Beam divergence and operating wavelength bands effects on free space optics communication channels in local access networks

Article *in* Journal of Optical Communications · August 2020

DOI: 10.1515/joc-2019-0276

5 authors, including:

Aadel M Alatwi
University of Tabuk
32 PUBLICATIONS **1,997** CITATIONS

Ahmed Nabih Zaki Rashed
faculty of electronic engineering menoufia university
531 PUBLICATIONS **14,816** CITATIONS

Shahriar Rifat Parvez
Jahangirnagar University
1 PUBLICATION **105** CITATIONS

Bikash Kumar Paul
Mawlana Bhashani Science and Technology University
161 PUBLICATIONS **4,802** CITATIONS

Aadel M. Alatwi, Ahmed Nabih Zaki Rashed, AHM Shahriar Parvez, Bikash Kumar Paul* and Kawsar Ahmed

Beam divergence and operating wavelength bands effects on free space optics communication channels in local access networks

https://doi.org/10.1515/joc-2019-0276
Received November 4, 2019; accepted June 2, 2020; published online August 8, 2020

Abstract: The paper outlines the divergence of beam and operating wavelength bands effects on free-space optics communication channels in local access networks. The max Q factor and min bit error rate are measured based on the divergence of beam and operating wavelength bands variations. The signal is tested also at the receiver side by using an optical power meter visualizer at various operating signal wavelength bands and under the optimum values of the divergence of the beam. The study has presented the optimum operating conditions for upgrading network operation efficiency.

Keywords: beam divergence; free space optics; local access networks; wavelength bands.

***Corresponding author: Bikash Kumar Paul**, Department of Software Engineering, Daffodil International University, Sukrabad, Dhanmondi, Dhaka, 1207, Bangladesh; Group of Bio-photomatiχ, Mawlana Bhashani Science and Technology University, Santosh, Tangail, 1902, Bangladesh; and Department of Information and Communication Technology, Mawlana Bhashani Science and Technology University, Santosh, Tangail, 1902, Bangladesh, E-mail: bikash.k.paul@ieee.org. https://orcid.org/0000-0002-4414-2751
Aadel M. Alatwi: Electrical Engineering Department, Faculty of Engineering, University of Tabuk, Tabuk, Saudi Arabia, E-mail: aadel.alatwi@ut.edu.sa
Ahmed Nabih Zaki Rashed: Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia University, 32951, Menouf, Egypt, E-mail: ahmed_733@yahoo.com
AHM Shahriar Parvez: Department of Computer Science and Engineering, Bangladesh University, 15/1, Iqbal Road, Mohammadpur, Dhaka, 1207, Bangladesh; Department of Computer Science and Engineering, Dhaka University of Engineering & Technology, Gazipur, Bangladesh, E-mail: sha0131@gmail.com
Kawsar Ahmed: Group of Bio-photomatiχ, Mawlana Bhashani Science and Technology University, Santosh, Tangail, 1902, Bangladesh; Department of Information and Communication Technology, Mawlana Bhashani Science and Technology University, Santosh, Tangail, 1902, Bangladesh, E-mail: k.ahmed.bd@ieee.org

1 Introduction

In Radio over fiber communication network the optical fiber links mission is to execute the radio frequency signals distribution from a central location to the remote antenna units (RAUS). However, the routing, switching, and operations administration maintenance (OAM) processes are carried out by the central station [1–6]. through the propagation of the optical light signal in optical fiber channel, it exposed to different obstacles as losses and dispersion so the Erbium-Doped Fiber Amplifier has been applied with a channel for losses compensation [7–12].

Fiber Bragg grating (FBG) used for illumination effect of dispersion. On the other the conversion process of the optical signal into electrical signal takes place at receiver by very important component photodetector located in BS in proposal simulation model avalanche photodiode has full responsibility for this mission furthermore APD makes internally amplifying the photocurrent by an avalanche process [13–24]. The wavelength division multiplexing (WDM) technique is a common deployed application for communication systems because the wavelengths of channels are independent of other channels to recognize good simultaneous transmission features [25–37].

2 Simulation model description

This system has a transmitter and a Receiver and a free space optical channel (FSO) between them to connect the two parts with each other. The transmitter is an optical transmitter with a frequency of 1300 nm and a power 100 mW after the optical transmitter Figure 1.

Two optical visualizer devices are used such as the optical power meter visualizer that used to calculate the input power of the optical signal and also the optical time-domain visualizer that used to display the modulated light signal in the domain of time. Then the optical transmitter connects to a FSO that operates at attenuation of 5 dB/km, range of 3.5 km, and additional loses 1dB then a Dual Port

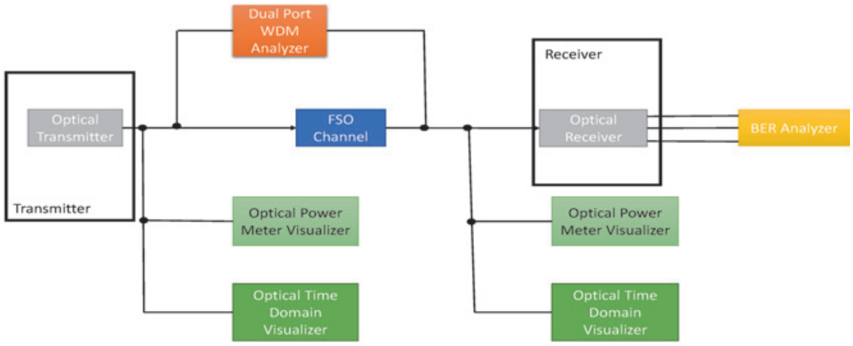

Figure 1: Proposed simulation model.

wavelength division multiplexing Analyzer that operates at lower frequency limit 1600 nm and upper frequency limit 600 nm that used to view the numerical results.

