CWDM/ DWDM	20nm/0.8nm 10MHz/2500MHz
Average Link Range	800km
Transmitter's & Receiver's Apertures	30cm
Dark Current	10nA
Extinction Ratio WDM Bandwidth: CWDM/DWDM	30dB 10GHz/20GHz

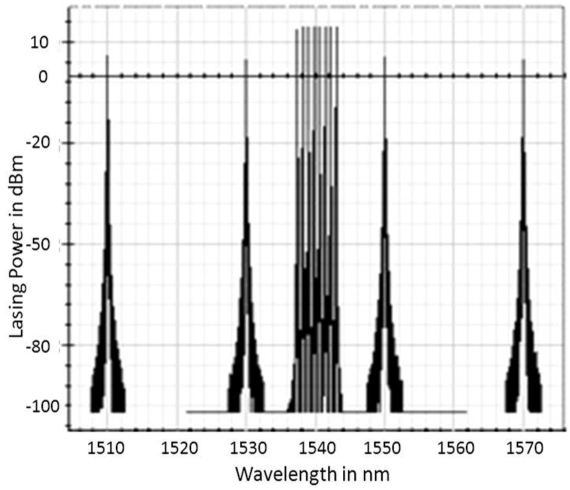
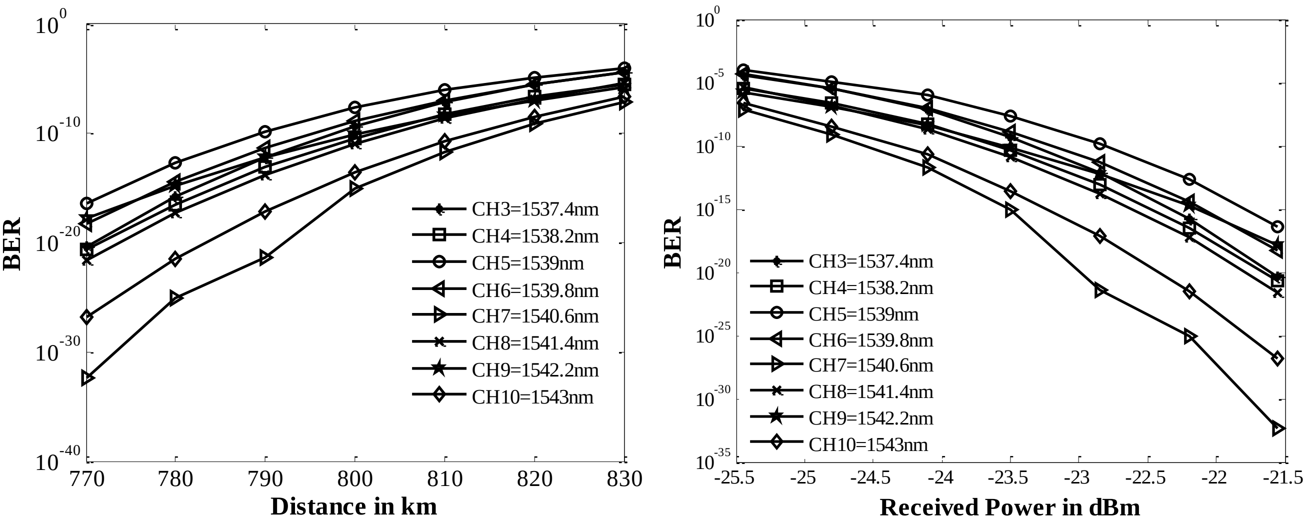


Fig.2. Power spectrum of transmitted signal in the proposed hybrid WDM-FSO system

3. SIMULATION RESULTS AND DISCUSSION

Four CWDM input and eight DWDM input signal is applied from the laser source which is combined through multiplexer and transmitted over free space. The received signal at the destination is separated by demultiplexer. The FSO system parameter such as Bit Error Rate (BER), receiver sensitivity, quality factor and transmission distance is estimated for the proposed Hybrid WDM-FSO system. The transmitted hybrid WDM-FSO signal after the multiplexer is shown in Fig.2, whose corresponding signal power is about 15dBm for DWDM Channels and 5dBm for CWDM channels. This variation in received power is due to the losses in the components that are employed in the link and linewidth of the proposed system.

