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TERRESTRIAL FREE SPACE OPTIC PROPAGATION ANALYSIS CONSIDERING MALAYSIA WEATHER CONDITION

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Abstract. The reflection of sunlight by mirrors or known as the heliograph is an early method of optical wireless communication (OWC). Naturally, modern communication system reveals much higher data rates with better quality of service (QoS) compared to those ancient methods. There are many advantages of OWC which are important for a terrestrial system for example the usage of an outdoor free space optics (FSO) system. In this paper, a description and system performance characterization of the FSO such as attenuation, bit error rate (BER), Q factor and the type of detectors that are highly useful for detection in FSO systems are presented. The system are designed and simulated for performance characterization considering Subang terrestrial.
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Keywords: bit error rate; photodetector; Q factor; terrestrial system

Abstrak. Pemantulan cahaya matahari oleh cermin atau dikenali sebagai heliograf adalah kaedah awal komunikasi optik wayarles (OWC). Sewajarnya, sistem komunikasi moden mendedahkan kadar data yang tinggi di samping kualiti perkhidmatan yang lebih baik berbanding kaedah terdahulu. Sistem komunikasi optic wayarles mempunyai banyak kebaikan dimana ia adalah penting untuk sistem daratan, sebagai contoh penggunaan Optik Ruang Bebas (FSO) di kawasan luar. Di dalam kertas kerja ini, gambaran dan pencirian prestasi sistem Optik Ruang Bebas seperti pelemahan, kadar bit kesalahan (BER), faktor Q dan jenis pengesan yang berguna untuk pengesanan dalam sistem FSO dibentangkan. Sistem telah direkabentuk dan disimulasi untuk perincian prestasi dengan mengambil kira kawasan Subang.

Kata kunci: Pelemahan; kadar bit kesalahan; pengesan foto; faktor Q; sistem daratan

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1.0 INTRODUCTION

Optical communication means any forms of communication that uses light as the transmission medium. It involves a transmission, emission or reception of visual signs and optical signals. An optical communication link consists of a transmitter, a channel and a receiver. One of the most common medium for modern digital communication is the usage of optical fiber.

But because of the high cost and the time require, fiber is not a very practical solution. One of the possible solutions to the problem is the use of free space laser communication. Free space laser communication is very similar to fiber optic communication, except that instead of light being travel within a glass fiber, the light is actually transmitted through the atmosphere. However, the important different between fiber optic and FSO is the predictable of the attenuation of laser power in the atmosphere compared to fiber [1]. On the other hand, these systems are vulnerable to atmospheric turbulence, such as attenuation and scintillation

Outdoor FSO is a potentially high capacity and cost effective communication technique, which has been receiving attention and commercial interest. Furthermore, FSO communications is not a subject to frequency spectrum regulations [2]. Apart from that, the cost of installation is mainly economic because there is no extra cost for digging the street to lay fiber. In term of security, FSO uses narrow laser beam which make detection, interception and jamming are very difficult. However, the usage of FSO is still rare in Malaysia most likely due to environmental factor.

A FSO communication system consists of three main communication parts which are transmitter, propagation channel and the receiver [3]. Basically, the transmitter converts the electronic signal into light. The propagated light through the atmosphere to the receiver, will converts the light back into an electronic signal.

2.0 FSO SYSTEM

2.1. Literature Review

FSO is a line-of-sight (LOS) technology that uses invisible beams of light to provide optical bandwidth connections that can send and receive voice, video and data information. It requires a strict line of sight and critical alignment of laser beams from the two transceivers. Today, this technology has enabled the development of a new category of an outdoor wireless that can transmit voice, data and video at bandwidth up to 2.5Gbps. In as much as FSO and fiber optics transmission systems use similar IR wavelengths of light and have similar transmission bandwidth capabilities, FSO is often referred to as “fiberless optics” or “optical wireless” transmission [4].

The concept of transmitting information through the air by means of a modulated light signal is quite old. Although significant advances have been made over the past 10 years, the concept remains relatively simple. A narrow beam of light is launched at a transmission station, transmitted through the atmosphere, and subsequently received at the receive station. Light travels through air faster than it does through glass. So it is fair to classify FSO as optical communications at the speed of light.