The two optical visualizers are used such as the optical time-domain visualizer and optical power meter visualizer. Then we connect the FSO channel to the receiver which contains an Optical Receiver which has a filter inside it. Finally, we connect the optical receiver to the electrical visualizer (BER Analyzer) to calculate the maximum quality factor and the minimum error rate of data received.

3 Mathematical model description

The loss in free space optics communication due to the fog is [3–5, 15, 17, 20]:

$$\alpha_{fog}(\lambda) = \frac{3.912}{V}\left(\frac{\lambda}{55x10^4}\right)^{-q} \quad (1)$$

Where V is transmission range in km, and λ is the wavelength of the signal. The parameter q is regarding to the transmission distance. The loss of beam depends on the scattering loss coefficient; rain, snow and the total attenuation are given by [3–5, 9, 15, 18–20]:

$$\alpha_{scat}(\lambda) = \frac{17}{V}\left(\frac{550}{\lambda}\right)^{0.195\,V}, \text{dB/km} \quad (2)$$

$$\alpha = \alpha_{fog}(\lambda) + \alpha_{snow} + \alpha_{rain} + \alpha_{scat}(\lambda), \text{ dB/km} \quad (3)$$

$$\alpha_{rain} = 1.076R^{0.67} \text{dB/km} \quad (4)$$

$$\alpha_{snow} = aS^b \text{ dB/km} \quad (5)$$

$$a = 5.42x10^{-4}\lambda + 5.495876,\ b = 1.38 \quad (6)$$

The electrical signal per noise ratio is expressed by [3–5, 15, 17, 20–22]:

$$S/N = P_T - 30 + G_T + G_R - 20\log\left(\frac{4\pi}{\lambda_c}\right) - 10\log(k_B B.WT) - \alpha - NF - F_m, \text{dB} \quad (7)$$

$$L = 10^{-\alpha/20}, \quad (8)$$

The transceiver antenna gains are:

$$G_T = \frac{32}{\theta_{div}^2},\ G_R = \left(\frac{\pi D_r}{\lambda}\right)^2, \quad (9)$$

Where θ_{div} is beam divergence in radians and given by:

$$\theta_{div} = \frac{4\lambda}{\pi D_t}, \quad (10)$$

The received power with a function of free space link range and beam divergence is [3–5, 15, 17, 20, 23–26]:

Table 1: Parameters for the proposed study.

Components	Parameter description	Value/Unit
Optical Transmitter	Frequency	850 nm–1550 nm
	Power	100 mW
	Linewidth	10 MHz
	Extinction ratio	30 dB
	Symmetry factor	−1
FSO channel	Divergence of beam	0.25 mrad
	Range	10 km
	Attenuation	2 dB /km
	Additional losses	1 dB
	Tx./Rx. aperture diameter	5 cm
	Tx./Rx. Loss	1 dB
	Propagation delay	0.2 ps/km
Optical Receiver	Responsitivity	1 A/W
	Dark current	10 nA
	Insertion loss	0 dB
	Filter Depth	100 dB
	Filter Order	4

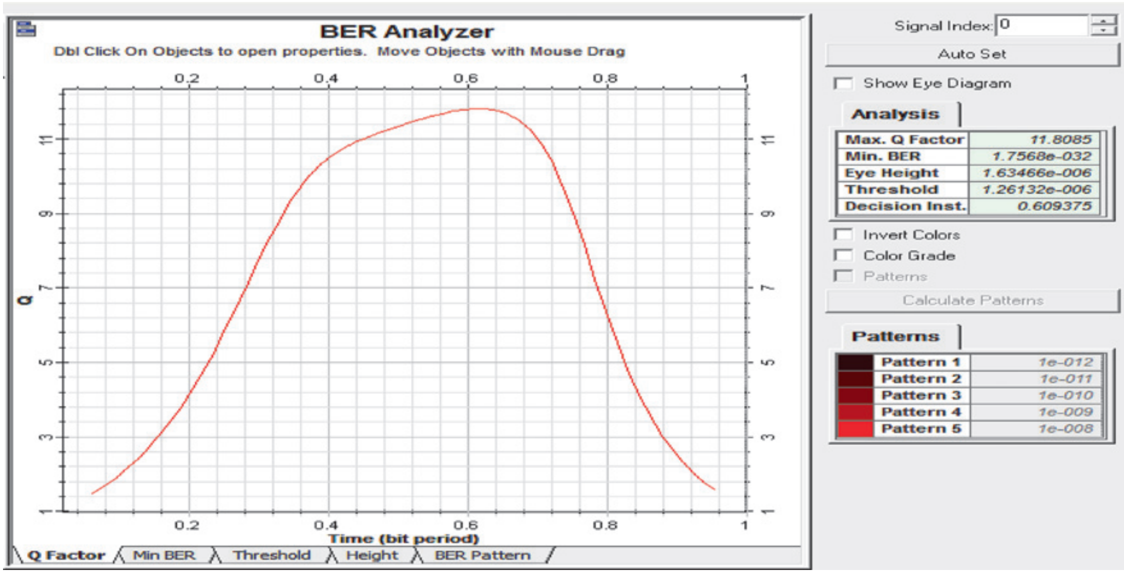

Figure 2: Quality signal factor and bit error rate with the operating signal wavelength of 850 nm and divergence of a beam of 0.25 mrad.

