Design and Development of Free Space Optic (FSO) Communication under Haze and Rain Weather Conditions

by

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A thesis submitted in fulfillment of the requirements for the degree of Master of Science in Communication Engineering

School of Computer and Communication Engineering
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2017

ACKNOWLEDGEMENT

I would like to express my sincere appreciation and gratitude to our Director Advanced Communication Engineering, Centre of Excellent School of Computer & Communication Engineering, Associate Profesor Dr. Alwee Aljunid Bin Syed Junid, respectfully for the smooth sailing that I have had these past one and a half years, and successfully to complete this MSc titled Design and Development of Free Space Optic (FSO) Communication under Haze and Rain Weather Conditions.

Next, I would like to give special thanks to my supervisor and co supervisor, Dr. Mohd Rashidi Bin Che Beson and Dr Abdul Rahman Bin Kram for guiding me continuously and giving moral support for my MSc project progress during these past one and a half years. Without their guidance and advice, it would have been very hard for me to complete my project and I am sure I would take longer time to finish my research. I really appreciate their endless efforts for me. Besides, I would like to send my gratitude to Meteorological Centre at Chuping, Perlis and also Innovate Malaysia Committee for guiding towards industrial standard research work.

Besides them, I would like to thank my parents for their sacrifices in term of moral and financial supports and to my siblings for always giving me suggestions, encouragements and emotional support from the beginning of my research till the end.

Last but not least, I would like to send my gratitude to my friends and my ACE member for mutually sharing their expertise and ideas during the meeting sessions with our supervisor.

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LIST OF ABBREVIATIONS

AO	Adaptive Optics
BER	Bit Error Rate
CW	Continuous Wave
EDFA	Erbium-Doped Fiber Amplifiers
FCC	Federal Communications Commission
FSO	Free Space Optics
LAN	Local Area Network
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light Emitting Diodes
LOS	Line of Sight
MIMO	multiple input, multiple output
MMD	Malaysia Meteorological Department
NRZ	Non Return Zero
RF	Radio frequency
RVR	Runway Visual Range
SISO	Single input, single output
SONET	Synchronous Optical Networking
S/N	signal-to-noise
VLC	Visible light communication

LIST OF SYSBOLS

V	velocity (km)
λ	Wavelength (nm)
q	Size distribution of the scattering particles
β	Scattering coefficient
R	link range (km)
a	droplet radius (cm)
ρ	Water density (g/cm^3)
g	Gravitational constant (cm/sec^2)
Z_a	rainfall rate (cm/sec)
η	Viscosity of air (cm/sec)
Q_{scat}	scattering efficiency
N_a	number of water droplets contained in the atmosphere (cm^3)
V_a	Limiting speed of raindrop
τ(R)	Atmospheric transmittance
d_2	diameter receiver aperture (m)
d_1	diameter transmitter aperture (m)
θ	Beam divergence (mrad)
W	width
$P(R)$	Laser power at range
$P(0)$	Laser power at the sources
I_{Max}	Maximum estimated light level
I_{Min}	Minimum estimated light level

