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# Analysis of Atmospheric Attenuation Haze and Rainfall Effect on Free Space Optic Performance with Different Transmission Wavelength

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**Abstract:** This study presents the haze and the rainfall effect on FSO link system in tropical rainforest region. These two natural phenomena caused high signal attenuation as they create limited distance for visibility. This condition contributes to the impairment of the FSO link performance. With the analysis through theoretical, simulation and measurement the haze and rainfall effect can be investigated. Various transmission wavelength of FSO system is applied to investigate the attenuation effect on the system. The finding analysis shows that the low visibilities contribute high attenuation to transmission links. This attenuation effect can be reduced by manipulating several parameters such as narrow beam divergence, small transmitter and larger area receiver, longer wavelength medium and APD detector. As a result, the maximum visibility can be predicted that can begin impair the link. Overall, wavelength 785 nm improves the free space optic system by 14% compared to other wavelengths. Thus the continuous good link transmission can be acquired.

**Key words:** Tropical rainforest region, scattering coefficient, atmosperic attenuation, total attenuation, low visibility, parameters

## INTRODUCTION

Free space optic systems operate in the near-IR wavelength range between roughly 750 and 1600 nm with one or two systems being developed to operate at the IR wavelength of 10,000 nm. Because they use invisible infrared light which corresponds to frequencies in the order of terahertz they will not interfere with RF equipment which operates in the gigahertz band. In addition, the very narrow laser beam used makes it unlikely that nearby FSO systems would interfere with one another. Hence, unlike RF, the frequencies used by FSO do not have to be assigned or actively regulated (Bloom *et al*., 2003).

The physics and transmission properties of optical energy as it travels through the atmosphere are similar throughout the visible and the near-IR wavelength range. However, there are several factors that influence its propagation which wavelength choice by the design team turned out to be one of the most critical (Kim *et al*., 1998).

The general acceptance of free-space laser communication or optical wireless as the preferred wireless carrier of high bandwidth data has been hampered by the potential down time of these FSO systems in heavy rain and visibility limiting weather. The capability of laser in free space optic varies with wavelength. Under the scattering consequence, rain is beneath non-selective scattering which independent of wavelength (Rahman *et al*., 2014; Kim and Korevaar, 2001).

Reliable FSO communication is required with increasing bandwidth demands of multiple applications. FSO communication terminals also have to address variable link conditions in order to maximize the system availability and through put. For the optimization of overall system, the FSO communication terminals must dynamically respond to varying atmospheric conditions. A proper free-space communication system should be designed to dynamically improve performance under varying atmospheric conditions. Figure 1 shows the tree diagram of various atmospheric mitigation methods. One of the methods which is wavelength diversity is applied in this research. The ranges of wavelengths used are 780-850, 1520-1600 and 10000 nm. However, wavelength 10000 nm is not emphasized much in this study as it is still in development. The main components of an FSO system are modulator, optical source, optical detector and a demodulator. The basic block diagram of a FSO system

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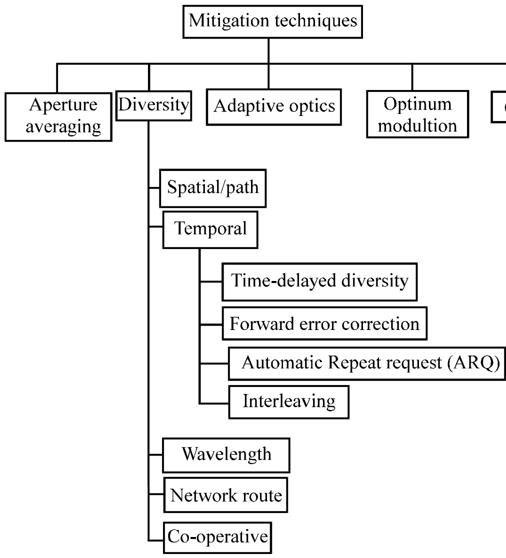


Fig. 1: Tree diagram showing the various atmospheric mitigation methods (Naimullah *et al*., 2008)