The Fig.3(a) and Fig.3(b) shows the effect of BER with respect to link distance and receiver sensitivity of the proposed hybrid WDM-FSO system at very clear conditions. The average link distance and receiver sensitivity for the BER of 10-9 for DWDM channels are 810km and -21dBm. Similarly, the average link distance for CWDM channels are 780km which is depicted in Fig.4. It is noticed that the receiver sensitivity for CWDM and DWDM channels are about -21dBm and the link distance for CWDM channels are reduced than DWDM Channels as the linewidth of the CWDM channels are higher than DWDM channels. BER determine the FSO receiver performance at high data rate of 2.5Gbps. The signal quality is reduced while increasing BER at receiver resulting in minimum transmission distance. It is investigated that the minimum received power to obtain the desired BER (10-9) lies -21dBm for DWDM and CWDM channels.



(a) (b)

Fig.3. (a) BER vs Distance (b) BER vs Received Power for DWDM system at Very clear condition

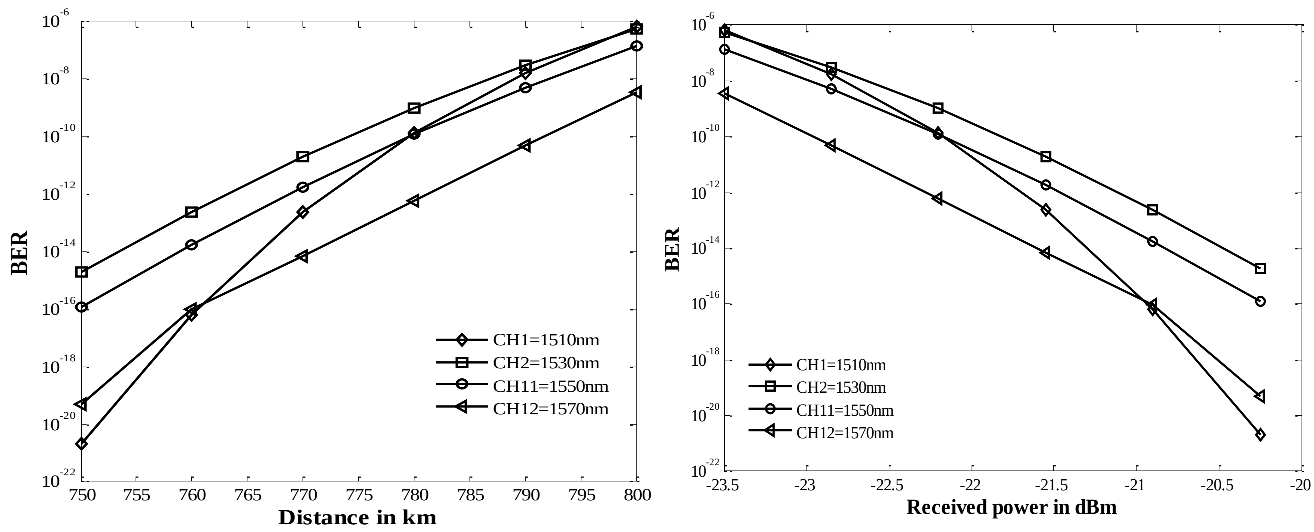
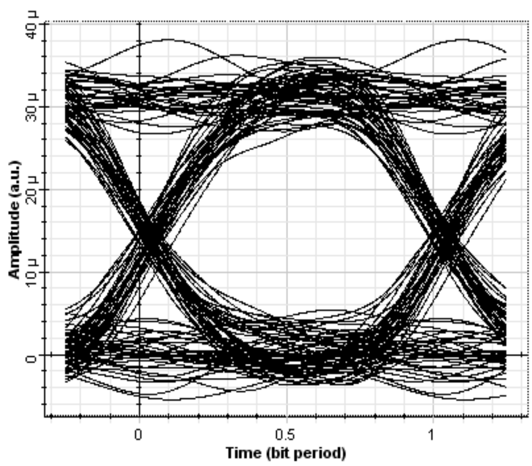