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ABSTRACT

This research was conducted to study the effects of haze and rainfall on the improved performance of FSO system. An FSO system is an optical wireless system which use atmosphere as the transmission medium. Despite excellent advantages of high bandwidth, secured, low cost and flexibility, it is vulnerable towards weather conditions such as haze and rain as these phenomena cause signal attenuation due to the atmospheric scattering. An FSO system with improved performance under these heavily attenuated conditions was selected from three different proposed designs of FSO system. These three designs of FSO system were made and simulated using simulation software called *OptiSystem*. Compared to the basic design of FSO system which only has one FSO channel, Design 1 has been installed with two optical channels. Then the effects of rain and haze were studied on the design based on the Bit Error Rate (BER) and Q Factor achieved. From the result analysis, Design 2 was proposed as an effort to improve the system performance of Design 1. Compared to Design 1, Design 2 has two CW lasers as optical source installed and just one optical channel. The two-beam link and single FSO channel have improved the system performance in term of the BER and Q Factor. The BER reduced and the Q Factor increased. Based on the simulation analysis of Design 1 and Design 2, Design 3 has been ultimately proposed as a measure to create the best improved FSO system which could operate the most efficiently in haze and rain conditions compared to the previous designs. Design 3 was installed with an optical amplifier at both transmitter and the receiver sides to amplify the optical signal and maintain it at a high level. The design has also been installed with five optical channels to increase the scattering attenuation on the system for study purposes. Despite that, the system still operated at high performance and still has a better performance than Design 1 and Design 2. In the study, several parameters were altered for the purposes of the research, namely bit rate, effective received power, link distance, aperture diameter and attenuation. Bit Error rate and Q Factors of the proposed designs were analysed to study the improved performance of FSO system in rainy and hazy days. Theoretical analysis was done on the data collected from the meteorological centre and the results were used for the simulation analysis using *Optisystem*. From the results, the data were plotted on the graphs. It was found that, Design 3 has proven its improved capabilities to transmit transmission signal from the optical transmitter to the optical receiver at high performance under haze and rain conditions compared to Design 1 and 2. The lowest BER of 10^{-80} was achieved by Design 3 in rainy days and 10^{-127} in hazy days. The known threshold BER for optical communication system was 10^{-9} which meant that all designs were exceptionally good. As for the Q Factor, the corresponding value was six (6) when the BER was 10^{-9}. However, Design 3 has successfully reached the maximum value of 18.9 in rain condition and 23.98 in haze condition which has surpassed that. This has proved the superiority improved performance of Design 3, compared to Design 1 and Design 2 in haze and rain conditions.

Rekabentuk dan Pembinaan Komunikasi Optik Ruang Bebas (FSO) Semasa Keadaan Cuaca Jerebu dan Hujan

ABSTRAK

Kajian ini telah dijalankan untuk mengkaji kesan jerebu dan hujan kepada prestasi sistem FSO yang semakin meningkat. Sistem FSO merupakan satu sistem optik tanpa wayar yang menggunakan atmosfera sebagai media penghantaran. Selain kelebihan-kelebihannya iaitu jalur lebar yang tinggi, selamat, murah, dan fleksibel, ia mempunyai satu kekurangan besar iaitu kelemahannya terhadap keadaan cuaca iaitu keadaan jerebu dan hujan kerana fenomena-fenimena ini menyebabkan gangguan isyarat yang disebabkan oleh penyerakan atmosfera. Satu sistem FSO yang mempunyai prestasi tinggi semasa dalam keadaan yang sangat melemahkan isyarat tersebut akan dipilih dari tiga rekabentuk berlainan yang dicadangkan. Tiga Rekabentuk FSO ini telah dibuat dan disimulasi menggunakan satu perisian simulasi yang dikenali sebagai *OptiSystem*. Berbanding rekabentuk asas sistem FSO yang hanya mempunyai satu saluran FSO, Rekabentuk 1 telah dipasang dengan dua saluran optik. Kemudian, kesan keadaan jerebu dan hujan ke atas rekabentuk tersebut telah dikaji berdasarkan Kadar Ralat Bit (BER) dan Faktor Kualiti yang diperolehi. Daripada analisis keputusan, Rekabentuk 2 dicadangkan sebagai satu usaha untuk menambahbaik prestasi sistem Rekabentuk 1. Berbanding Rekabentuk 1, Rekabentuk 2 mempunyai dua laser CW sebagai sumber optik yang dipasang dan hanya satu saluran optik. Penghubung yang mempunyai dua pancaran dan saluran FSO tunggal ini telah menambahbaik prestasi sistem dari segi BER dan Faktor Kualiti. BER telah berkurang dan Faktor Kualiti telah meningkat. Dari penilaian analisis simulasi Rekabentuk 1 dan Rekabentuk 2, akhirnya Rekabentuk 3 dicadang sebagai langkah untuk mencipta satu sistem FSO yang boleh berfungsi dengan paling berkesan dalam keadaan berjerebu dan hujan berbanding dengan rekabentuk yang sebelumnya. Rekabentuk 3 telah dipasang dengan satu penguat optik di kedua-dua bahagian pemancar dan penerima untuk menguatkan isyarat optik dan mengekalkannya pada tahap yang tinggi. Rekabentuk ini juga dipasang dengan lima saluran FSO untuk meningkatkan gangguan isyarat pada sistem untuk tujuan kajian. Namun begitu, sistem tersebut masih berfungsi pada prestasi yang tinggi dan masih mempunyai prestasi yang lebih baik berbanding Rekabentuk 1 dan Rekabentuk 2. Dalam kajian ini, terdapat beberapa parameter yang telah diubah untuk mencapai tujuan kajian iaitu kadar bit, penerimaan kuasa berkesan, jarak hubungan, diameter aperture, dan pengecilan. BER dan Faktor Kualiti rekabentuk yang dicadangkan telah dianalisis untuk mengkaji prestasi sistem FSO yang semakin meningkat semasa hari berjerebu dan hujan. Analisis secara teori dibuat pada data yang dikumpul dari pusat meteorologi dan keputusan tersebut digunakan untuk analisis secara simulasi menggunakan *OptiSystem*. Dari keputusan tersebut, data yang diperolehi diplotkan pada graf. Dari keputusan yang diperolehi juga, Rekabentuk 3 telah membuktikan keupayaannya yang telah meningkat untuk menghantar isyarat penghantaran dari pemancar optik ke penerima optik pada prestasi yang tinggi semasa keadaan berjerebu dan hujan berbanding Rekabentuk 1 dan Rekabentuk 2. Kadar Ralat Bit yang paling rendah telah dicapai oleh Rekabentuk 3 semasa keadaan hujan iaitu 10^{-80} dan 10^{-127} semasa keadaan berjerebu. Untuk Faktor Kualiti pula, Rekabentuk 3 telah berjaya mencapai nilai maksimum sebanyak 18.9 semasa keadaan hujan dan 23.98 semasa keadaan berjerebu.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Free-space optical communication (FSO) systems have been established in response to an increasing demand for high-speed and secure communication systems. It is the most practical alternative to deal with the bottleneck broadband connectivity problem. Recently, it is very active with countless impressive technological challenges to enhance its performance in a range of scenarios. FSO is a technology which uses line-of-sight and application of lasers to offer optical bandwidth connections. It is an optical communication method that transmits light in free space. It is an effort to wirelessly transfer data for telecommunication and computer networking purpose.