$$P_R = P_T \frac{D_r}{(D_t + (\theta_{div} + L))^2} e^{-\alpha L}, \tag{11}$$

The data error rate with a function of the electrical signal per noise ratio is given by [3–5, 15, 17, 20, 36, 37]:

$$BER \approx \left(\frac{2}{\pi.S/N}\right).\exp\left(\frac{-S/N}{8}\right), \tag{12}$$

4 Simulation results with performance analysis

The optical free space communication transceiver system is composed of three parts. The first part is the transmitter or the light transmitter whose operating frequency ranges from 850 nm to 1550 nm in order to cover near-infrared

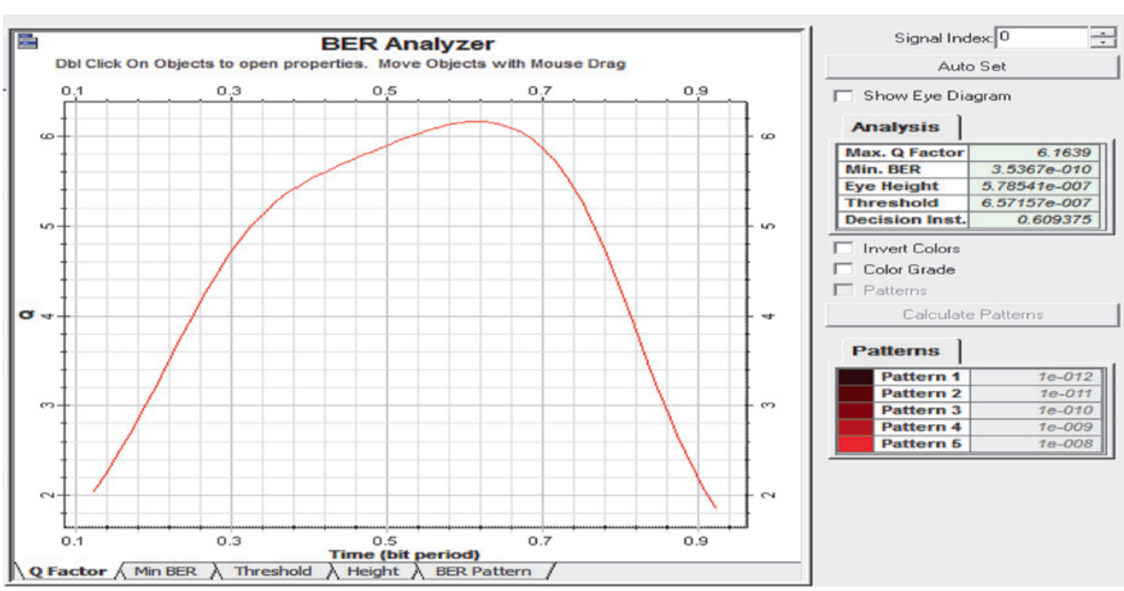

Figure 3: Quality signal factor and bit error rate with the operating signal wavelength of 850 nm and divergence of a beam of 0.35 mrad.

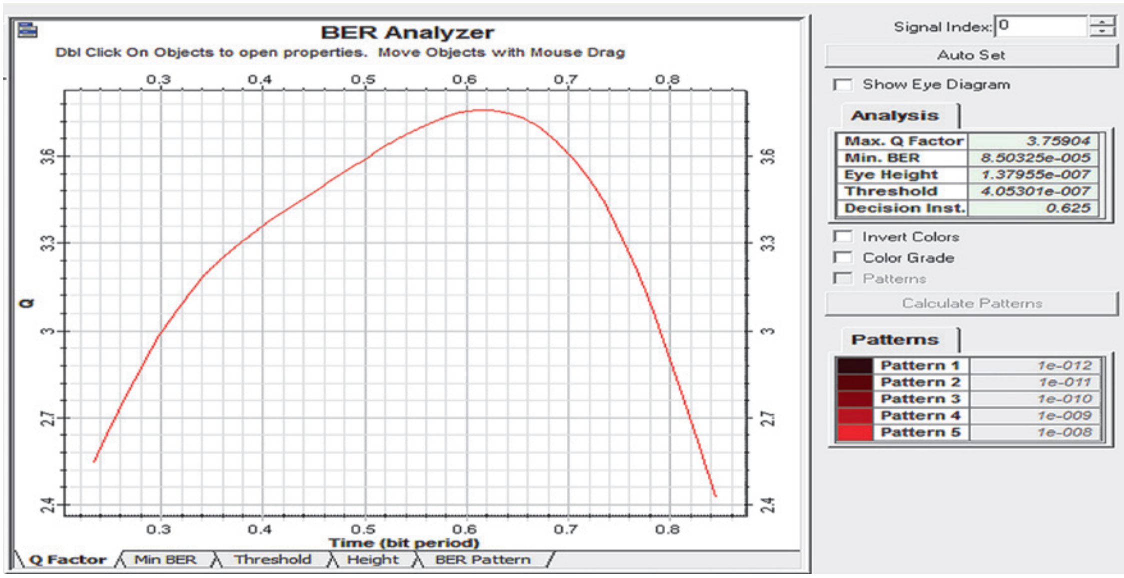

Figure 4: Quality signal factor and bit error rate with the operating signal wavelength of 850 nm and divergence of a beam of 0.45 mrad.

bands. The power is taken as 100 mW, the light source linewidth is 10 MHz, the internal modulator extinction ratio is 30 dB. The second part is the free space optics channel whose divergence of beam ranges from 0.25 mrad to 0.45 m rad, the attenuation factor is 2 dB/km, propagation range is 10 km distance, the propagation delay time is 0.2 ps/nm, additional losses are 1 dB, Tx./Rx. loss is 1 dB, and Tx./Rx. the aperture diameter is 5 cm. Operating variables for the network are outlined in Table 1.