Fig.4. (a) BER vs Distance (b) BER vs Received Power for CWDM system at Very clear condition

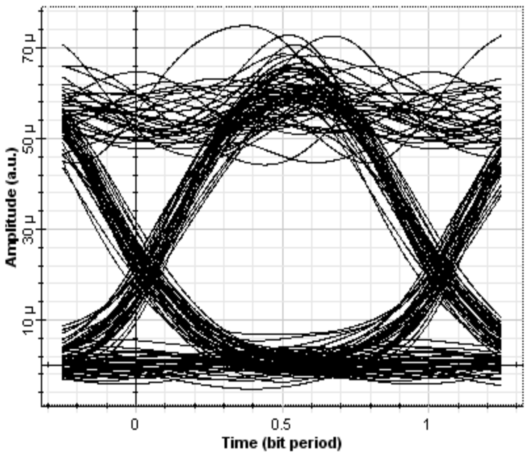
Table.2. Maximum Link Range of proposed hybrid WDM-FSO for various atmospheric conditions

Weather Conditions	**Travelling Distance in Km DWDM Channels**								**Travelling Distance in Km CWDM Channels**			
	CH3	**CH4**	**CH5**	**CH6**	**CH7**	**CH8**	**CH9**	**CH10**	**CH1**	**CH2**	**CH11**	**CH12**
Very clear Clear	798 225	810 225	795 222	800 224	825 229	810 227	810 227	820 228	785 220	780 210	790 220	800 222
Light haze Heavy haze	95 22.1	95 22.1	94 22	95 22.1	97 22.4	96 22.3	96 22.2	98 22.5	93 21.5	92 21	93 21.5	94 22
Light fog Thick fog	3.4 2.05	3.5 2. 06	3.35 2.04	3.4 2.05	3.5 2.06	3.47 2.06	3.47 2.06	3.55 2.1	3.25 2	3.2 2	3.25 2.03	3.35 2.04
Light rain Medium rain Heavy rain	8.35 5.55 2.65	8.4 5.6 2.62	8.27 5.4 2.6	8.3 5.5 2.65	8.45 5.7 2.68	8.4 5.5 2.65	8.4 5.5 2.65	8.5 5.8 2.7	8.15 5.2 2.55	8.15 5.2 2.55	8.2 5.2 2.5	8.27 5.4 2.6
Wet snow	8.45	8.5	8.37	8.4	8.55	8.5	8.5	8.6	8.25	8.25	8.3	8.37
Dry Snow	3.64	3.65	3.63	3.64	3.68	3.66	3.66	3.69	3.58	3.58	3.58	3.62

The Table.2 reported that the maximum transmission distance of proposed hybrid WDM-FSO at various atmospheric conditions by incorporating its calculated attenuation values [24]. From the table it is clearly noticed that the transmission distance is decreased while increasing the attenuation for all the channels. It is noticed that DWDM channels can able to transfer the data longer distance than CWDM system. The maximum link distance for CWDM system is limited to the channel width and nature of the wavelength. In addition, link distance is decreased while increasing attenuation value. The eye diagram for DWDM (Channel 3) and CWDM (Channel 12) system at very clear condition is shown in Fig.5(a) and Fig.5(b), respectively. From the figure it is clearly seen that the eye opening and its relative eye pattern is highly sufficient to detect the received signal.