Free Space Optics (FSO) has the capability to transfer data between two points using light propagation (Jabeena et al., 2012). Light emitting diodes (LEDs) or light amplification by stimulated emission of radiation (LASERs) are used for the light sources. The use of laser and fiber optic cables has a quite similar concept in optical transmission. Both of them transmit the signal in optical form. The only dissimilarity is the transmission media. Typical links deployed are in the range of 300 m to 5 km. However, longer deployment distances up to 8–11 km are possible. It depends on the speed and the required availability.

Since FSO is an optical wireless system which transmits the optical signal via the atmosphere, it possesses a weakness to weather conditions due to the high atmospheric attenuation on the link performance. Two weather conditions focused in this research were haze and rain since the study location was Malaysia which has a tropical climate. The term “haze” can be defined as the weather phenomenon that causes an atmospheric visibility to be less than 10 km. This happens because of the amount of suspended particles, smoke, and vapor in the midair. Generally, rainfall can be defined as the fall of rain. To be exact, rain is the water in the form of droplets. They are formed from the condensation process of atmospheric water vapor and fall to the earth after precipitation has occurred. These challenges have become the bottleneck of FSO system since the early development of the system. The challenges faced by FSO system are to be briefly explained later.

1.2 Problem Statements

The research focused on the weather conditions in Malaysia which has heavy rainy seasons throughout the year (Lam et al., 2011 & Mandeep et al., 2010). Frequently, this heavy rainy condition leads to floods. Moreover, the thick, dirty white haze is an annual phenomenon mostly caused by fires illegally set to clear land for farming purposes (Sahani et al., 2014 & Ling et al., 2010). These atmospheric phenomena lead to the presence of particles (haze particles and rain droplets) in the midair.

The fluctuation of the atmosphere phenomena is a major threat for FSO system as the system is highly susceptible and sensitive to the weather especially haze and rain condition as both have been studied in this research. These phenomena cause signal attenuation as the light passage is absorbed, scattered or reflected by the particles presented in midair. This results a serious degradation and poor link performance of the system (Zabidi et al., 2010 & Nor et al., 2012).

In this research, the effects of haze and rain on FSO system were investigated based on the raw data of rain rate and haze visibility of Malaysia obtained from the meteorological centre. The raw data were calculated theoretically to obtain the atmospheric attenuation and the scattering coefficient of rain and haze.