The third part is the light detector or a light receiver. The light detector has two elements which are namely avalanche photodetectors and internal filtration unit. The avalanche photodetector unit whose it is responsitivity is 1 A/W, the dark current value of 1 n. The filtration unit has an insertion loss value of approximation zero, modulation depth is 100 dB, and the internal filter order is 4.

Figures 2, 3, and 4 clarify the Quality signal factor and bit error rate in the presence of the operating signal wavelength of 850 nm and divergence of beam variations of 0.25 mrad to 0.45 mrad. The quality signal factor is 11.8 and data error rates reach 1.75×10^{-32} in the case of 0.25 mrad beam divergence. While the quality signal factor is reduced to 6.16 and data error rates are increased to 3.53×10^{-10} in the case of 0.35 mrad beam divergence. In

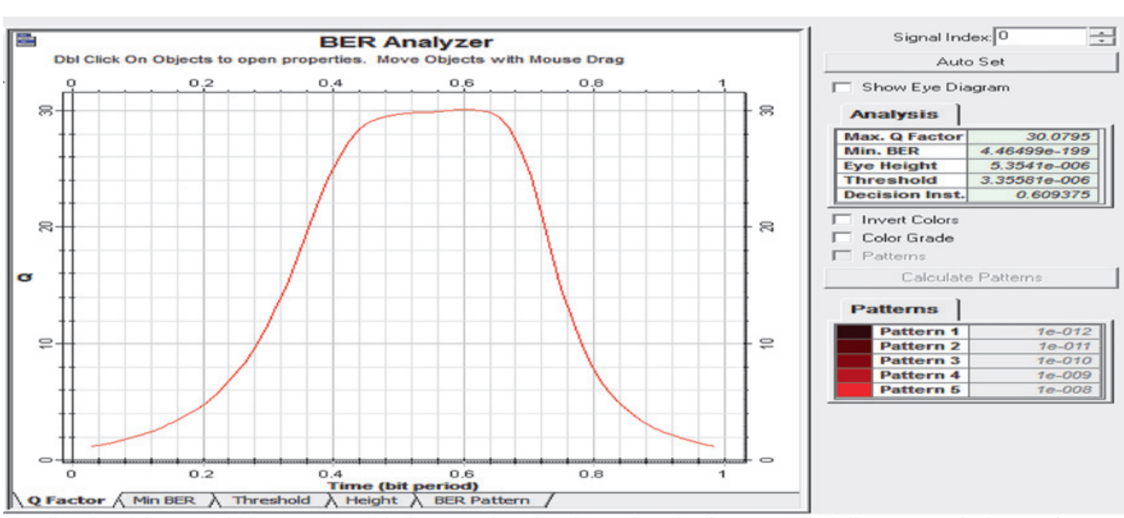

Figure 5: Quality signal factor and bit error rate with the operating signal wavelength of 1300 nm and divergence of a beam of 0.25 mrad.

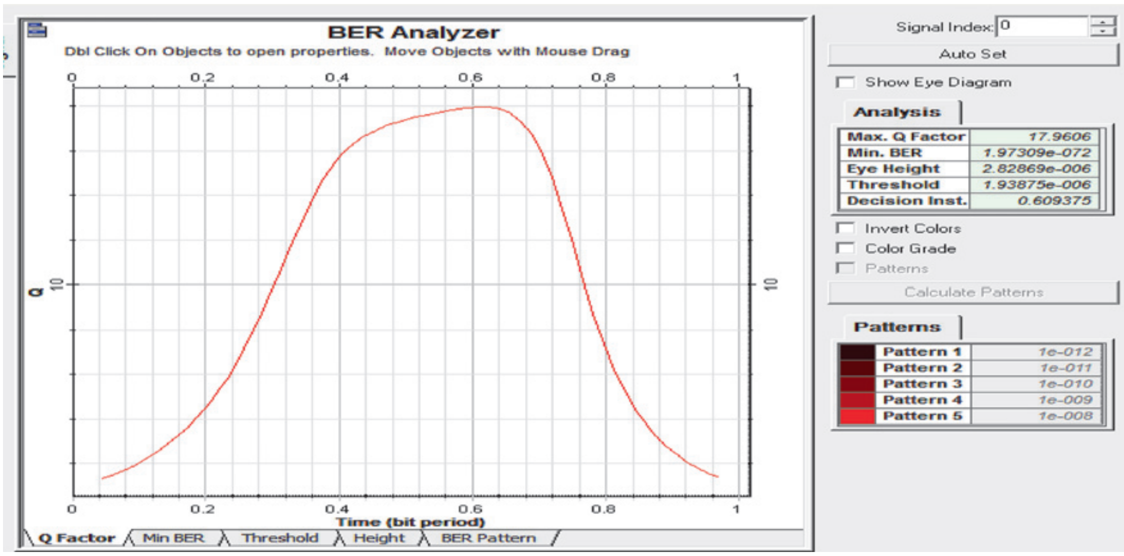

Figure 6: Quality signal factor and bit error rate with the operating signal wavelength of 1300 nm and divergence of a beam of 0.35 mrad.

