Journal of Theoretical and Applied Information Technology
31st December 2021. Vol.99. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

PREDICTION LASER BEAM EFFECT UNDER HAZY WEATHER FOR FREE SPACE OPTICAL PROPAGATION

[1]A.K RAHMAN, [2]TAMRIN F.K, [1]SAHARI S.K, [1]ZAMHARI N

[1]Department of Electrical & Electronic Engineering, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan 94300, Sarawak, Malaysia

[2]Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan 94300, Sarawak, Malaysia

E-mail: [1]karahman@unimas.my, [2]tkfikri@unimas.my, [1]sskudnie@unimas.my, [1]znurdiani@unimas.my

ABSTRACT

This paper focus impact of haze in free space optic transmission focusing on Malaysia-Indonesia region. Haze is one of the factors that contributed to atmosphere attenuation that can affecting this system's performance. It will cause the beam propagation will attenuate and wander from line of sight. Ultimately drag the transmission into burst error. The analysis is carried out using simulation optical software with original data. In the simulation, analyses are carried out looking in bit error rate, eye diagram pattern and received power at receiver. From there, the prediction of laser beam effect can be estimated. The performance for free space optic transmission will investigate under different parameters values such as wavelength, visibility, receiver sensitivity and beam divergence are analyzed. From the result, as increases the haze effect it will deteriorate the signal beam. The system maximum system can support to operate is attenuation at 45 dBm/km.

Keywords: *haze, laser beam, free space optic, bit error rate*

1. INTRODUCTION

FSO has the quality to provide faster, license-free and secured communication and to be promoted in the market commercial as the demand for data services is increasing nowadays. However, as FSO uses free space as its transmission medium, the system is vulnerable to atmospheric changes [1].

The performance of FSO system is heavily impaired during poor weather as example, rainy, hazy, and foggy day. This research focuses on the effect of haze on FSO system where smoke, dust and other dry particles are being suspended in the air. This phenomenon hinders the propagation of light in terrestrial atmosphere [2]. During bad weather, haze particle stays longer in the atmosphere compared to rain or water molecule. The combination of scattering, absorption and turbulence results in atmosphere attenuation which causes visibility to be restricted and thus can interrupt and disturbed the FSO transmission.

FSO systems is possible to be mounted inside buildings and operated in favorable environment but a preliminary stage is vital before the installation of FSO. Local weather patterns condition needs to be investigated, analysis and recognized as a preparation for worst scenario performance. This stage is important to ensure the operation of FSO system is at high performance with minimal losses even during bad weather conditions [3].

In [19], the spontaneous variations in the temperature and pressure of the atmospheric area into which the FSO signal has to travel have caused turbulence to occur. It changes the air refractive index as the temperature changes in the environment, which allows the light beam to deviate from its expected direction towards receiver [20]. The other term for this condition is scintillation where intensity of light on receiver plane varies in time and spaces. These changes in the index make the atmosphere act like a series of tiny lenses that deflect the light beam parts into and out of the planned propagation direction [21]. When the day temperature is at the peak stage, the influence of this phenomena would be extremely high, which happens around noon.

Visibility is identified as the highest distance projected by a detectable optical signal of 550nm wavelength (maximum light intensity for human eye) while recognizing dim objects aligned with surroundings at two percent [15]. As stated in [22], visibility in scientific explanation is the distances when light loses 2% of its initial power. Another

Journal of Theoretical and Applied Information Technology
31st December 2021. Vol.99. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

description implies that visibility is the distance which a dark object against the horizon can be identified [23]. Based on research in [15], visibility is a metric originally designed for meteorological uses. Annual calculations have increased, and calculation precision is assured. Eye reading and instrumental methods are the most common measuring methods for visibility. In eye reading, visibility is measured by the observer (human) based on the reference visibility point around his/her station. The other technique used computer sensor devices to assess the optical range of the runway. In measuring visibility, the concept behind forward scatter meter technology is embraced. The sensor tests the light intensity that is dispersed in the atmosphere by the sample volume of trapped aerosol particles.

The region to be investigated is Malaysia-Indonesia as haze occurred almost every year in this selected region. This phenomenon occurred due to open burning which as a results of high agriculture activities during harvesting season.

Therefore, this research is carried out to investigate the haze impacts on free space optical transmission. To eliminate the effect of attenuation on the system, the beam divergence, transceiver conditions and propagation distances is being manipulated and tested. The performance will be investigated by analyzing the bit-error-rate (BER), signal-noise-ratio (SNR) and gain power using Opti-System software.

2. HAZE DATA CATEGORIES

In Malaysia, the qualities of air are measured and defined in Air Pollutant Index (API) terms. Using universally accepted numerical value range, API chart is created as a purpose to report the pollution level in air rather than using exact air pollutant concentration. During haze period, the API can deteriorate drastically and fast. Table 1 below show the classification range of air quality.

The safe condition of air quality ranging from 0-100 and this reading usually recorded during good and clear weather. From 101-150, it is still acceptable however affecting the sensitive groups of people such that the one that have asthma or older generations. 151-300 will raised the red alert and this reading can be seen during hazy day. It is dangerous as high numbers of hazardous pollutants are being suspended in the air. On worst and heavy haze weather, it can reach up to 301-500 reading and visibility is very restricted in this situation.