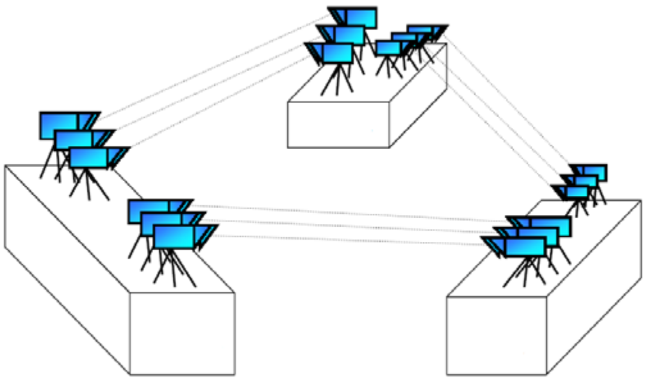

Figure 1 A point to point FSO link

In fact, FSO links have some other advantages in various situations, such as a temporary communications when fiber optic cabling is under construction or as a disaster recovery by providing an active and reliable secondary path to keep a network up and running until the primary path is restored. Other application of FSO is for communications between spacecraft, including elements of satellite constellation and can be found in an interstellar communication. Besides that, FSO should be a very interesting alternative for military applications due to its portability, high bit rate data and low risk of exposure to the enemies. In other word, FSO hardware is portable and quickly deployable [6-8].

Selection of appropriate wavelength in FSO is an important issue. The safety concern related to the effect of FSO beam to human eye and skin should be considered. The most common wavelength used for optical communication ranges from 850 to 1550 nm. Many FSO installers utilize 780, 850 and lately 1550nm beam. Wavelength of 1550nm produces higher power and more eye safe compared to both 780–850 nm. Wavelengths that are 400–1400 nm allow the light to focus on the cornea and lens, thus causing potential hazard to human eye.

In contrast, wavelength which is greater than 1400 nm is absorbed by lens and cannot penetrate beyond the cornea. Hence, eye is more protected. In additional, higher wavelength beam is able to go through haze, smog and fog.

2.2 Scattering of Light

In a tropical country such as Malaysia, rain is our major concern. But the primary challenge to FSO based communications is fog. Rain and snow have little effect on FSO technology, but fog is different. Fog is vapor composed of water droplets, which are only a few hundred microns in diameter but can modify light characteristics or completely hinder the passage of light. Since fog results in more particles stay longer in atmosphere compared to rain, it presents more serious degradation on FSO performance.

By understanding weather parameters such as humidity, visibility and temperature, together with the features of a FSO system and its deployment characteristics, it is possible to model the atmospheric propagation. The three most significant conditions that affect optical transmission are absorption, scattering and scintillation [9]. All these three can reduce the amount of energy arriving at the receiver, thereby compromising the overall reliability of the system and BER levels of the received information. But among these three, fog is the main cause of attenuation. Fog is presented when the concentration of condensed water is higher at the lower part of the atmosphere [10]. A good understanding of atmospheric phenomena such as fog, haze, mist and snow and their effect on the performance of a wireless link is of great importance when designing the transmitter and receiver of a FSO system.

Fog is the most common scattering element. In scattering (unlike absorption), there is no loss of energy, only a directional redistribution of energy that may have significant reduction in beam intensity for longer distances. In Malaysia, fog is due mainly to forest fires in the neighbouring country of Indonesia. The particles present in this type of fog are different from those encountered in temperate countries where fog occurs mainly around coastal areas.To assess the effect of fog on FSO links in Subang terrestrial, visibility data from the Malaysian Meteorological Department (MMD) were processed to obtain the cumulative distribution of visibility. Most of the time, the visibility at Subang is greater than 10 km.

The scattering coefficient can be expressed as a function of the visibility and wavelength. The scattering coefficient in clear weather can be determined by using the expression in Equation (1) below.

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

where V is the visibility in km, λ is the wavelength in nanometers (nm) and q is the size distribution of the scattering particles [1.3 for average visibility (6 km< V< 50 km), 0.16 V+0.34 for haze visibility (V<6 km), V–0.5 for mist visibility (0.5 km< V<1 km) and 0 for fog (V<0.5 km)]. Meanwhile, the atmospheric attenuation is described by the following Beer's Law [11] that can be converted to logarithms scale given by,

$$\tau(R) = 10 \log e^{\beta R} \tag{2}$$

where β is the scattering coefficient while R is the path length in km.