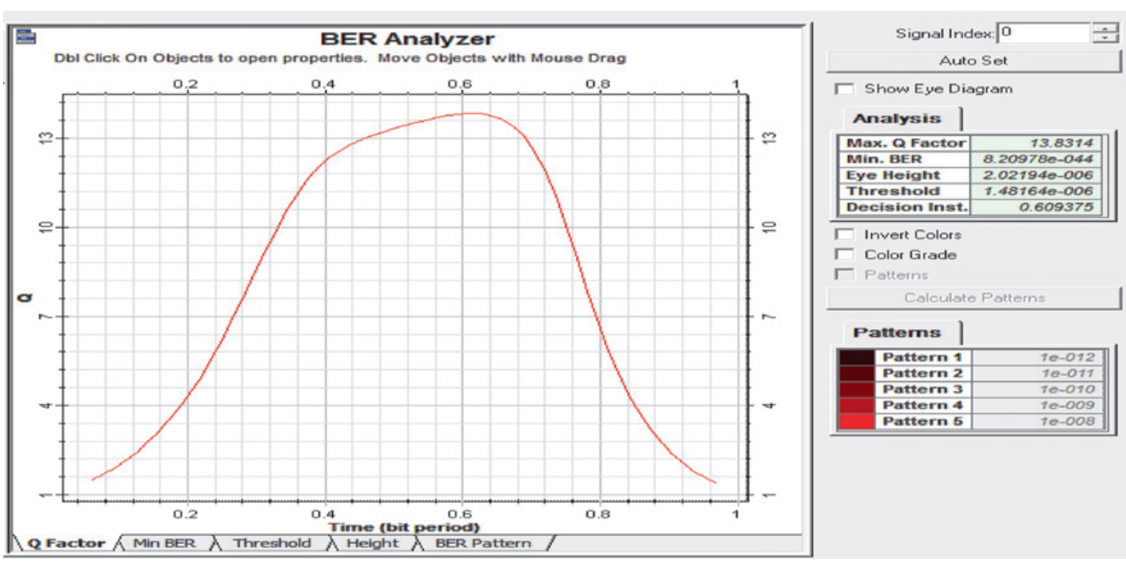

Figure 7: Quality signal factor and bit error rate with the operating signal wavelength of 1300 nm and divergence of a beam of 0.45 mrad.

addition to the quality signal factor is reduced to 3.75 and data error rates is increased to 8.5×10^{-5} in the case of 0.45 mrad beam divergence

Figures 5, 6, and 7 clarify the signal quality and bit error rate in the presence of the operating signal wavelength of 1300 nm and divergence of beam variations of 0.25 mrad to 0.45 mrad. The quality signal factor is 30.07 and data error rates reach 4.46×10^{-199} in the case of 0.25 mrad beam divergence. While the quality signal factor is reduced to 17.96 and data error rates are increased to 1.9×10^{-72} in the case of 0.35 mrad beam divergence. In addition to the quality signal factor is reduced to 13.83 and data error rates are increased to 8.2×10^{-43} in the case of 0.45 mrad beam divergence.

Figures 8, 9, and 10 clarify the signal quality factor and bit error rate in the presence of the operating signal wavelength of 1550 nm and divergence of beam variations of 0.25 mrad to 0.45 mrad. The quality signal factor is 61.03 and data error rates reach zero in the case of 0.25 mrad beam divergence. While the quality signal factor is reduced to 41.19 and bit error rate are zero also in the case of 0.35 mrad beam divergence. In addition to the quality

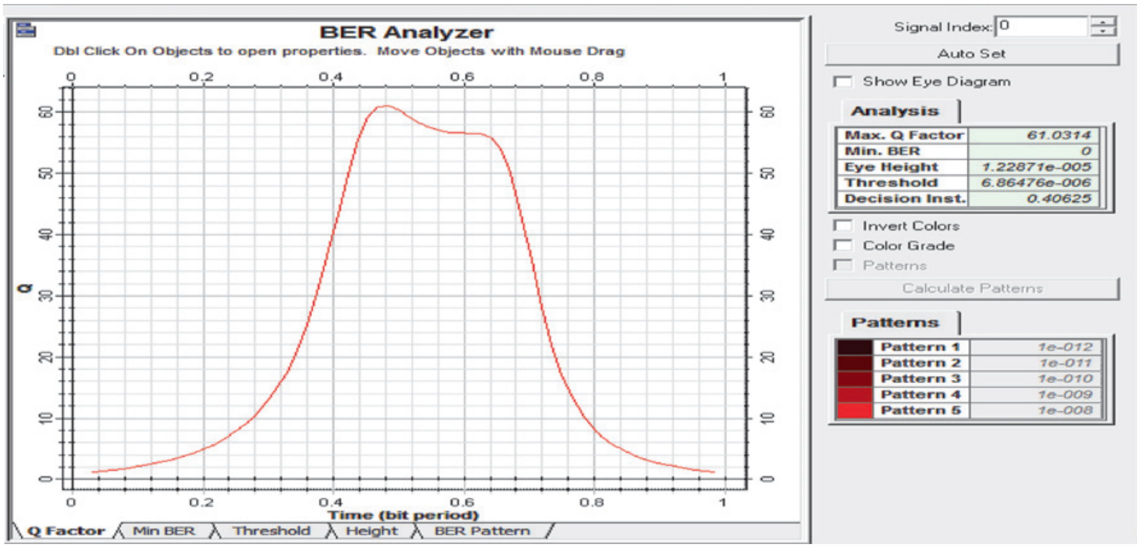

Figure 8: Quality signal factor and bit error rate with the operating signal wavelength of 1550 nm and divergence of a beam of 0.25 mrad.