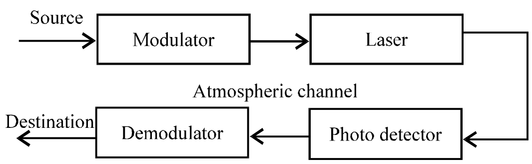


Fig. 2: Basic block diagram of the FSO system

is given in Fig. 2. The Local Area Network (LAN) based FSO system has the probability to explain the "last-mile" problem for the foreseeable future as a bandwidth in excess of 2THz is readily available in optical wavelengths. The performance of the FSO link is vulnerable by several atmospheric conditions such as fog, smoke, rain, snow etc. There are few other conditions when the performance of the FSO system may get influenced which include building sway during earthquake or some temporary blockage between line-of-sight connections required for data transmission. The main issue linked to this FSO system is the atmospheric turbulence which influences upon the temperature and pressure of the atmosphere (Kedar and Arnon, 2004). The power consumption of FSO link is comparatively less and they also offer tighter security to the data as the data transmitting light rays are confined to very narrow area as the light beam is of small diameter. The FSO signals are also less sensitive to the electromagnetic interferences. Both the modulation and demodulation are done in the electrical domain. The research is going on to implement other modulation techniques to get the better performance of the system as the Pulse Position Modulation (PPM) and On-Off Keying (OOK) modulation methods are used extensively (Xu *et al*., 2009). Implementation of Free-space point-to-point optical links can be achieved using infrared laser light, though low-data-rate communication over short distances is likely using LEDs. Infrared data association technology is a very simple form of free-space optical communications (Barua, 2011; Majumdar, 2015).

## MATERIALS AND METHODS

### Optical wavelength

**780-850 nm wavelength:** Wavelengths are well suited for FSO operation and several suppliers provide higher-power laser sources that operate in this region. Around 850 nm, reliable, cheap, high-performance transmitter and detector components are readily available and generally used in network and transmission equipment. Highly sensitive Silicon (Si) Avalanche Photo Diode (APD) detector technology and advanced Vertical-Cavity Surface-Emitting Laser (VCSEL) technology can be used for operation in this wavelength.

**520-1600 nm wavelength:** These wavelengths are suitable for free-space transmission and high quality transmitter and detector components are readily available. The combination of low attenuation and high component availability in this wavelength makes the development of Wavelength-Division Multiplexing (WDM) FSO systems feasible. However, components are abit expensive, plus the detectors are usually less sensitive and have a smaller receive surface area compared to Si APD detectors which operate using 850 nm wavelength. Finally, 50-65 times as much power can be used at 1520-1600 nm than can be transmitted at 780-850 nm for the same eye safety classification, owing to the low transmission of the human eye at these wavelengths.

**10,000 nm (10 nm) wavelength:** This wavelength range is relatively new to the commercial FSO arena and is being developed due to claims of better fog transmission characteristics. At this time, there is considerable debate regarding these characteristics because they are heavily dependent upon fog type and duration. In general, there are few components available at 10 μm as it is not normally used in telecommunications equipment. In addition, 10 μm energy does not penetrate glass so it is ill-suited to behind-window deployments. Another topic concerning the performance of FSO systems is the issue of atmospheric propagation in extreme rain (heavy fog) conditions for different wavelengths. Until recently, the generally held belief was that systems operating at longer wavelengths had better range performance than those operating at shorter wavelengths. However, recent studies have shown that in heavy fog conditions, attenuation is almost constant with wavelength over the 780-1600 nm region. In fact, there are no benefits until one gets to millimetre-wave wavelengths. So far, the vast majority of research suggests that 10 μm radiation propagates better under medium rain (hazy) and heavy rain (very moderate fog) conditions.

**Essential of mathematical model for FSO link:** The haze effect to FSO systems can be discovered by determining scattering coefficient. The scattering coefficient is influenced by the visibility conditions. The low visibility means the concentration and size of the particles are higher compared to average visibility. Thus, scattering and attenuation may be triggered more in low visibility conditions. The atmospheric attenuation can be calculated based on the scattering coefficient. The attenuation coefficient has contributions from the absorption and scattering of laser photons by different aerosols and gaseous molecule in the atmosphere. Since the laserbit wavelengths used (typically 785, 850 and 1550 nm) were chosen and they fall inside the transmission windows within the atmospheric absorption spectra, the contributions of absorption to the total attenuation coefficient were found to be very small (Rahman *et al*., 2014). Hence, the effects of scattering dominate the total attenuation coefficient. The type of scattering is determined by the particular atmospheric particle size with respect to the transmission laser wavelength.