Table.1: Malaysia Air Pollution Index (Api) [30]

When the AQI is in this range:	...air quality conditions are:	...as symbolized by this color:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

3. TABULATION OF HAZE

The installation of Free Space Optic system in Malaysia-Indonesia region is constrained due to the unpredictable weather changes. Therefore, there is a need to know the weather pattern in this region so that the transmission process of light beam can be boosted. The haze occurrence is investigated throughout the years between the two countries. This phenomenon usually occurred in this two-country due to high agriculture activities which involved open burning that causes the index pollutant particles to increase. As weather is uncontrollable, therefore this pattern is important for worst case scenario preparation. The system then can be adjusted according to the situation observed.

Figure 1 shows the API reading on good weather condition while Figure 3.3 shows the index during heavy haze. The data in Figure 3.2 is obtained on 1st January 21, 2021. Figure 3.3 is taken during the outbreak of Southeast Asian Haze in 2015, which affecting few Southeast Asian counties, including Malaysia, Indonesia, Brunei, Singapore, Vietnam, Thailand, Cambodia and also Philippines. This occurrence began from late June of 2015 until the end of October, a long-term problem that happens in

Journal of Theoretical and Applied Information Technology
31st December 2021. Vol.99. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the mentioned areas during dry season at changing intensities.

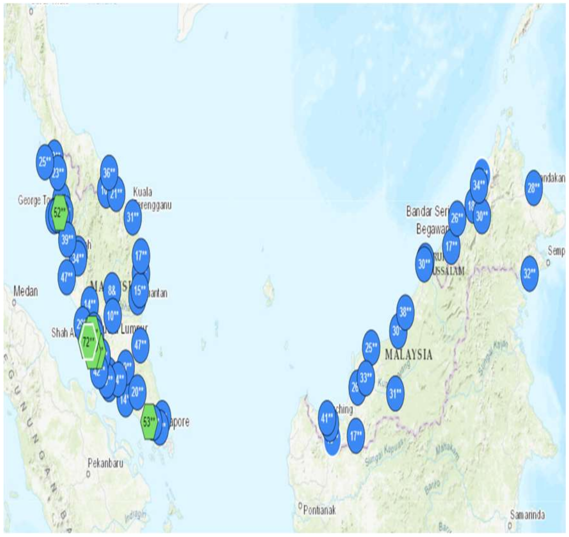


Figure 1 API Index On 1st January 2021

Figure 2: API Index On 3rd October 2015

When it comes to predicting haze attenuation, optical engineers prefer to use visibility range. The worst hourly recorded visibility range was about 200m on November 16, 2015, during the hazy weather produced by forest fire in Indonesia. As a result, haze attenuation must be addressed as one of the key elements in the design of FSO links in Malaysia. Low visibility is defined as visibility less than 6 km, moderate visibility is between 6 km to 50 km, and excellent visibility is when the visibility greater than 50 km. The scattering coefficient will depend on visibility and wavelength. For the months of July, August, and September 2015, data on haze visibility was acquired from the Malaysian Meteorological Department (MMD) at Subang Airport. Hourly observations were used to get the visibility data. The average visibility for each day over the course of three months is represented in Fig. 1. As seen in the graph, the lowest visibility value was recorded in September, with average visibility of barely a few hundred meters on certain days.

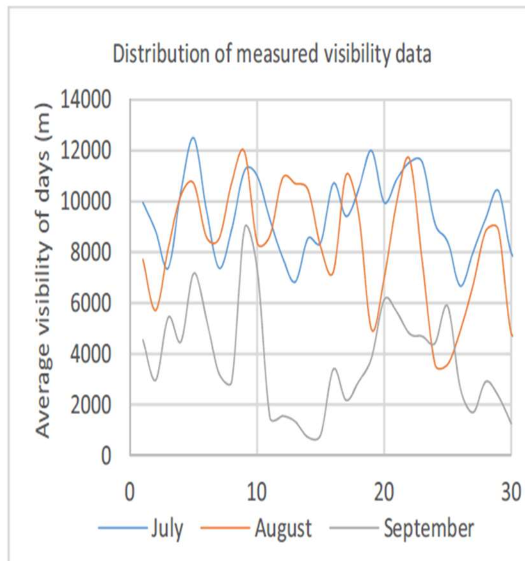


Figure 3: Distribution Visibility Data [32]

4. MIE SCATTERING

As mentioned in [15], Mie Scattering happens because of the particles' size is greater than one-tenth or comparable to the incident wavelengths. This phenomena theory is valid for isotropic spherical elements dissipation not including the quantum factor of particles emission by monochromatic light incident. In the near wavelength spectrum of infrared, the main causes that contributed to the occurrence of this phenomena are aerosol molecule such as haze and fog particles. The main elements in Mie-scattering that causes attenuation is visibility and the frequency of light beam. According to [31], the most significant variable required to assess attenuation of FSO system is the meteorological visual range (visibility). When observing a set of objects, it is found out that the contrast between the objects and their surroundings drops along the increasing distances measured. The contrast gradually becoming weak

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

that the object can no longer be perceived; this happens when the contrast decreases to around 2 percent for human eyes able to see. It is possible to classify visual range into two groups, which are low and average visibility. The first classification ranging from 0.5km – 4.5km while second group falls between ranges of 7km - 16km.