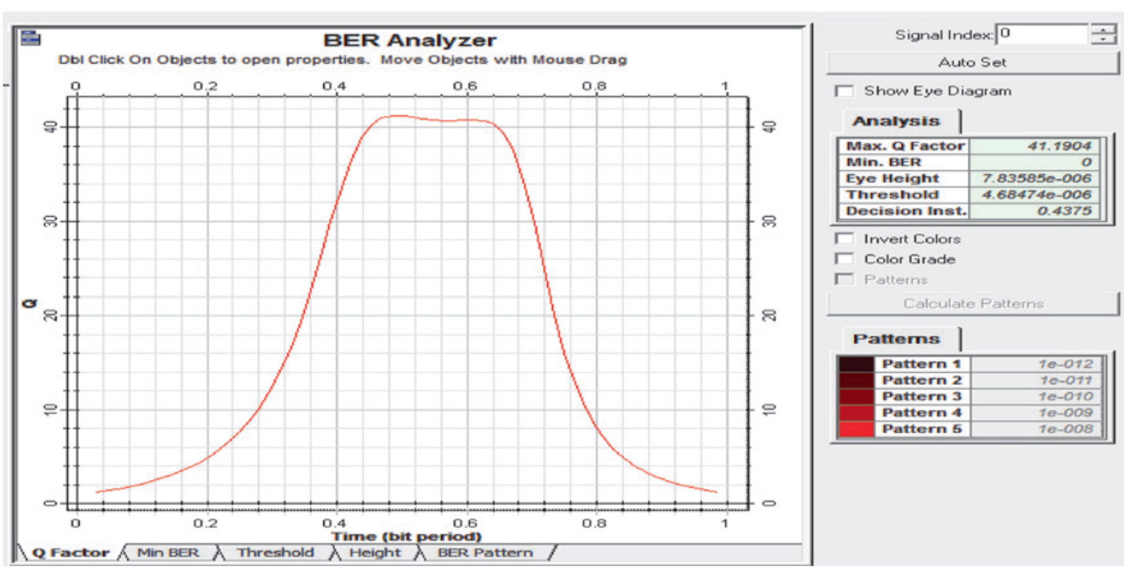

Figure 9: Quality signal factor and bit error rate with the operating signal wavelength of 1550 nm and divergence of a beam of 0.35 mrad.

signal factor is reduced to 17.96 and data error rates are increased to 1.97 × 10^{-72} in the case of 0.45 mrad beam divergence. The divergence of the beam with higher values has a greater bad effect on the free space optics communication systems.

Figure 11 shows the receiver signal at the receiver side in the presence of the operating signal wavelength of 850 nm and divergence of a beam of 0.25 mrad. Where the signal power reaches to −23.777 dBm and its value is 4.191 × 10^{-6} W. While the signal received at the receiver side in the presence of the operating signal wavelength of 850 nm and divergence of a beam of 0.25 mrad.

Where the signal power reaches to −21.622 dBm and its value is 6.884 × 10^{-6} W as shown in Figure 12. Moreover, the signal received at the receiver side in the presence of the operating signal wavelength of 850 nm and divergence of a beam of 0.25 mrad. Where the signal power reaches to −18.748 dBm and its value is 13.342 × 10^{-6} W as clarified in Figure 13. It is indicated that the received signal power is reached its maximum value at an operating signal wavelength of 1550 nm in compared to other operating

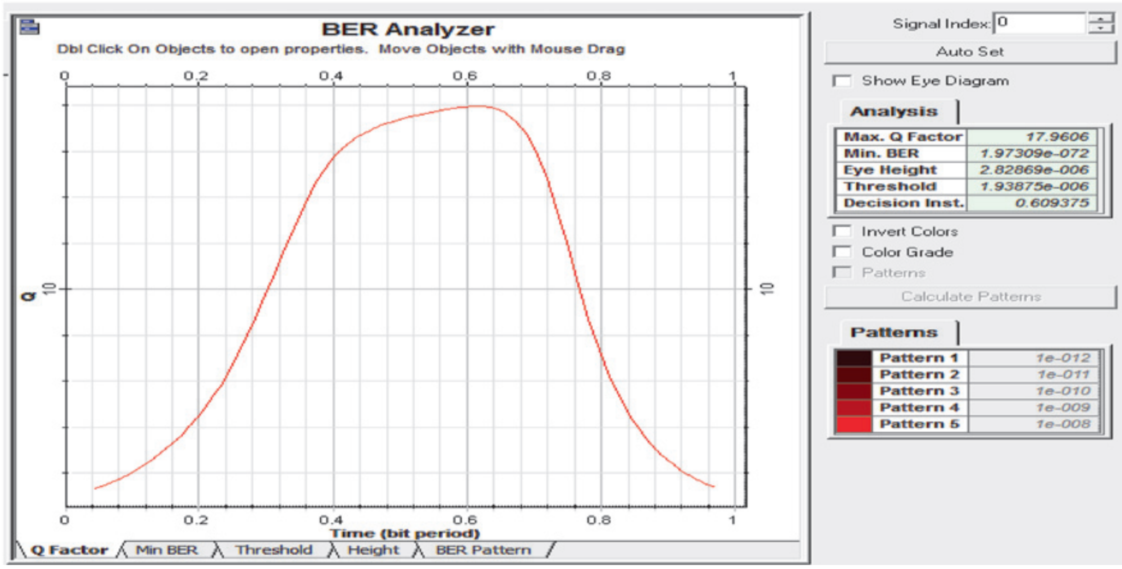

Figure 10: Quality signal factor and bit error rate with the operating signal wavelength of 1550 nm and divergence of a beam of 0.45 mrad.