2.3 System Performance

The system performance can be evaluated in many ways such as by analyzing the BER and Q factor. In digital transmission, BER is the number of received binary bits that have been altered due to noise and interference on a digital signal, divided by the total number of transferred bits. Meanwhile, Q factor measures the quality of an analog transmission signal in terms of its signal to noise ratio (SNR). As such, it takes into account physical impairments to the signal for example noise or chromatic dispersion which can degrade the signal and ultimately cause bit errors. The relationship between BER and Q factor is given in Equation (3) [12].

$$BER \approx \frac{1}{\sqrt{2\pi Q}} \exp\left(\frac{-Q^2}{2}\right) \tag{3}$$

It can be seen that the BER is inversely proportional to Q factor. In other words, the higher the value of Q factor, the better the SNR and therefore the lower the probability of bit errors.

3.0 SYSTEM MODELLING

FSO system basic design was modeled and simulated for performance characterization by using OptiSystem 7.0 which is a powerful software design tool that enables to plan, test and simulate almost every type of optical link in the transmission layer of a broad spectrum of optical networks from LAN, MAN to ultra long haul. It can minimize time requirement and decrease cost related to the design of optical systems, links and even components. There are several parameters of the system varied to obtain the optimum system performance. The main parameter that was considered is the laser propagation distance between the specific FSO channel. The FSO design model is shown below in Figure 2.

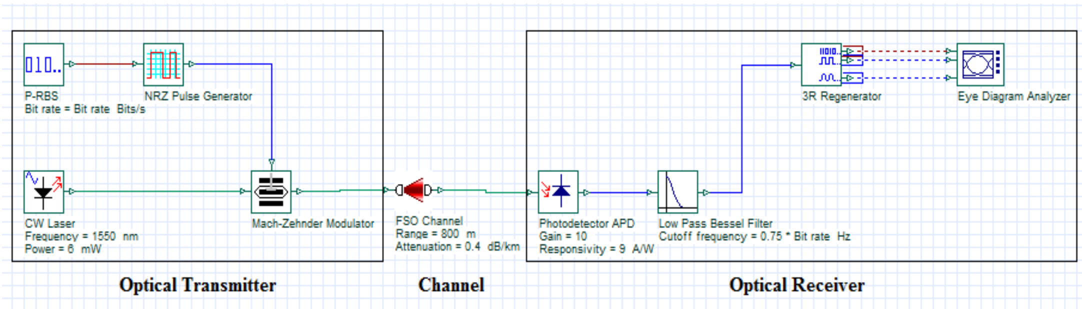

Figure 2 Schematic design of a simplex FSO system

The optical transmitter consists of four subsystems. The first subsystem is the Pseudo-Random Binary Sequence (P-RBS) generator. This subsystem is to represent the information or data that wants to be transmitted. The output from a PRBS generator is a bit stream of binary pulses; a sequence of "1"s (ON) or "0"s (OFF), of a known and reproducible pattern. The second subsystem is the Non-Return-to-Zero (NRZ) electrical pulse generator. This subsystem encodes the data from the PRBS generator by using the NRZ encoding technique. A NRZ line code is a binary code in which 1's are represented by one significant condition and 0's are represented by some other significant condition. The third subsystem in the optical transmitter is the Fabry-Perot and Distributed-Feedback lasers. FP and DFB lasers based on InGaAs semiconductor technology with operating wavelengths around 1550nm were developed specifically for fiber optic communications systems because of the low attenuation characteristics of optical fiber in this wavelength range. The last subsystem is the Mach-Zehnder modulator. It is an optical modulator that the function is to vary intensity of the light source from the laser according to the output of the NRZ pulse generator. The device comprises of two Y junctions which give an equal division of the input optical power.

The free space between transmitter-receiver is considered as FSO channel which is a propagation medium for the transmitted light. In the OptiSystem software used, the FSO channel is between an optical transmitter and optical receiver with aperture diameter of 5 cm and 8 cm at each end respectively. Meanwhile, the beam divergance is set to 2mrad.

The optical receiver consist of an avalanche photodiode (APD) followed by a front-end amplifier, a low pass filter and a 3R regenerator. The InGaAs APD must be capable of meeting the system bandwidth requirements. A Low Pass Filter (LPF) after the front-end amplifier is used to filter out the unwanted higher frequency signals. Bessel LPF is used with a cut-off frequency of 0.75xbit rate of the signal. The 3R (Re-shaping, Re-timing, Re-generating) regenerator is the last subsystem in the optical receiver. The 3R fuction is use to regenerate electrical signal of the original bit sequence, and the modulated electrical signal as in the optical transmitter to be used for BER analysis. In other words, it normalized the signal waveform with Gigabit class transmission. This is in order to allow relay transmissions without deterioration of signal quality between buildings that are more than 1km apart or that do not provide a good LOS.

