Evaluation of FSO System Availability in Haze Condition

A. A. Anis\textsuperscript{1}, C. B. M. Rashidi\textsuperscript{1}\textsuperscript{*}, S. A. Aljunid\textsuperscript{1} and A. K. Rahman\textsuperscript{2}

\textsuperscript{1} Advance Communication Engineering, Centre of Excellence School of Computer \& Communication Eng. Universiti Malaysia Perlis, (UniMAP) Kangar, 01000, Kangar Perlis
\textsuperscript{2} Departments of Electrical and Electronic Eng. Universiti Malaysia Sarawak, (UNIMAS), Sarawak

E-mail: rashidibeson@unimap.edu.my

Abstract. In this paper, we proposed the evaluation of FSO system availability in haze condition. The atmospheric attenuation by weather conditions in the atmosphere as the most challenging problem of FSO system as the system performance is severely degraded and causing the signal optic to be transmitted poorly. The effects of haze condition on the performance of FSO system is stressed out and focused in this paper. From the evaluation of the analysis, designs of FSO system are proposed to obtain a system with improved link performance in haze conditions. The scattering coefficient and the atmospheric attenuation are determined using Beer’s Lambert equation. From the research, the link performance of the systems greatly improved using Design 2 with minimum BER of $10^{-127}$ and maximum Q Factor of 23.98. The FSO system using Design 2 has better performance compared to Design 1 in haze condition as the optical signals could penetrate the dense haze better without losing much optical power during the transmission to the scattering.

1. Introduction
Free space optic (FSO) communication is the transmission of modulated near-infrared (NIR) beams. They are transmitted via the atmosphere to obtain optical communication \cite{1}. There are several important features of FSO system such as that it is unaffected by electromagnetic interference and radio frequency interference, high bandwidth and requires no licensing. Due to these interesting advantages, FSO system has been use in many applications. They are metro network extension, fiber backup, backhaul, enterprise connectivity, and military applications \cite{2}.

Despite its multiples advantages, FSO systems have its weaknesses. One of the primary drawbacks which could effectively degrade the Free Space Optics (FSO) link performance is none other than the weather condition. Several parameters such as the link range, the bit error rate (BER), quality factor, and optical power will experience extreme attenuation in the weather environment. Atmospheric attenuation due to this problem happens to prevent the link transmission in the weather conditions effectively thus achieving a high performance FSO system is impossible \cite{3}. It can affect the system by means of absorption and scattering of laser beam by aerosols and particles in mid-air \cite{4}.

One of the local weather conditions which severely affect the optical transmission of FSO system is haze. The signal transmission during hazy days is really bad especially in low visibility haze condition. A laser beam experiences power loss when it travels through the air. The selection of distance between transmitter and receiver, bit rate, attenuation, and diameter aperture can be adjusted to greatly reduce
the attenuation effect on FSO system. The scattering coefficient and atmospheric attenuation could be obtained by theoretical analysis of the local weather studies to determine the severity of weather conditions. The information obtained could help in expecting potential impact on signal transmission quality and transmission interference system operation. Furthermore, FSO system design could be enhanced to overcome possible interference and thus improve the system operation.

The common wavelengths used for FSO communication are 785 nm, 850 nm, and 1550 nm. The choice of wavelength for FSO system design happens to be one of the most decisive. Nonetheless, the FSO transmission link power is carefully exploited as it is potentially harm the eyes [5-6].

2. Free Space Optics (FSO) Link Budget
The scattering coefficient is used to evaluate the haze on FSO systems and it is affected by the visibility conditions. In addition, it is used to calculate the atmospheric attenuation. In low visibility of haze conditions, the particles size and concentration are higher compared to average visibility. So, scattering and attenuation is easily triggered in low visibility conditions. There are two factors affecting the attenuation coefficient. They are scattering and absorption [7]. These absorption and scattering are happening due to aerosols and gaseous particle exists in the atmosphere. Typically, the laser bit wavelengths used (785 nm, 850 nm and 1550 nm) were chosen for the system. These wavelengths fall inside the transmission windows in the atmospheric absorption spectra. Thus, the contributions of absorption to the total attenuation coefficient were found to be very small. So, the total attenuation coefficient is influenced by the effects of scattering. The size of the atmospheric particle with respect to the transmission laser wavelength determines the type of scattering. There are three types of scattering which are Mie scattering, Rayleigh scattering, and non-selective scattering.

The scattering coefficient can be expressed as a function of the visibility and wavelength. Hypothetically, low scattering coefficient caused high visibility caused by higher concentration and bigger particle sizes of haze along the transmission path of optical signal. Equation (1) is used to determine the scattering coefficient in hazy days.

\[ \beta = \frac{3.91}{V} \left( \frac{\lambda}{550\text{nm}} \right)^q \]  

where

- V = visibility in kilometres
- \( \lambda \) = wavelength in nanometers
- q = the distribution size of the scattering particles
  
  \[ q = \begin{cases} 
  1.6 & \text{for } V>50\text{Km} \\
  1.3 & \text{for } 6\text{Km}<V<50\text{Km} \\
  0.585V^{1/3} & \text{for } V<6\text{Km}
  \end{cases} \]

There are three parameter which affected the visibility which are the degree of sources coherence, the different in length between the paths and the detector location with based on the source. The performance of FSO systems degrades when the visibility is low when the concentration and size of the particles are higher compared to average visibility. The atmospheric attenuation can be calculated using the following Beer’s Law Equation [8].