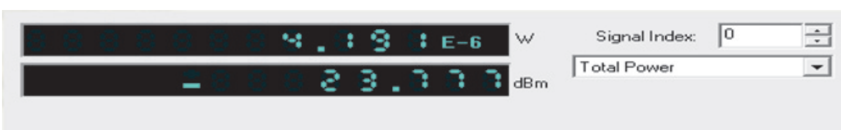

Figure 11: The signal at the receiver side in the presence of the operating signal wavelength of 850 nm and divergence of a beam of 0.25 mrad.

Figure 12: The signal at the receiver side in the presence of the operating signal wavelength of 1300 nm and divergence of a beam of 0.25 mrad.

Figure 13: The signal at the receiver side in the presence of the operating signal wavelength of 1550 nm and divergence of a beam of 0.25 mrad.

wavelength bands in near-infrared region bands at the optimum divergence of beam value.

5 Conclusion

In summary, the divergence of beam and operating wavelength bands' effects on free-space optics communication channels in local access networks are studied. The study has outlined the numerical values of max. Q factor and minimum bit error rate at different operating wavelength bands near-infrared regions and divergence of beam levels. The maximum Q factor is degraded with increasing divergence of beam values. The optimum network operation efficiency can be achieved by the choice of the optimum divergence of beam value and operating wavelength value at 1550 nm. The received power signal is reached its maximum value at an operating signal wavelength of 1550 nm in compared to other operating wavelength bands in near-infrared region bands at the optimum divergence of beam value. The optimum system performance efficiency is achieved at 0.25 mrad divergence of beam and 1550 nm operating wavelength.

Author contribution: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.
Research funding: None declared.
Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