(a)



(b)

Fig.5. Eye diagram of (a) DWDM channel (1537.4nm) (b) CWDM channel (1570nm) at very clear condition

4. CONCLUSION

In this paper, hybrid WDM-FSO system is proposed, designed and the network parameters namely BER, Q Factor, Receiver sensitivity are analyzed. For the transmission of 2.5Gbps data, the proposed hybrid WDM-FSO system supports the optical link range up to 830km under very clear weather condition. When the atmospheric attenuation increased (dry snow condition), the achievable distance is extended to 0.64km with acceptable BER. In addition, that the link distance for DWDM system is higher than CWDM system owing to the linewidth. Also, the travelling distance is decreased while increasing the attenuation values. The hybrid WDM network could be a right candidate to solve the last mile problems and the rapid increase in capacity without any new infrastructure by combining CWDM and DWDM channels.

REFERENCES

[1] M.A. Khalighi and M. Uysal, “Survey on Free Space Optical Communication: A Communication Theory Perspective”, *IEEE Communications Surveys & Tutorials*, Vol. 16, No. 4, pp. 2231-2258, 2014.

[2] S.A. Al-Gailani, A.B. Mohammad and R.Q. Shaddad, “Evaluation of a 1 Gb/s Free Space Optic System in Typical Malaysian Weather”, *Proceedings of IEEE 3rd International Conference on Photonics*, pp. 121-124, 2012.

[3] A. Mahdy and J.S. Deogun, “Wireless Optical Communications: A Survey”, *Proceedings of IEEE Wireless Communications and Networking Conference*, Vol. 4, pp. 2399- 2404, 2004.

[4] G. Nykolak, P.F. Szajowski, G. Tourgee and H. Presby. “2.5Gbit/s Free Space Optical Link over 4.4km”, *Electronic Letters*, Vol. 35, No. 7, pp. 578-579, 1999.

[5] A. Ramezani, M.R. Noroozi and M. Aghababaee, “Analyzing Free Space Optical Communication Performance”, *International Journal of Engineering and Advanced Technology*, Vol. 4, No. 1, pp. 46-51, 2014.

[6] Scott Bloom, Eric Korevaar, John Schuster and Heinz Willebrand, “Understanding the Performance of Free Space Optics”, *Journal of Optical Networking*. Vol. 2, No. 6, pp. 178-200, 2003.

[7] Jitendra Singh and Naresh Kumar, “Performance Analysis of Different Modulation Format on Free Space Optical Communication System”, *Optik - International Journal of Light and Electron Optics*, Vol. 124, No. 20, pp. 4651-4654, 2013.

[8] Antonio García-Zambrana, Carmen Castillo-Vázquez and Beatriz Castillo-Vázquez, “*Rate-Adaptive Free-Space Optical Links over Atmospheric Turbulence and Misalignment Fading Channels*”, Book Chapter 13, Intech Open Science, pp. 321-340, 2012.

[9] Hilal A. Fadhil, Angela Amphawan, Hasrul A.B. Shamsuddin, Thanaa Hussein Abd, Hamza M.R. Al-Khafaji, S.A. Aljunid, Nasim Ahmed, “Optimization of Free Space Optics Parameters: An Optimum Solution for Bad Weather Conditions”, *Optik - International Journal of Light and Electron Optics*, Vol. 124, No. 19, pp. 3969-3973, 2014.

[10] Aditi Malik and Preeti Singh, “Comparative Analysis of Point to Point FSO System Under Clear and Haze Weather Conditions”, *Wireless Personal Communications*, Vol. 80, No. 2, pp. 483-492, 2015.

[11] Mitsuji Matsumoto, “Next Generation Free-space Optical System by System Design Optimization and Performance Enhancement”, *Proceedings of Progress in Electromagnetics Research Symposium*, pp. 501-506, 2012.