The scattering coefficient can be expressed as a function of the visibility and wavelength. Theoretically, high scattering coefficient caused less visibility due to higher concentration and bigger particle sizes of haze along the path of laser beam. Equation 1 is used to determine the scattering coefficient in hazy days:

$$\beta = \frac{3.91}{v}\left(\frac{\lambda}{550 \text{ nm}}\right)^{-q} \quad (1)$$

Where:

V = Visibility in kilometers
λ = Wavelength in nanometers
q = The size distribution of the scattering particles

$$q = \begin{cases} 1.6 & \text{for} \quad V>50 \text{ km} \\ 1.3 & \text{for} \quad 6 \text{ km}<V<50 \text{ km} \\ 0.585V^{1/3} & \text{for} \quad V<6 \text{ km} \end{cases} \quad (2)$$

Define the visibility depends on the degree of coherence of the source, on the difference in length between the paths as well as on the detector location with respect to the source. The effectiveness and availability of FSO systems is decreased by low visibility and it can occur during a specific time period within a year or at specific times of the day. Low visibility is defined when the concentration and size of the particles are higher compared to average visibility. So that the more scattering and attenuation may cause the low visibility conditions (Naimullah *et al*., 2008). The following Beer's Law, Eq. 2 (Achour, 2002; Willebrand and Ghuman, 2001) describes the atmospheric attenuation:

Table 1: FSO parameters

| Parameters | Values |
|---|---|
| Transmission power | 70 mW |
| Beam divergence | 1 m rad |
| Receiver dimensions | 20 cm |
| Receiver sensitivity | 2000 nW |
| Wavelength | 780, 850, 1550nm |

$$\tau(R) = \frac{P(R)}{P(O)} = e^{-(\beta) R} \quad (2)$$

Where:

τ(R) = Transmittance at range R
P(R) = Laser power at R
P(0) = Laser power at the source
β = Attenuation or total extinction coefficient (per unit length)

The conversion of Eq. 2 can be done as it is in linear scale in logarithms scale:

$$= -10 \log \frac{P(R)}{P(O)} \quad (3)$$

$$\begin{aligned} &= -10 \log e^{-\beta R} \\ &= 10 \log e^{\beta R} \end{aligned} \quad (4)$$

Equation to calculate the atmospheric attenuation on hazy days can be obtained by substituting Eq. 1 into 4:

$$\tau(R) = \log e\left[\left(\frac{3.91}{V}\right)\times\left(\frac{\lambda}{550 \text{ nm}}\right)^{-q}\times R\right] \text{dB} \quad (5)$$

where, $P_{transmit}$ = transmitted power (Watt); Areceiver = area of the receiver ($m^2$); θ = beam divergence in radian (rad); R = distance between transmitter and receiver (m); α = average atmospheric attenuation coefficient (dB/km). FSO Parameters.

Table 1 shows the specifications of FSO system used in this study. Data calculations and simulations are also made using the specifications set. The amount of received power is proportional to the amount of power transmitted and the area of the collection aperture and inversely proportional to the square of the beam divergence and the square of the link range. The total loss coefficients are determined by:

$$\alpha R = \alpha_{rain} R + \alpha_{haze} R \tag{6}$$

Where:

$\alpha_{rain} R$ = Scattering due to rain ($km^{-1}$)
$\alpha_{haze} R$ = Scattering due to haze ($km^{-1}$)

To calculate losses due to rain, one uses the empirical (Eq. 7):

$$\alpha_{rain} = 1.25\,\mu \frac{Z}{a^3} \tag{7}$$

Where:

Z = Rainfall rate (cm/sec)
a = Rain drops radius (cm)

To be exact, the raindrop radius varies and affected by several factors. However, the data could be obtained from any meteorological department in the region. Table 1 shows the parameter of free space optic.