4.1 SCATTERING COEFFICIENTS

The coefficients of scattering can be determined by manipulating the variables of visibility and wavelength. It is possible to calculate the scattering coefficient value during haze phenomena by using the formula in (3.1) [15].

$$\beta = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right)^{-q} \qquad (1)$$

Where V is the visibility in km (kilometers), λ is the wavelength in nm (nanometers) and q is the particles size.

4.2 SCATTERING COEFFICIENTS

Research [13] stated that hazy condition is under Mie scattering classification due to the particle size of haze is equal to the projected wave frequency and the variables are wavelength-dependent. The attenuation occurs because of haze particles stayed in the air and interrupt the transmission of wave energy which causes the FSO's performance to deteriorate. By combining (3.1) with Beer's Law equation which used to calculate transmittance value in atmosphere (3.2) [8], haze from earth to satellite link can be estimated by using equation (3.3) [26].

$$\tau_a = e^{-(\beta_{abs}+\,\beta_{scat})R} \qquad (2)$$

$$A_{haze} = 10\log e^{\left[\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-q}\times L\right]} dB \qquad (3)$$

Where βabs = absorption coefficient, βscat = scattering coefficient, R = optical transmittance in degree, L = propagation distances in km (kilometers)

For geometric attenuation, will using below:

$$A_G = 10\log(\frac{L*\theta}{D})^2 \qquad (4)$$

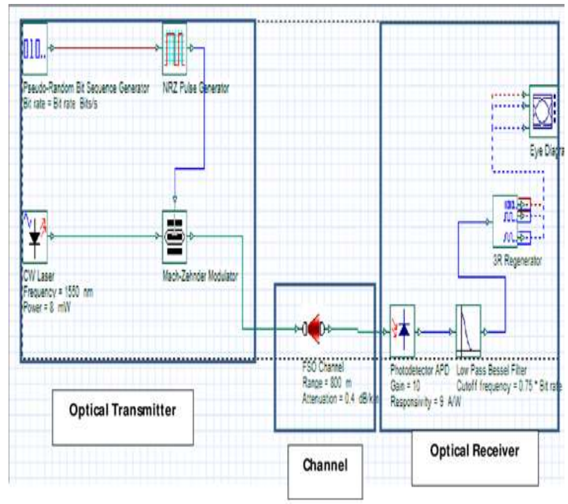


Figure 4: Simulation Haze Effect

In the simulation part, the system's configuration is illustrated in Figure 3.6. The transmitter is a combination of laser and modulator. The modulator that being used to modulate the phase is Mach-Zehnder. This modulator is commonly used as it provides flexibility which is not offered by another modulator. It is possible to determine the capacity of light beam wavelength for refractive index estimation of materials and air. To obtain a high-speed transmission, modulator is a costly element that need to be chosen wisely. In data-center implementation, bandwidths, density of packaging and energy consumed by modulator are the important criteria that need to be assessed. When the modulator specification is sub-optimal, the cost of other components in a system and its complexity will rise significantly, with only minimal performance gains. Therefore, Mach-Zehnder modulator (MZM) is used in this system.

For receiver side, it consists of sensor and low pass filter. The sensor used is APD (Avalanche Photodiode) where it converts the optical data to electrical form. This photodetector has greater sensitivity compared to PIN diode as it used high speed sensor. The behavior of avalanche raises the diode's gain several times, offering greater sensitivity. Even though the gain of APD produced high signal noise ratio, this however make it compatible with laser-based and lengthy transmission compared to PIN diode which more suitable to be used in RF technology. APD photodiode is well-suited to be applied in a system that require large band capacity and bitrates where the expenses are unavoidable. The most significant

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

benefit of this sensor is that the gain of APD does not partake in the noise of system therefore it aids to minimize and cancel other noises generated in the system.

For analysis part, distances between transmitter and receiver that will be tested is ranging from 0.5km to 3km under different visibility of 0.2km, 0.4km and 0.8km. The FSO performance using frequency of 785nm, 850nm, 1250nm and 1550nm under different haze attenuation is also being observed for optimization. The performance evaluation will then be measured by observing the bit error rate (BER), signal noise ratio (SNR) and output power.

5. RESULT AND DISCUSSION

Table 2: Parameter Analysis

Parameter	Value
Power Transmit	13 dBm
Wavelength	850nm and 1550nm
Bit Rate	155Mbps
Distance	1-3km

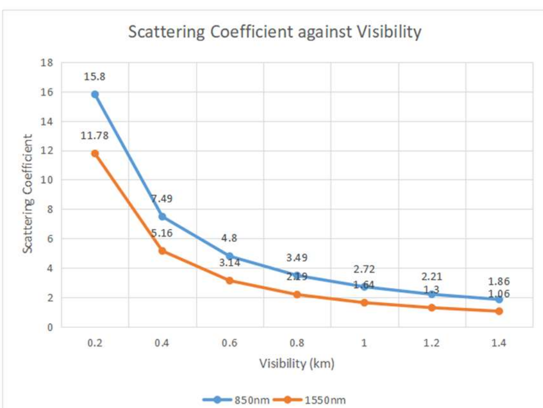


Figure 5: Scattering Coefficient Versus Visibility

By using Equation (1), the scattering coefficient Figure 5 shows the performance of scattering coefficient versus low for two wavelengths under different visibility. The size distribution used in the calculation is [0.585V]^(1/3) for visibility below V < 6km. In the first wavelength (850nm), the simulation of the scattering coefficient showed a value of (15.80km-1) under extreme low visibility (0.2 km) which was the lowest amount recorded from MMD in 2015. The second wavelength (1550nm) scattering coefficient was (11.78km-1) at the same visibility value of 0.2km. From the graph, it showed that the wavelength of 850nm is much more scattered than the wavelength of 1550nm during hazy day.