[12] ITU-T Recommendation G 694.2, Spectral Grids for WDM Applications: CWDM Wavelength Grid, 2003, Available at https://www.itu.int/rec/T-REC-G.694.2/en

[13] B. Patnaik and P.K. Sahu, “Novel QPSK Modulation for DWDM Free Space Optical Communication System”, *Wireless Advanced*, pp. 170-175, 2012.

[14] Salasiah Hitam, Siti N. Suhaimi, Ahmad S.M. Noor, Siti B.A. Anas and Ratna K.Z. Sahbudin, “Performance Analysis on 16-Channels Wavelength Division Multiplexing in Free Space Optical Communication Under Tropical Regions Environment”, *Journal on Computer Science*, Vol. 8, No. 1, pp. 145-148, 2012.

[15] Hilal A. Fadhil, Angela Amphawan, Hasrul A.B. Shamsuddin, Thanaa Hussein Abd, Hamza M.R. Al - Khafaji, S.A. Aljunid and Nasim Ahamed, “Optimization of Free Space Optics Parameters: An Optimum Solution for Bad Weather Conditions”, *Optik - International Journal of Light and Electron Optics*, Vol. 124, No. 19, pp. 3969-3973, 2013.

[16] Abisayo O. Aladeloba, Malcolm S. Woolfson and Andrew J. Phillips, “WDM FSO Network with Turbulence Attenuated Interchannel Crosstalk”, *Journal of Optical Communication and Networking*, Vol. 5, No. 6, pp. 641-651, 2013.

[17] E. Ciarramella, Y. Arimoto, G. Contestabile, M. Presi, A. D’Errico, V. Guarino and M. Matsumoto, “1.28 terabit/s (32x40 Gbit/s) WDM Transmission System for Free Space Optical Communications”, *IEEE Journal on Selected Areas in Communications*, Vol. 27, No. 9, pp. 1639-1645, 2009.

[18] Ibrahim Khalil, Atanu Biswas, Rakibul Bari Rakib, Md. Abu Sayeed and Md. Sohel Mahmud Sher, “WDM Transmission for Free Space Optics Under Different

Atmospheric Conditions", *Trends in Opto-Electro & Optical Communications*, Vol. 4, No. 1, pp. 1-4, 2014.

[19] Ming Sheng and Xiu-xiu Xie, "Average Bit Error Rate Analysis for Free-Space Optical Communications Over Weak Turbulence with Pointing Errors", *Optical Engineering*, Vol. 51, No. 10, pp. 5009-5014, 2012.

[20] D.W. Young *et al.*, "Demonstration of High Data Rate Wavelength Division Multiplexed Transmission Over A 150km Free Space Optical Link", *Proceedings of IEEE Military Communications Conference*, pp. 1-6, 2007.

[21] Nur Haedzerin Md. Noor, Ahmed Wathik Naji and Wajdi Al-Khateeb, "Performance Analysis of a Free Space Optics Link with Multiple Transmitters/Receivers", *IIUM Engineering Journal*, Vol. 13, No. 1, pp. 49-58, 2012.

[22] S.A. Al-Gailani, A.B. Mohammad and R.Q. Shaddad, "Enhancement of Free Space Optical Link in Heavy Rain Attenuation Using Multiple Beam Concept", *Optik - International Journal of Light and Electron Optics*, Vol. 124, No. 21, pp. 4798-4801, 2013.

[23] S.A. Al-Gailani, A.B. Mohamed, R.Q. Shaddad, U.U. Sheikh and M.A. Elmagzoub, "Hybrid WDM/Multibeam Free Space Optics for Multigigabit Access Network", *Photonic Network Communications*, Vol. 29, No. 2, pp. 138-145, 2014.

[24] S. Jasmine, S. Robinson and K. Malaisamy, "Investigation on Free Space Optical Communication for Various Atmospheric Conditions", *Proceedings of 2nd International Conference on Electronics and Communications Systems*, pp. 1030-1034, 2015.