## RESULTS AND DISCUSSION

Figure 3 shows the graph of maximum rainfall rate against range. The maximum rate is 155 mm/h when the range is 0.5 km. The receiver sensitivity is at bit error rate of 10-9 and the aperture selected with small transmitter and wide receiver area. It can be seen that at short distance, the rainfall rate is higher for the FSO system to transmit considering the sensitivity of receiver. As the link range increases the rainfall rate will drop. This prediction rate is significant to determine the maximum range of laser light transmission and limit rainfall rate. Figure 4 shows the prediction of maximum visibility rate at different link range between wavelength channel 785 and 1550 nm. Both units are in km. Bit error rate is $10^{-9}$ and aperture size area is the same with rain parameter. It can be observed that the visibility increases when the link range increases. In comparison of wavelength channel, the longer wavelength (1550 nm) is much better in performance than short wavelength (785 nm). The FSO system which can be operated at long distance and lower visibility is a good design of FSO system. The maximum visibility is approximately 2.6 km for 1550 nm wavelength and 3.4 km for 785 nm wavelength. It can be seen that the haze effect is worsen as the link range increases. The range depends on the maximum visibility. However, laser with 785 mm wavelength is proven has the capability to handle the worst condition better than 1550 nm wavelength laser.

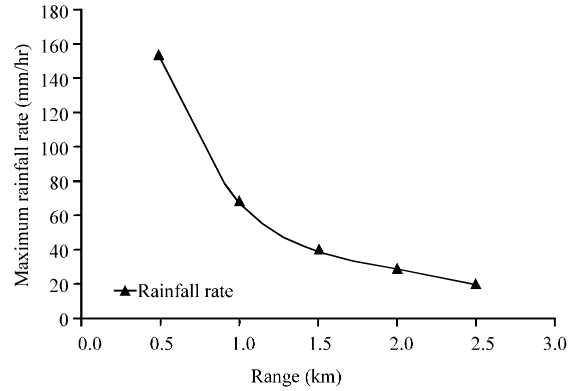


Fig. 3: Graph of maximum rainfall rate (mm/hr) vs. range (km)

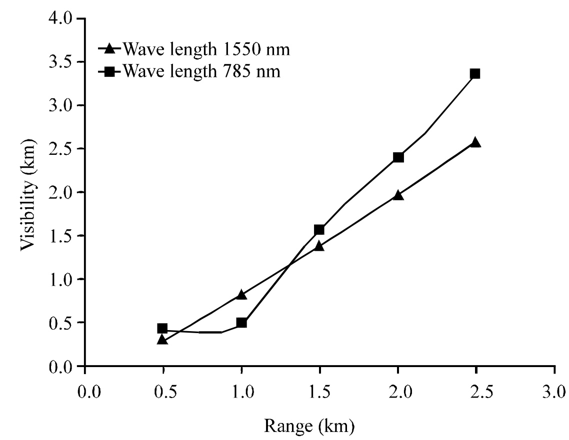


Fig. 4: Graph of maximum rainfall visibility (km) vs. range (km)

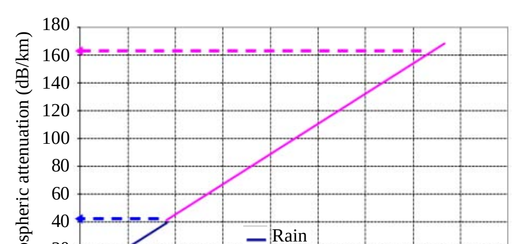


Fig. 5: Graph of atmospheric attenuation (dB/km) vs. scattering coefficient

Figure 5 shows the graph of atmospheric attenuation against scattering coefficient between rain and haze. Based on the graph, atmospheric attenuation is linearly proportional to the scattering coefficient. The highest atmospheric attenuation for rain is approximately 40 dB/km which is represented by blue dotted line meanwhile for haze, the atmospheric attenuation can reach almost >160 dB/km that is represented by pink dotted line as shown in Fig. 3. It can be seen that haze effect is more than rain effect. The typical laser communication system can handle up to 60-100 dB/km attenuation for 30-60 dB of margin for 500 m range. Therefore, heavy haze (low visibility) weather has greater potential to impair the FSO transmission link compare to rain.

## CONCLUSION

Rainfall and haze effects show a significant role to cause high atmospheric loss (dB/km). However, haze effect has verified to contribute more compared to rain effects over Free Space Optic (FSO) systems as the maximum atmospheric attenuation recorded is higher than 160 dB/km while the maximum atmospheric attenuation recorded for rain is 40 dB/km. The 1550 nm wavelength was found to be the most suitable for free space optic system compared to 780 nm wavelengths. Therefore, it can supply sufficient signal power at the receiver in order to maintain the quality of transmission even in bad weather.

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