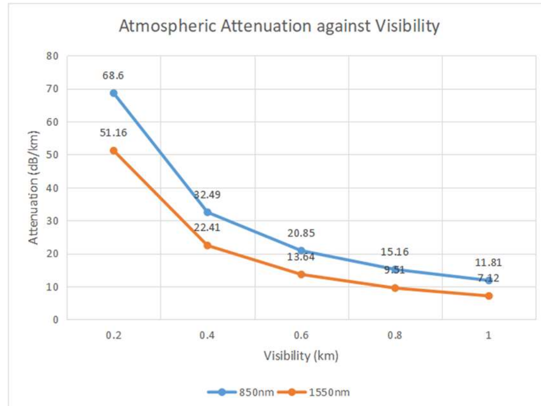


Figure 6: Atmospheric Attenuation Versus Visibility

Equation 2 is used to calculate the haze attenuation of two wavelengths under different visibility and the data are tabulated in table and simplified as shown in Figure 6. The link range is 1km between the transmitter and receiver. The atmospheric attenuation at the low visibility of 0.2km is 68.60dB and 51.16dB for 850nm and 1550nm wavelengths, respectively. In the middle visibility of 0.6km, the atmospheric attenuation is approximately 20.85dB at 850nm and 13.64dB at 1550nm. This is also consistent with the Kruse model proposed by Ali as the predicted attenuation is lower at the near infrared (NIR) wavelength than at the visible wavelengths (1550nm has a lower attenuation than 850nm for all visibility ranges). This reveals that the atmospheric attenuation in haze days is wavelength dependent. Furthermore, the wavelength of 1550nm was able to reduce the atmospheric attenuation effect on the FSO system. Thusly, operating at 1550 nm wavelength will minimize the effects of atmospheric attenuation on the FSO system.

Journal of Theoretical and Applied Information Technology
31st December 2021. Vol.99. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

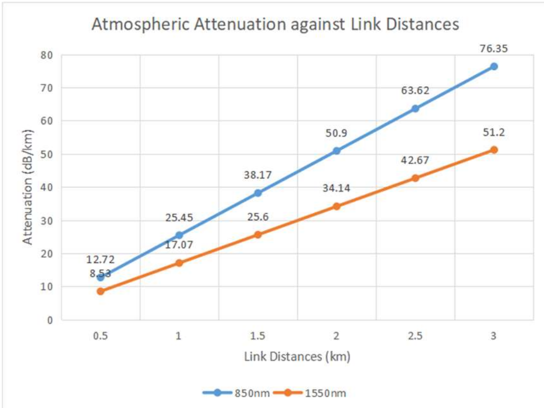


Figure 7: Atmospheric Attenuation Versus Link Transmission

In Figure 7 shows the atmospheric attenuation over the transmission range of 0.5km to 3km. Atmospheric attenuation increases as the distance between the transmitter and receiver increases. That is, the transmission quality of the FSO technique depends directly on the link range between transmitter and receiver. Based on the result obtained under lower visibility at 0.5km, the atmospheric attenuation was about 38.17dB for 850 nm wavelength and 25.60dB for 1550nm wavelength at the distance of 1.5km. Also, the atmospheric attenuation was about 76.35 dB for wavelength 850 nm and 51.20dB for wavelength 1550nm at link range of 3km.

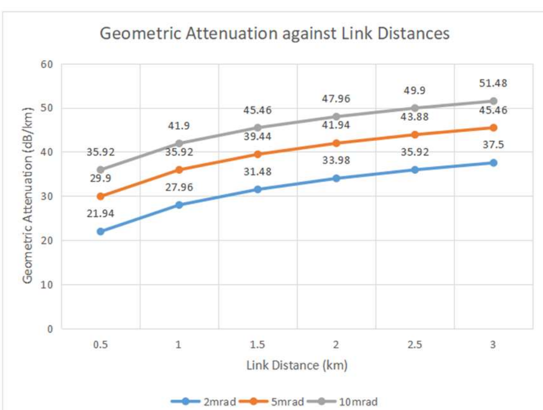
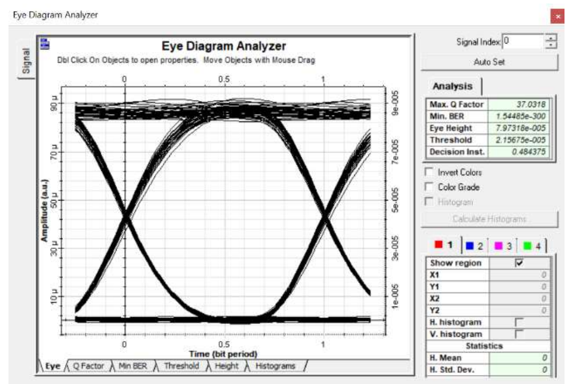
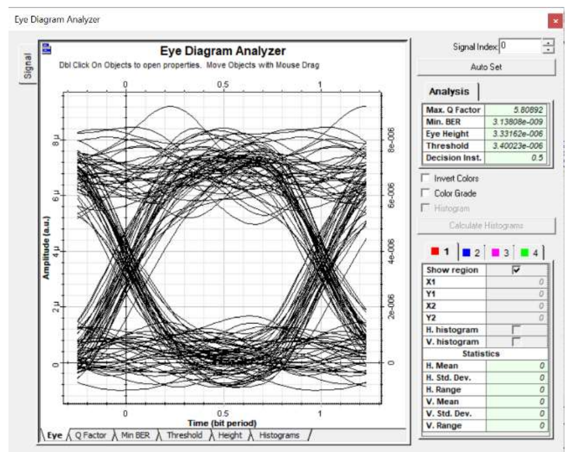