References

1. Rubel MH, Mahmud SG. BER performance analysis for optical communication using DPSK Modulation. Int J Com Appl 2012;59: 39–4.
2. Oukli M, Kandouci M, Bouzid M, Bendaoud A. Study and optimization of high-bit rate optical fiber transmission. Serbian J Elect Eng 2008;5:361–70.
3. Kumar N, Sohal H. Impact of various weather condition on the performance of free space optical communication system. J Opt Comm 2014;35:45–9.
4. Esmail MA, Fathallah H, Alouini MS. Outdoor FSO communications under fog: attenuation modeling and performance evaluation. IEEE Photo J 2016;8:1–2.
5. Singh M. Performance analysis of WDM-FSO system under adverse weather conditions. Photon Net Comm 2018;36:1–10.
6. Osman WM, Billal KH, Al Nabi AB. Bit error rate performance for optical fiber system. J Elec Elect Sys 2018;7. https://doi.org/10.4172/2332-0796.1000250.
7. Jain S, Dubey R. A survey: optimization of bit error ratio in fiber optic communication system. Int J Com Sci Eng 2015;3:30–4.
8. Mukherjee K. Comparative analysis of various optimization methodologies for WDM system using optisystem. Int J Innov Res Com Comm Eng 2017;5.
9. Alam SMJ , Rabiul Alam M, Hu G, Zakirul Mehrab Md. Improvement of bit error rate in fiber optic communications. Int J Future Com Comm 2014;3:281–6.
10. Vandana GP. BER and Q-value performance analysis of WDM network using DPSK modulation format. Int J Adv Res Com Eng Tech (IJARCET) 2014;3:2409–415.
11. Saha S, Majumder P, Soundarya M. Optimization of gain and bit error rate of an erbium doped fiber amplifier for WDM system. Int J Eng Res Tech (IJERT) 2013;2:775–79.
12. Alabady S. Simulation and best design of an optical single channel in optical communication network. Int Arab J e-Tech 2011; 2:91–5.
13. Rashed ANZ, Mohammed Salah FT. Suitable optical fiber communication channel for optical nonlinearity signal processing in high optical data rate systems. Wireless Personal Comm J 2017;97:397–416.
14. Rashed ANZ, Mohammed SF. Tabour, El-Meadawy S. Optimum flat gain with optical amplification technique based on both gain flattening filters and fiber bragg grating methods. J Nanoelectr Optoelect 2018;13:665–76.
15. Ijaz M, Ghassemlooy Z, Perez J, Brazda V, Fiser O. Enhancing the atmospheric visibility and fog attenuationusing a controlled FSO channel. IEEE Photon Technol Lett 2013;25:1262–5.
16. Rashed ANZ, Mohamed SEDN, Mohamed Abd El-NA, Fathi E. El-Samie Abd. Performance enhancement of IM/DD optical wireless systems. Photonic Network Comm 2018;36:114–7.
17. Islam MR, Omer Elshaikh ZE, Khalifa OO, Alam AZ, Khan S, Naji AW. Prediction of signal attenuation due to dust storms using MIE scattering. IIUM Eng J 2010;11:71–7.
18. Rashed ANZ, Tabbour MSF, El-Meadawy S, Anwar T, Sarlan A, Yupapin P, Amiri IS. The effect of using different materials on erbium-doped fiber amplifiers for indoor applications. Res Phys 2019 Dec;15. https://doi.org/10.1016/j.rinp.2019.102650 [Epub ahead of print].
19. Dadabayev R, Malka D. A visible light RGB wavelength demultiplexer based on polycarbonate multicore polymer optical fiber. Opt Laser Technol J 2019;116:239–45.
20. Wang HQ, Wang YG, Cao MH, Ke XZ. Influence of atmospheric visibility on laser pulse delay and broadening in sand and dust weather. Acta Opt Sinica 2015;35, 0701002.
21. Rashed ANZ, Mohamed AENA, Sharshar HA, El-dien ES. Optical wireless transmitting communications based satellite orbit to orbit communication systems enhancement with EDFA amplifiers. Int J Adv Res Comp Sci Elect Eng (IJARCSEE) 2016;5: 97–4.
22. Rashed ANZ, Mohamed AENA, Sharshar HA, TabourMS, El-Sherbeny A. Optical cross connect performance enhancement in optical ring metro network for extended number of users and different bit rates employment. Accep Pub Wirel Personal Comm 2016 Sep 3;94:927–47. https://doi.org/10.1007/s11277-016-3658-1. [Epub ahead of print].
23. Rashed ANZ, El Gawad Mohamed AENA, Rahim Salman Hanafy SAE, Aly MH. A comparative study of the performance of graded index perfluorinated plastic and alumino silicate optical fibers in internal optical interconnections. Optik J 2016;127:9259–63.
24. Amiri IS, Rashed ANZ, Yupapin P. Interaction between optical sources and optical modulators for high-speed optical communication networks. J Opt Comm 2019 Mar 15. https://doi.org/10.1515/joc-2019-0041 [Epub ahead of print].
25. Amiri IS, Rashed ANZ, Yupapin P. Effects of order super gaussian pulses on the performance of high data rate optical fiber channel in the presence of self phase modulation. J Opt Comm 2019 Apr 5. https://doi.org/10.1515/joc-2019-0039 [Epub ahead of print].
26. Amiri IS, Rashed ANZ, Yupapin P. Mathematical model analysis of dispersion and loss in photonic crystal fibers. J Opt Comm 2019 Apr 5. https://doi.org/10.1515/joc-2019-0052 [Epub ahead of print].
27. Amiri IS, Rashed ANZ, Yupapin P. Basic functions of fiber bragg grating effects on the optical fiber systems performance efficiency. J Opt Comm 2019 Apr 5. https://doi.org/10.1515/joc-2019-0042 [Epub ahead of print].
28. Amiri IS, Rashed ANZ, Mohammed AENA, Aboelazm MB, Yupapin P. Nonlinear effects with semiconductor optical amplifiers. J Opt Comm 2019 Apr 12. https://doi.org/10.1515/joc-2019-0053 [Epub ahead of print].
29. Amiri IS, Rashed ANZ, Mohammed AENA, El-Din ES, Yupapin P. Spatial continuous wave laser and spatiotemporal VCSEL for high-speed long haul optical wireless communication channels. J Opt Comm 2019 Apr 24. https://doi.org/10.1515/joc-2019-0061 [Epub ahead of print].
30. Amiri IS, Rashed ANZ, Yupapin P. Average power model of optical raman amplifiers based on frequency spacing and amplifier section stage optimization. J Opt Comm 2019 May 4. https://doi.org/10.1515/joc-2019-0081 [Epub ahead of print].

31. Amiri IS, Rashed ANZ, Yupapin P. Pump laser automatic signal control for erbium-doped fiber amplifier gain, noise figure, and output spectral power. J Opt Comm 2019 Dec 17. https://doi.org/10.1515/joc-2019-0203 [Epub ahead of print].
32. Amiri IS, Rashed ANZ, Parvez AHMS, Paul BK, Ahmed K. Performance enhancement of fiber optic and optical wireless communication channels by using forward error correction codes. J Opt Comm 2019 Dec 24. https://doi.org/10.1515/joc-2019-0191 [Epub ahead of print].
33. Amiri IS, Rashed ANZ, Yupapin P. Comparative simulation study of multi stage hybrid all optical fiber amplifiers in optical communications. J Opt Comm 2020 Feb 4. https://doi.org/10.1515/joc-2019-0132 [Epub ahead of print].
34. Amiri IS, Rashed ANZ, Hala M. Kader A, Amr A, Awamry A, et al. Optical communication transmission systems improvement based on chromatic and polarization mode dispersion compensation simulation management. 2019, Optik J 2020;207:163853.
35. Samanta D, Sivaram M, Rashed ANZ, Boopathi CS, Amiri IS, Yupapin P. Distributed feedback laser (DFB) for signal power amplitude level improvement in long spectral band. J Opt Comm 2020 Apr 2. https://doi.org/10.1515/joc-2019-0252 [Epub ahead of print].
36. Amiri IS, Rashed ANZ, Yupapin P. Analytical model analysis of reflection/transmission characteristics of long-period fiber bragg grating (lpfbg) by using coupled mode theory. J Opt Comm 2020 Apr 2. https://doi.org/10.1515/joc-2019-0187 [Epub ahead of print].
37. Amiri IS, Rashed ANZ, Rahman Z, Paul BK, Ahmed K. Conventional/phase shift dual drive mach–zehnder modulation measured type based radio over fiber systems. J Opt Comm 2020 Apr 14. https://doi.org/10.1515/joc-2019-0312 [Epub ahead of print].