4.0 RESULT ANALYSIS

4.1 Data Rate

By varying the data rate and the path length between the two transceivers, the system performance in terms of Q factor was obtained by using two different laser wavelengths of 850 and 1550 nm. Then, the system performances were plotted in Figure 3 and 4 respectively. The path length was set from 200 m to 2 km while the transmit power was set at a constant value of 6mW in a clear weather (average visibility). The data rates were set at 3 levels which are fast Ethernet (100 Mbps), asynchronous transfer mode (ATM) (155 Mbps) and Gigabit Ethernet (1.25 Gbps). Using the mathematical model proposed in Equation 1 and 3 earlier, the attenuations per kilometre in clear weather are 0.4 dB/km and 1 dB/km depending on the exponent in the expression for atmospheric attenuation.

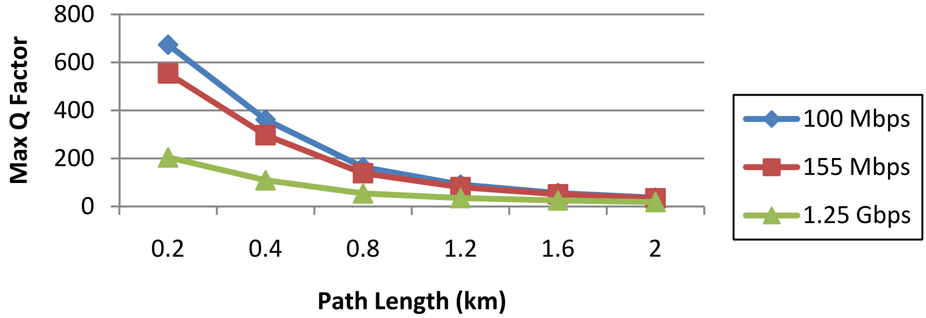

Figure 3 Max Q factor for variable length at 850nm in clear weather

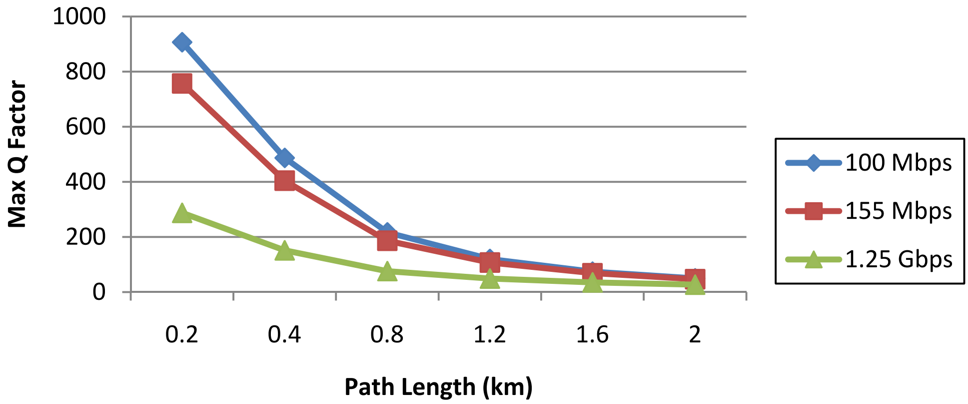

Figure 4 Max Q factor for variable length at 1550nm in clear weather

From the line chart of both Figure 3 and 4, it can be observed that maximum Q system decrease when path length is longer. In other words, it shows that the error in the received signal increases when the distance increases too. Besides that, the line chart also shows that with higher data rate, maximum achievable Q factors are also reduced.

4.2 Weather Condition

The relationship between laser wavelength and weather condition was also investigated.The system performance in terms of Q factor was obtained in three different weathers at Subang. The first scenario is in a clear weather (average visibility), second of haze weather (low visibility) and lastly assuming in fog. The visibility data used in this analysis are the average of hourly observation in March 2010 taken at Subang by the Malaysian Meteorological Department (MMD).