Figure 8: Geometric Attenuation Versus Link Distance

The geometric loss in the system over transmission range for 3 different divergence angles were calculated using Equation 3 as shown in Figure 8 where the divergent angle for receiver aperture was 0.08 m. It shows the impact of these parameters on the geometric loss for link distance up to 3km. In a setup of divergence angle 10 mrad and receiver aperture of 0.08m, it can be seen that the geometric loss at the link distance 0.5km is around 35.92dB to almost 51.48dB at 3km whereas in a setup of divergence angle 2 mrad, the geometric loss is around 21.94dB and 37.50dB at 1km and 5km respectively. This finding reveals alternative ways of increasing FSO link availability in Malaysia. Using smaller receiver aperture will results in lesser loss thus helps in boosting the performance of free space optic during bad weather.



(a)



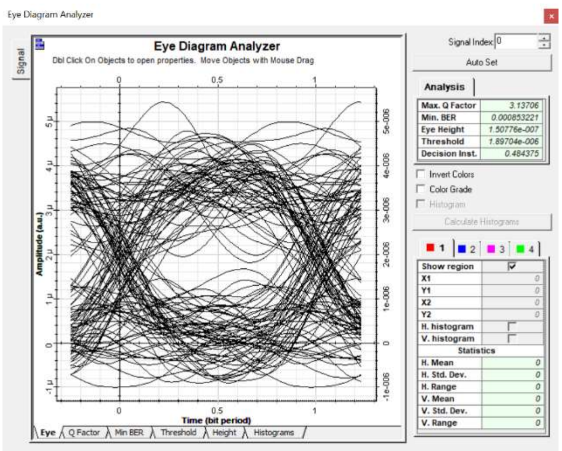
(b)

Figure 9 shows the eye diagram performance for different attenuation effect of haze. As shown in Figure 9 (a) the signal is in good shape which represent transmission at high quality. Minimum bit error rate is at 1.5 x 10-300.When increasing amount of attenuation, the shape of eye diagram begins to change. As we can Figure 9 (b), the minimum bit error rate is at acceptable error where 3.1 x 10-9 with attenuation 45dBm/km. Meanwhile Figure 9 (c), as

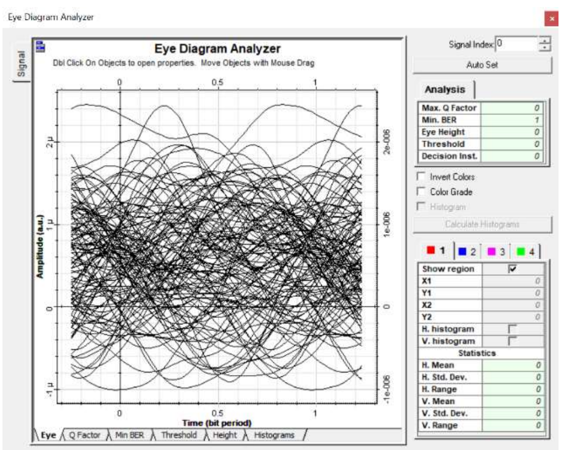
Journal of Theoretical and Applied Information Technology
31st December 2021. Vol.99. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

expected shape of eye diagram almost disappears with attenuation at 50dBm/km and 0.00085-bit error rate. Finally, signal can be recognized as totally lost when attenuation surpass 55dBm/km. Therefore, it is important to make sure system can operate at minimum acceptable error that is at 10-9. Beyond this value, the free space optical system will not function well.

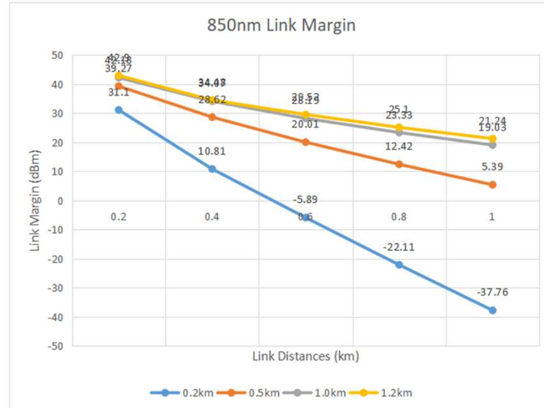


(c)