\[ \tau(R) = \frac{P(R)}{P(0)} = e^{-(\beta)R} \]  

where

- \( \tau(R) \) = transmittance at distance R,
- \( P(R) \) = laser power of R,
- \( P(0) \) = laser power at the source
- \( \beta \) = attenuation or total extinction coefficient (per unit length)
If Beer's Lambert equation can be derived into equation (2)

\[ I = -10 \log \frac{P(R)}{P(\theta)} \]

\[ = -10 \log e^{-\beta R} \]

\[ = 10 \log e^{\beta R} \] (3)

\[ \tau(R) = \log e \left[ \left( \frac{3.91}{V} \right) \left( \frac{\lambda}{550nm} \right)^{-q} \right] dB \] (4)

Equation (1) is substituted into equation (3) to form equation (4) which is used to determine the atmospheric attenuation of the FSO system in haze conditions.

\[ P_{\text{received}} = P_{\text{transmit}} \frac{A_{\text{receiver}}}{(\theta R)^2} e^{-\alpha R} \] (5)

where

- \( P_{\text{transmit}} \) = transmitted power (Watt)
- \( A_{\text{receiver}} \) = area of the receiver (m²)
- \( \theta \) = beam divergence in radian (rad)
- \( R \) = distance between transmitter and receiver (m)
- \( \alpha \) = average atmospheric attenuation coefficient (dB/km)

### 3. Simulations and Setup Analysis

Two designs of FSO systems are proposed in this paper to study the attenuation effects of haze conditions on the FSO system and the availability of the system in low visibility condition. Figure 1 shows the block diagram of Design 1. It is the basic design of FSO system with a CW laser, a Mach-Zehnder Modulator, an FSO channel, and a PIN photodetector installed. A BER analyzer is installed at the receiver of the system to analyse and determine the BER of the system. Figure 2 shows the performance evaluation of Design 1 in the haze conditions. Similar to Design 1, this design has a single transmitter and a single receiver installed. However, five optical channels and an optical amplifier at each end of the channel are included in the design. Both designs are made and simulated under haze conditions to observe and analyse their performance using software called OptiSys™[9].
Design 1

![Block diagram of Design 1](image1)

**Figure 1.** The block diagram of Design 1.

Design 2

![Block diagram of Design 2](image2)

**Figure 2.** The block diagram of Design 2.
4. Simulation and Setup Analysis

Figure 3. The graph of bit error rate versus the distance.

Figure 3 shows the graph of bit error rate (BER) versus link distance in haze condition. The distance investigated in this research ranges from 0.5 km to 0.7 km. At 0.5 km distance, the BER value of both designs achieved their minimum point which is $10^{-60}$ for Design 1, and $10^{-127}$ for Design 2. As the distance increases, the BER value for each design increases too. It is due to the haze attenuation along the path. The longer the distance between the transmitter and the receiver, the greater the attenuation caused by haze particles, and thus the higher the BER. Therefore, the performance of FSO system becomes poorer.

Figure 4. The graph of bit error rate versus the bit rate.
Figure 4 shows the bit error rate (BER) versus bit rate in haze condition. From the figure, it can be observed that Design 2 shows promising capabilities in haze condition. As the bit rate used is increased, more bits are transmitted through the transmission channel. This caused the increment of error bits. From the graph, it is clearly shown that Design 2 has the lower BER value. At bit rate 155 Mbps, the BER of Design 2 reaches until $10^{-123}$ compared to BER of Design 1 which is $10^{-56}$ respectively. Obviously, Design 2 is the best design for haze condition as it could maintain better BER value compared to Design 1.

5. Conclusions

Optical communication system especially FSO system is the first choice in transmitting data at high speed since it uses light for signal transmission. However, the high atmospheric attenuation caused on the FSO link by the weather conditions makes the system performance to be poor. In this research, Design 2 is proposed for the system to efficiently transmit the optical signal eventhough in dense haze conditions. The attenuation effects on the link performance is greatly reduced as the minimum BER achieved is $10^{-127}$.

References

[1] Alkholidi, A. G., & Altwij, K. S. (2014). Free space optical communications—Theory and practices. InTech

[2] Zhu, X., & Kahn, J. M. (2002). Free-space optical communication through atmospheric turbulence channels. IEEE Transactions on communications, 50(8), 1293-1300.

[3] Kim, I. I., McArthur, B., & Korevaar, E. J. (2001, February). Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications. In Information Technologies 2000 (pp. 26-37). International Society for Optics and Photonics.

[4] Alnajjar, S. H., Noori, A. A., & Moosa, A. A. (2017). Enhancement of FSO communications links under complex environment. Photonic Sensors, 7(2), 113-122.

[5] Anis, A. A., Rahman, A. K., Rashidi, C. B. M., & Aljunid, S. A. (2016, August). Investigation of haze effects via utilizing different wavelength on free space optical communication. In Electronic Design (ICED), 2016 3rd International Conference on (pp. 358-360). IEEE.

[6] Anis, A. A., Rahman, A. K., Rashidi, C. B. M., & Aljunid, S. A. (2016, August). Link budget analysis for free space optical (FSO) communication under haze condition with adverse wavelength. International Conference on Electronic Design (pp. 354-357). IEEE.

[7] Rashidi, C.B.M., Anuar, M.S., Aljunid, S.A.(2010). Study of direct detection technique for zero cross correlation code in OCDMA, International Conference on Computer and Communication Engineering. 10.1109/ICCCE.2010.5556830, IEEE.

[8] Killinger, D. (2002). Free space optics for laser communication through the air. Optics and Photonics News, 13(10), 36-42.

[9] Rashidi, C.B.M., Aljunid, S.A. Ghani, F., Anuar, M.S, Fadhil, H. A. (2012). Code length optimization using Flexible Cross Correlation (FCC) code in OCDMA networks, 3rd International Conference on Photonics. 10.1109/ICP.2012.6379828. Pages 355-359.