This problematic occurrence has been faced by the wireless communication system specifically FSO system since years ago. It becomes a bottleneck to achieve a greater potential to the advanced communication system. Nonetheless, countless researches and studies were made by persistent and determined scholars to improve the system performance in haze and rain conditions (Islam et al, 2016; Shumani et al., 2016; Ghoname et al., 2016; Basahel et al., 2017 & Prakash et al., 2017). Some of the mitigation techniques are aperture averaging and diversity techniques, spatial diversity, time diversity, temporal-domain detection, coding, adaptive optics (AO), and other techniques. Even so, a high performance FSO system to be used under heavy haze and rain conditions are yet to be created despite the efforts made.

1.3 Research Objectives

The main aims of this research were as follows:

i. To design a high performance FSO system for haze and rain conditions.

ii. To investigate the weather condition in Malaysia, focusing on haze and rain using FSO system.

iii. To evaluate the developed FSO systems.

1.4 Scope of Research Work

In this project, *OptiSystem* software was used to design the FSO system with specific parameters to investigate the effects on visibility which attenuated the signals. These investigations focused on one of the major disadvantages of wireless communication system which was the vulnerability to weather change especially rain and haze condition. Previously, the investigations of rain and haze effects on FSO system have been done by many researchers and the results obtained were quite satisfactory. However, there were plenty of enhancements available to the existing FSO system and technology.

A study model was a must to ensure the success of this project. This research focused on the investigations of haze and rain effects on the performance of the designs of FSO system. The sample data were provided by Malaysia Meteorological Department (MMD) focusing on Perlis only (specifically Chuping region). FSO systems for outdoor applications are susceptible to atmospheric attenuation due to weather conditions such as rain and haze. The link performance is greatly affected since these phenomena create particles in the midair which scatter the transmission signal and thus degrade the system performance. Theoretical analysis was made on the designs by calculating raw data obtained from the meteorological centre. The models representing haze and rain conditions were made and used for a simulation analysis of the designs. From the analysis, the atmospheric attenuation and the scattering coefficient caused during hazy and rainy days were obtained. Several parameters were used to investigate the effects of atmospheric attenuation due to weather conditions on the link performance of FSO system. The improved performance of the system was obtained from the bit error rate (BER) and Q Factor of the system in the heavily attenuated conditions. Figure 1.1 shows the flow chart of the scope of work.