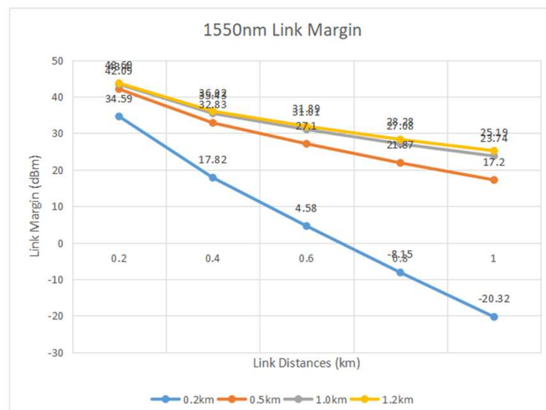


(d)

Figure 9: Eye Diagram Performance Due To Attenuation Haze Effect (A) Attenuation 35dbm/Km (B) Attenuation 45 Dbm/Km (C) Attenuation 50dbm (D) Attenuation 55dbm/Km



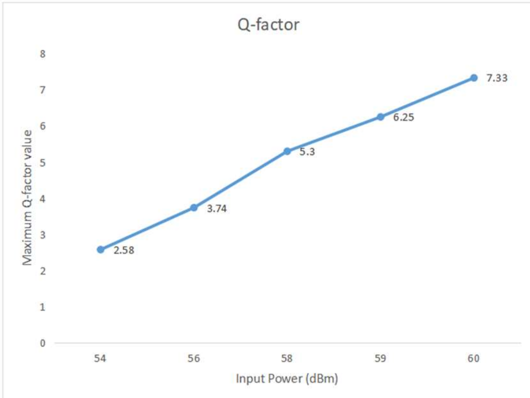
(a)



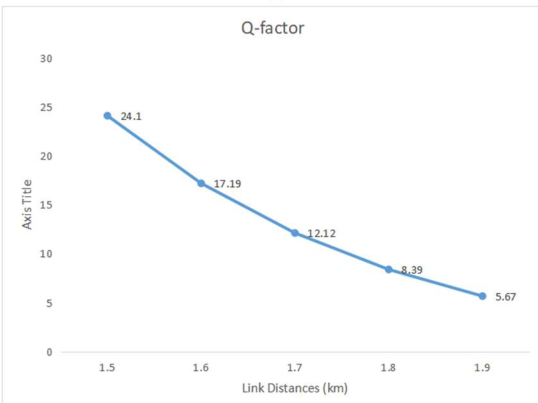
(b)

Figure 10: Link Margin Performance, (A) 850 Nm Wavelength And (B) 1550 Nm.

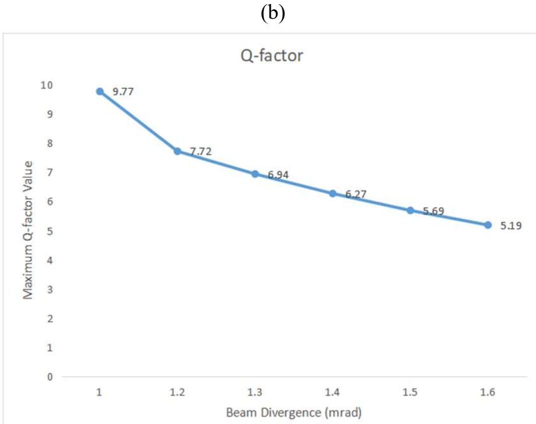
For link margin performance, as shown in Figure 10, (a) 850 nm wavelength and (b) 1550 nm. The link margin the clear weather condition is 58.8 dBm when considering the total attenuation is zero. Haze attenuation and geometric attenuation are the two attenuations that we took into consideration for two different wavelengths 1550nm and 850nm at different low visibility: 0.2km, 0.5km, 1km, and 1.2km. From the graph, we can conclude that FSO system with wavelength 1550 nm is better to overcome the attenuation of haze and geometric under haze condition. For all range allocated under different link distances and visibility value, 1550nm wavelength system have extra link margin compared to 850nm wavelength system. From these results, it was proven that 1550nm wavelength is suitable for FSO performances under haze attenuation therefore will be further manipulated using OptiSystem Software to see other variations that can help to improve the quality of the system.



(a)



(b)



(c)

Figure 11: Performance Q- Factor. (A) Q Factor For Power, (B) Q-Factor For Link Transmission, (C) Q-Factor For Beam Divergence

In term of Q factor performance can be shown in Figure 1 where (a) Q Factor for power, (b) Q-Factor for link transmission and (c) Q-Factor for beam divergence. For (a) the pattern of the graph showed a linear decline of BER values when the power increasing as well as the Q-factor. From the graph it can be seen that, the desired BER and Q-factor is satisfied when input power equal to 58dBm. Comparing to the input power during clear day, which is 0dBm, the power needed for FSO system in hazy condition is considered high. Most of the past research have not considered raising the input power of the transmitter as when the power increases, higher noises are produced in the system which then can affected the FSO system even more. However, this manipulation is done to show that there are other alternative ways rather than only focusing on wavelengths to increase the FSO performances.

In (b) it proofs that the performances declined as the link between transceiver increases. From the simulation results, the longer the transmission range, min BER increases while Q-factor drops. Each condition is satisfied over link distances of 1.9km which 2 times shorter compared to 4km range during clear weather. Hence, for the FSO to perform well in haze weather, the transceivers need to be mounted at a shorter-range distance.