The first scenario is in a clear weather with most of the time, visibility in Malaysia is greater than 10km. Meanwhile, the second is in lower visibility that to be at 2km later in the evening. It is believed that in that particular evening, the visibilities lower than normal was due to heavy rain at Subang. Last but not least, the lowest visibility encountered was during the *El Nino* in 1997 and was observed to be only 700 m [5]. Figure 5, 6 and 7 shows the system performances according to the level of visibility mentioned.

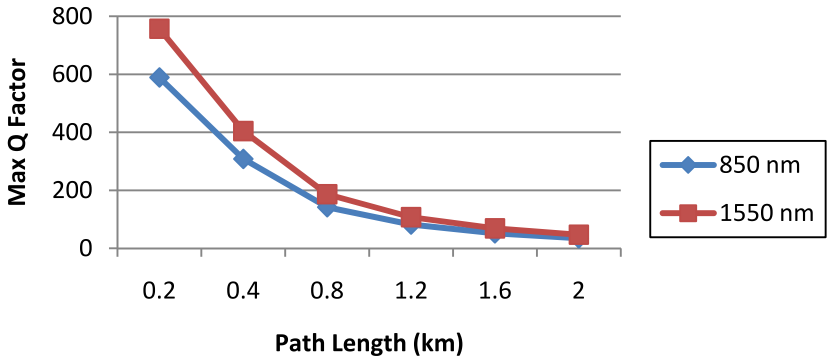

Figure 5 Max Q factor for variable length in clear weather

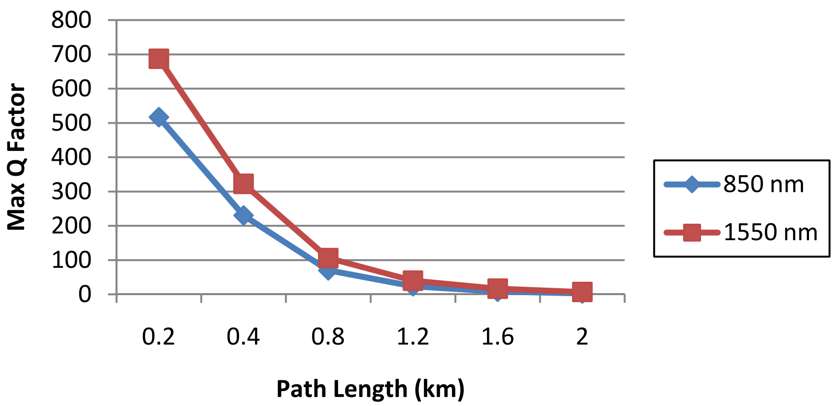

Figure 6 Max achievable Q factor in hazy weather

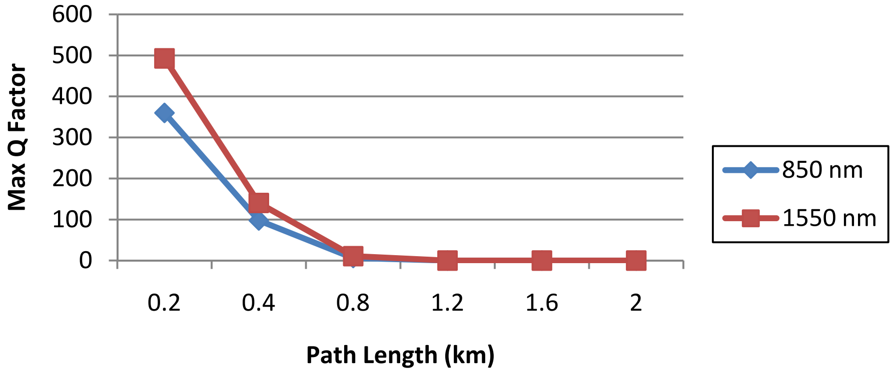

Figure 7 Max Q factor during foggy weather

From the graph of Figure 5, 6 and 7, it can be observed that the error in the received signal increases as the distance increases due to the value of Q factor that decreasing. At the distance of 1km in foggy weather, only wavelength at 1550nm can be used as the Q factor received does not equal to zero. It also can be declare that laser communication outages due to the attenuation of laser light can be a problem during lower visibility.

4.3 Photodetectors

Compared with transmitters, receiver choices are much more limited. Figure 8 and 9 shows the comparison of laser propagation by using two different major device types (PIN and APD) for optical detection over the wavelength range 0.8 to 1.6µm.