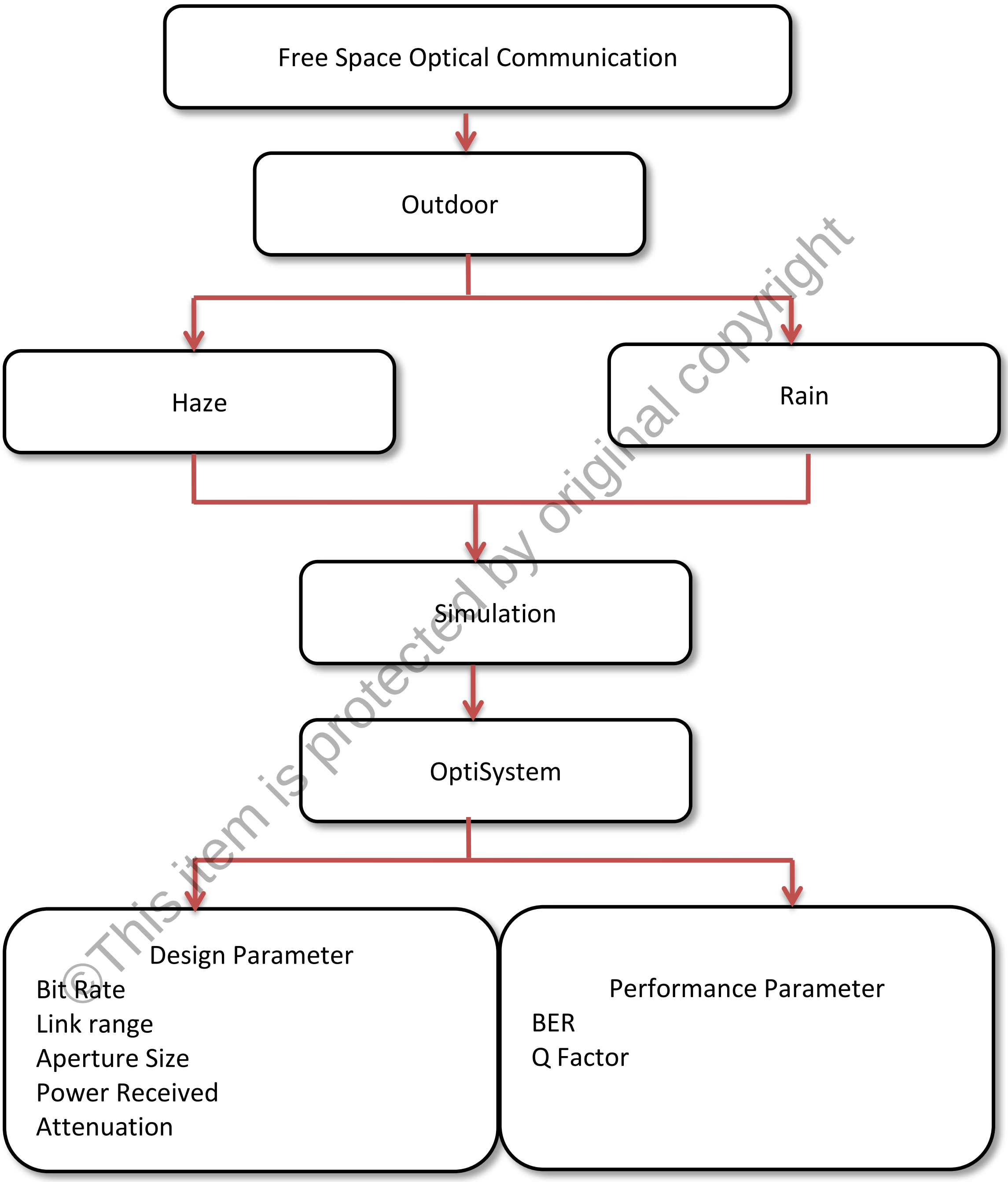

Figure 1.1: Scope of work diagram.

1.5 Contributions

There were several contributions that have successfully been implemented from this research as new remarkable discoveries have been found from the studies. The first significant contribution was regarding the new proposed high performance FSO system in haze and rain conditions. From the data analysis of past researches on FSO system in these heavily attenuated conditions, an improved design was made to efficiently mitigate the attenuation effects.

Furthermore, this research has contributed on the overall process of designing an improved FSO system from design of the proposed systems, simulation and analysis of the systems. All of these were simply achievable using the superior software called *OptiSystem*. Raw data collected were theoretically analyzed to be used for the simulation analysis using the software.

The third contribution was on the analysis of the designs performances of FSO system under haze and rain condition with improved bit error rate and Q Factor. As the simulations have been done, analysis was made thoroughly to make evaluations on the designs to determine which one was capable to mitigate the attenuation effects the most.

1.6 Thesis Outline

There were five (5) chapters in the thesis and each chapter has its own subtopics. The first chapter of the thesis was allocated for the introduction of the topic to be discussed in the thesis. It gave an overall explanation of the wireless systems including FSO background, problem statements, objectives, scope of work and research overview.

Literature review in the second chapter focused mainly on the theories and principles related to FSO. Previous researches on FSO system, haze and rain conditions were also included in the chapter and have been explained thoroughly. The previous work has been a great reference to improve the performance of the FSO system to a higher level.

In the third chapter, it described the methodology of data analysis on the systems by varying several parameters. The atmospheric model was used to determine the scattering coefficient and atmospheric attenuation of rain and haze conditions. The simulation using *OptiSystem* software to investigate performance of BER and Q factor was discussed in the subtopic of Chapter 3.

Chapter 4 covered the results and discussions based on data analysis of FSO systems so that comparisons could be made at the end of the thesis. The scattering coefficient and atmospheric attenuation can be determined in haze and rain conditions. The studies on the simulation analysis have proved that the link performance and parameters were able to reduce attenuation effects. The factors contributed to increase in atmospheric attenuation on the system performance were also briefly discussed. Furthermore, alternative solutions were proposed to reduce the attenuation effects by using simulations.

Chapter 5 was mainly about the conclusions and recommendations for future work for wireless technology implementation. The continuity of the research on the FSO system to make the system better was a way to improve the optical communication system.