Meanwhile for (c), performance of different value of beam divergence. As shown in (a) and (b) respectively, the larger the beam divergence, BER value increased while Q-factor decreased. BER value of 10-19 and Q-factor value of 6 are achieved when the beam divergence equal to 1.4mrad. It is better to use smaller divergence for lesser dispersion of light particles. Bigger beam divergence will cause the light to scattered more which then results in lesser data can be transmitted and collected at the receiver side.

6. CONCLUSION

The relationship between haze attenuation and visibility was investigated. The selection of wavelength has a strong impact on the attenuation coefficient and capable of influencing the quality of transmission in free space optical. An increase in weather visibility will lead to a decrease in attenuation coefficient. The results showed that the wavelength 1550nm is more effective than wavelength 850nm, therefore, the wavelength 1550nm is more suitable for FSO. In addition, the results shows that link margin for different visibility under wavelength 1550nm was better than at the wavelength 850nm.

However, the analysis is only considered low bit rate using 155Mbps. In current FSO technology is far in high-speed transmission between giga and tera bit per sec. So, this prediction not reliable for higher speed performance. Therefore, future research can be implemented to focus in this area.

ACKNOWLEDGMENTS:

This The authors are grateful to Universiti Malaysia Sarawak for the Grant no. FRGS/1/2019/TK04/UNIMAS/02/2 allocated to the project.

REFRENCES:

[1] A. K. Majumdar, "Fundamentals of Free-Space Optical Communications Systems, Optical Channels, Characterization, and Network/Access Technology," Opt. Wirel. Commun. Broadband Glob. Internet Connect., pp. 55–116, 2019, doi: 10.1016/b978-0-12-813365-1.00004-7.

[2] N. Ben Halima and H. Boujemaa, "Adaptive cooperation for free space optical communications," Telecommun. Syst., vol. 75, no. 1, pp. 31–41, 2020, doi: 10.1007/s11235-020-00672-y.

[3] R. Wang et al., "Structure design and simulation study of dual two-quadrant coherent tracking system in free space optical communication," Proc. 2018 IEEE Int. Conf. Mechatronics Autom. ICMA 2018, pp. 1705–1710, 2018, doi: 10.1109/ICMA.2018.8484367.

[4] S. Magidi and A. Jabeena, "Review on Wavelength Division Multiplexing Free Space Optics," J. Opt. Commun., no. July 2020, 2018, doi: 10.1515/joc-2017-0197.

[5] A. Malik and P. Singh, "Free Space Optics: Current Applications and Future Challenges," Int. J. Opt., vol. 2015, no. c, 2015, doi: 10.1155/2015/945483.

[6] H. Shuling and W. Ziao, "Effect of haze on the performance of free space optical communication," ICOCN 2017 - 16th Int. Conf. Opt. Commun. Networks, vol. 2017-Janua, no. 5, pp. 1–3, 2017, doi: 10.1109/ICOCN.2017.8121332.

[7] E. M. Reddy and A. Brintha Therese, "Analysis of atmospheric effects on free space optical communication," 2017 Int. Conf. Nextgen Electron. Technol. Silicon to Software, ICNETS2 2017, pp. 338–343, 2017, doi: 10.1109/ICNETS2.2017.8067957.

[8] B. Kasprzak, J. Pękala, A. F. Stępień, and Z. Świerczyński, "Metrology and measurement systems," Architecture, vol. XVII, no. 4, pp. 537–547, 2015, doi: 10.1515/mms-2017-0060.Unauthenticated.

[9] A. Carrasco-Casado and R. Mata-Calvo, Space Optical Links for Communication Networks. 2020.

[10] G. Sharma and L. Tharani, "Performance evaluation of spectrum slicing based WDM FSO using MZM modulation," Proc. - 2nd Int. Conf. Micro-Electronics Telecommun. Eng. ICMETE 2018, pp. 210–214, 2018, doi: 10.1109/ICMETE.2018.00054.

[11] S. Mahajan, D. Prakesh, and H. Singh, "Performance Analysis of Free Space Optical System under Different Weather Conditions," 2019 6th Int. Conf. Signal Process. Integr. Networks, SPIN 2019, pp. 220–224, 2019, doi: 10.1109/SPIN.2019.8711687.

[12] S. S. Dinesh Sharma, S. A. Khan, "Literature Survey and issue on Free Space Optical Communication System," Int. J. Eng. Res. Technol., vol. 4, no. 2, pp. 561–567, 2015, [Online]. Available: www.ijert.org.

[13] M. A. A. Ali, "FSO Communication Characteristics under Fog Weather Condition," Int. J. Sci. Eng. Res., vol. 6, no. 1, pp. 1350–1358, 2015.

[14] M. I. Basudewa, Z. H. Bagaskara, S. S. A. Damita, R. F. Putra, and D. Ahmadi, "Bit Error Rate performance analysis for Free Space Optic communication," IOP Conf. Ser. Mater. Sci. Eng., vol. 850, no. 1, 2020, doi: 10.1088/1757-899X/850/1/012056.