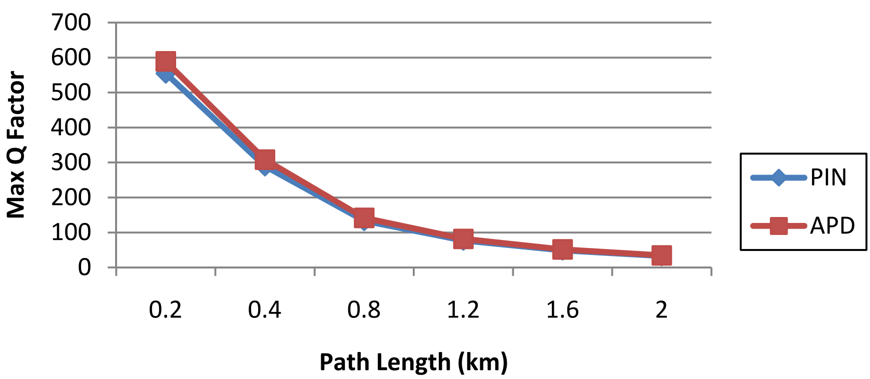

Figure 8 Max Q factor for respective detector at wavelength 850 nm

Si-PIN and Si-APD detectors are widely available. Silicon (Si) is the most commonly used detector material in the visible and near IR wavelength range. Si technology is quite mature, and Si receivers can detect extremely low levels of light. Detector based on Si typically have a spectral response maximum sensitivity around 850 nm, making Si detectors ideal for use in conjunction with short wavelength VCSELs operating at 850 nm. However, Si sensitivity drops off dramatically for wavelengths beyond 1000 nm. Figure 8 shows that Si-APD detector are more sensitive compared to Si-PIN. Therefore, Si-APD detectors are highly useful for detection in FSO systems.

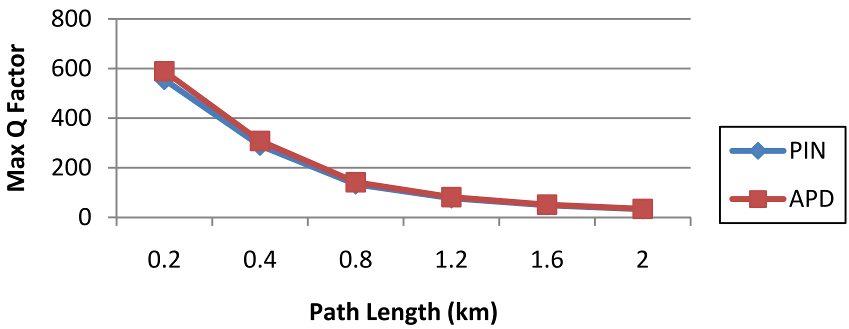

Figure 9 Max Q factor for respective detector at 1550nm

Indium Gallium Arsenide (InGaAs) is the most commonly used detector material for the longer wavelength range. Nearly 100% of all longer wavelength fiber optic systems use InGaAs as a detector material. Commercially, InGaAs detectors are optimized for operation at either 1310 or 1550 nm. Because of the drastic decrease in sensitivity toward the shorter wavelength range, InGaAs detectors are typically not used in the 850 nm wavelength. The majority of InGaAs receivers are based on PIN or APD technology. As with Si, InGaAs APDs are far more sensitive as shown in Figure 9 because of an internal amplification (avalanche) process.

5.0 CONCLUSION

FSO is an option that can be deployed as a trustworthy solution for a high bandwidth short distance applications. The applications of FSO is quite slow in tropical countries such as Malaysia but as the time goes through, FSO might be become one of the technology that could be use in data transmission.

In this paper, FSO communication systems were modeled and simulated where the system performances were analyzed when several parameters of the system were varied.The selection of wavelength is important according to the particular applications. From the results analysis, FSO wavelength with 1550 nm produces less error due to higher value of the Q factor compared to 850 nm. Thus, it is recommended to install FSO system with 1550 nm wavelength. But, such wavelength requires active heating and cooling to maintain intensity. Furthermore, lasers of 850 nm are much cheaper and favored for applications over moderate distances.

Besides that, detectors with a large responsivity are preferred since they requires less optical power. APDs can have much larger values of responsivity, as they are designed to provide an internal current gain in a way similar to photomultiplier tube. They are used when the amount of optical power that can be spared for the receiver is limited.

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