1.7 Summary

FSO system is a superior optical communication system with a super high bandwidth since it uses the atmosphere as the transmission channel. It also has countless other advantages compared to the conventional communication system such as radio frequency (RF) and fiber optic. Despite that, atmospheric attenuation is a huge enemy of the system as it hampers the link performance of the system. As a result, this research was done to investigate the atmospheric attenuation effects and to propose a design of improved FSO system which could greatly reduce the effects on the system performance based on the parameters investigated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The review of existing studies, researches, theories and principles of FSO system in this research project were discussed in this chapter. The optical communication technology was introduced with detailed explanations. This chapter also presented the atmospheric effects on the systems such as haze and rain attenuation over link performance.

2.2 Free Space Optic (FSO) Communications System

FSO is the acronym of Free Space Optic. It is a new technology that utilizes LASERs (light amplification by stimulated emission of radiation) to offer optical bandwidth connections and the system is highly depending on line-of-sight. It is an optical communication method that transmits the light in free space to wirelessly transfer data for telecommunication. Examples of free space are air, outer space, vacuum, or anything alike. Presently, the capability of FSO system is up to 2.5 Gbps bandwidth transmission (Fadhil et al., 2013 & Kumar et al., 2013) of communications through the atmosphere. It allows optical connectivity without the need of fiber optic cable or secured spectrum licenses. The wavelength bands of FSO system range from 780 – 1600 nm. Besides using optical to electrical and electrical to optical converters, light is a requirement for the system. The light is focused by using either light emitting diodes (LEDs) or lasers. The concept of lasers is quite the same as optical transmissions using fiber optic cables. However, the only slight difference between those two concepts is the transmission media. Light propagates through air faster than it does through glass. Thus it is justified to categorize FSO as optical communications at the speed of the light. FSO communication system is considered as a substitute to radio frequency (RF) system. The light beam in optical communication can be categorized into two types (Singh, 2013). The types are:

a) Guided beam communication
b) Unguided beam communication

The transmission medium of guided beam is optical fiber, which are transparent thin fibers for propagating light. The laser light is guided by the fibers to its final destination which is the receiver. There are several strengths of optical fibers. They are non-weather dependent, secured and capable to transfer messages within, under and around physical structures. They have the capability to transfer the information over much further distances compared to copper cables. The commonly used one is infrared laser light. It is chosen due to the least absorption of this particular wavelength. The 1300 nm and 1550 nm windows have much lower losses and are suitable to be used for a long-haul communication compared to the wavelength of 850 nm which has higher losses and is suited mostly for a short range data transmission. However, the wavelength of 1350 nm is unwanted (Abdul Rahman, 2010) due to very high losses at its wavelength. The weakness of using guided beam (fiber) communication is that the cost to manufacture, install and service is too high (Tatarko et al., 2012).

On the other hand, the transmission medium for unguided beam communication is an atmosphere and no fiber is used to guide the laser beam. Unlike fiber optic which transfers data by optical signal across glass, free space optic applies laser technology to transfer optic signal through the atmosphere.

FSO communication links are an option redundant to radio relay links and to optical fiber which meet the growing needs in high–speed telecommunication. Their implementation into operation needs a good understanding and knowledge of the atmospheric effects which can play an ominous role on the propagation and the available links.

2.2.1 FSO Structural design

The structural design of FSO can be divided into three types of connections which are Point-to-Point connections, Point-to-Multipoint connections, and Multipoint-to-Multipoint connections (Abouei & Plataniotis, 2012). Point-to-Point connections involve one transmitter and one receiver and they provide a higher bandwidth although they are less accessible. The second connection is Point-to-Multipoint connections which consist of one transmitter and multiple receivers. Point-to-Multipoint design provides low cost connections. Even though it facilitates node addition of the network, this type of connection provides a poor bandwidth level compared to the former. The last design of FSO network is Multipoint- to- Multipoint connections. They use multiple receivers and transmitters and are also termed as Mesh Network, which provide redundancy and better reliability with easy node addition. However, these connections have drawbacks which are higher costs compared to other FSO designs and the complexity of each node in mesh topology. The FSO networks were shown clearly in Fig. 2.1, Fig. 2.2 and Fig. 2.3.