[15] A. Basahel, I. M. Rafiqul, M. H. Habaebi, and A. Z. Suriza, "Visibility effect on the availability of a terrestrial free space optics link under a tropical climate," J. Atmos. Solar-Terrestrial Phys., vol. 143–144, pp. 47–52, Jun. 2016, doi: 10.1016/j.jastp.2016.03.005.

[16] P. Kumar, P. Verma, R. Singh, and R. K. Patel, "Proceeding of International Conference on Intelligent Communication, Control and Devices," no. September, pp. 979–989, 2016, doi: 10.1007/978-981-10-1708-7.

[17] A. Malik, S. Kumar, P. Singh, and P. Kaur, "Performance enhancement of point-to-point fso system under rain weather conditions," Adv. Intell. Syst. Comput., vol. 624, no. May, pp. 623–631, 2018, doi: 10.1007/978-981-10-5903-2_63.

[18] A. Trichili, M. A. Cox, B. S. Ooi, and M.-S. Alouini, "Roadmap to free space optics," J. Opt. Soc. Am. B, vol. 37, no. 11, p. A184, 2020, doi: 10.1364/josab.399168.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[19] S. H. Ali, "Advantages and Limits of free Space Optics," Int. J. Adv. Smart Sens. Netw. Syst., vol. 9, no. 3, pp. 1–6, 2019, doi: 10.5121/ijassn.2019.9301.

[20] N. A. M. Nor, Z. Ghassemlooy, S. Zvanovec, and M. A. Khalighi, "Performance analysis of all-optical amplify-and-forward FSO relaying over atmospheric turbulence," 2015 IEEE Student Conf. Res. Dev. SCOReD 2015, no. April 2016, pp. 289–293, 2015, doi: 10.1109/SCORED.2015.7449342.

[21] V. Janyani, M. Tiwari, G. Singh, and P. Minzioni, Optical and Wireless Technologies, 1st ed. Singapore: Springer Nature Singapore Pte Ltd, 2018.

[22] A. Basahel, M. R. Islam, A. Z. Suriza, and M. H. Habaebi, "Haze Impact on Availability of Terrestrial Free Space Optical Link," Proc. - 6th Int. Conf. Comput. Commun. Eng. Innov. Technol. to Serve Humanit. ICCCE 2016, pp. 366–369, 2016, doi: 10.1109/ICCCE.2016.83.

[23] R. Marbel, B. Ben-Moshe, and T. Grinshpoun, "Urban free-space optical network optimization," Appl. Sci., vol. 10, no. 21, pp. 1–26, 2020, doi: 10.3390/app10217872.

[24] D. A. Kadhim, A. J. Allah Shakir, A. N. Mohammad, and N. F. Mohammad, "System Design and Simulation using (OptiSystem 7.0) for Performance Characterization of the Free Space Optical Communication System," Int. J. Innov. Res. Sci. Eng. Technol. (An ISO, vol. 3297, pp. 4823–4831, 2015, doi: 10.15680/IJIRSET.2015.0406132.

[25] P. Kaur, V. K. Jain, and S. Kar, "Performance analysis of free space optical links using multi-input ulti-output and aperture averaging in presence of turbulence and various weather conditions," IET Commun., vol. 9, no. 8, pp. 1104–1109, 2015, doi: 10.1049/iet-com.2014.0926.

[26] M. M. Shumani, M. F. L. Abdullah, and A. Z. Suriza, "The Effect of Haze Attenuation on Free Space Optics Communication (FSO) at Two Wavelengths under Malaysia Weather," Proc. - 6th Int. Conf. Comput. Commun. Eng. Innov. Technol. to Serve Humanit. ICCCE 2016, no. 1, pp. 459–464, 2016, doi: 10.1109/ICCCE.2016.102.

[27] V. Takhi, "Free Space Optical Communication System under all weather conditions using DWDM," Int. J. Res. Appl. Sci. Eng. Technol., vol. 6, no. 2, pp. 137–149, 2018, doi: 10.22214/ijraset.2018.2023.

[28] T. Subekti, A. F. Isnawati, and D. Zulherman, "Optimization Free Space Optic (FSO) Design with Kim Model Using Space Diversity," J. Infotel, vol. 11, no. 3, pp. 93–98, 2019, doi: 10.20895/infotel.v11i3.444.

[29] R. Singh, M. Ahlawat, and D. Sharma, "A Review on Radio over Fiber communication System," Int. J. All Res. Educ. Sci. Methods, vol. 5, no. 4, pp. 2455–6211, 2017.

[30] "Air Pollutant Index (API) | Department of Environment." https://www.doe.gov.my/portalv1/en/info-umum/english-air-pollutant-index-api/100 (accessed Jan. 20, 2021).

[31] M. Ijaz, Z. Ghassemlooy, J. Perez, V. Brazda, and O. Fiser, "Enhancing the atmospheric visibility and fog attenuation using a controlled FSO channel," IEEE Photonics Technol. Lett., vol. 25, no. 13, pp. 1262–1265, 2016, doi: 10.1109/LPT.2016.2264046.

[32] Mohamed M. Shumani, M.F.L. Abdullah, A.Z. Suriza, "The Effect of Haze Attenuation on Free Space Optics Communication (FSO) at Two Wavelengths under Malaysia Weather" 2016 International Conference on Computer and Communication Engineering (ICCCE), 10.1109/ICCCE.2016.102