UNIVERSITI PUTRA MALAYSIA

EFFECT OF RAINFALL RATE AND VISIBILITY ON FREE SPACE OPTICAL COMMUNICATIONS IN MALAYSIAN ENVIRONMENT

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of Requirements for the Degree of Master of Science

October 2004

In the name of God, Most Gracious, Most Merciful

Dedication to

My parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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October 2004

Chairman: Associate Professor Mohd. Khazani Abdullah, Ph.D.

Faculty: Engineering

Rare usage of Free Space Optical (FSO) communications in Malaysia might be related to environmental factors. Unguided beam is also known as free space optics technology or ‘optical wireless’ or ‘infrared broadband’. This project explores the propagation of point-to-point FSO due to weather conditions. Weather severity has detrimental impact on FSO transmission performance. The impact could result in insufficient quality of transmission and communication failure. Therefore FSO implementation requires thorough study of local weather patterns. By studying the local weather pattern, scattering coefficient and atmospheric attenuation could be derived to determine weather severity in this area. This information could help in predicting possible impact on data transmission quality and transmission interference system operation. In addition, FSO system design could be improved and altered to overcome possible interference and optimize system operation.

This study is focused on the effect of rain and haze in Subang Airport. The Climate Division of Meteorological Department, Petaling Jaya branch, provided the data on rain and haze, which were collected hourly throughout year 2000. The rain data, which were collected in mm/hr, are categorized into three groups: heavy rainfall, moderate rainfall and light rainfall. The haze data was collected based on visibility distance in km. The visibility on hazy days is categorized into low visibility and average visibility.

The non-selective scattering contributed dominant loss on rainy days and Mie scattering on hazy days. The non-selective scattering is wavelength independent and Mie scattering is wavelength dependent. The wavelength of 1550nm is selected because it is not harmful to the human eyes, not aggressive to the environment and contributes to better performances.

The scattering coefficient and atmospheric attenuation for rain and hazy days are determined by using Stroke Law and Beer's Law. The atmospheric attenuation due to scattering coefficient has greater effect during hazy days than rainy days. From the result analysis, using small beam divergence, small transmitter aperture, larger receiver aperture and short link distance can optimize the FSO system transmission.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

KESAN TABURAN HUJAN DAN JARAK PENGLIHATAN PADA OPTIKAL WAYARLES KOMUNIKASI DALAM PERSEKITARAN MALAYSIA

Oleh

BIBI SARPINAH SHEIKH NAIMULLAH

Oktober 2004

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Penggunaan komunikasi Ruang Bebas Optik masih kurang mungkin disebabkan oleh faktor persekitaraan. Projek ini mengkaji kaitan faktor persekitaraan dengan mengkaji penyebaran titik ke titik Ruang Bebas Optik yang berpunca dari keadaan cuaca. Kesan ini menyebabkan kualiti penghantaran kurang baik dan komunikasi gagal. Oleh itu sebelum pemasangan Ruang Bebas Optik, kajian yang rapi perlu dibuat ke atas keadaan cuaca tempatan. Dengan membuat kajian ke atas keadaan cuaca, serakan koefisien dan gangguan di atmosfera diperolehi. Informasi ini boleh dipeolehi dengan mengandaikan kesan yang mungkin terjadi pada kualiti penghantaran data. Nilai andaian ini adalah untuk tujuan reka bentuk dan memastikan minimum gangguan yang terjadi dalam operasi penghantaran.

Kajian ini fokus kepada kesan hujan dan jerebu di Lapangan Terbang Subang. Data hujan dan jerebu disediakan oleh Bahagian Cuaca, Jabatan Meterologi, cawangan Petaling Jaya. Data tersebut berdasarkan bacaan untuk setiap satu jam. Data hujan diambil dalam mm/jam dan boleh dikategorikan kepada tiga kumpulan: hujan lebat,

hujan sederhana dan hujan renyai. Jerebu pula dibaca mengikut jarak penglihatan dalam km. Jarak penglihatan boleh dikategorikan kepada jarak penglihatan rendah dan jarak penglihatan biasa. Serakan koefisien dan gangguan di atmosfera dipeolehi dengan menggunakan persamaan matematik.

Penyelerakan bukan terpilih terjadi paling dominan pada hari hujan dan penyelerakan Mie terjadi pada hari berjerebu. Penyelerakan bukan terpilih tidak bergantung dengan panjang gelombang manakala penyelerakan Mie bergantung dengan panjang gelombang. Panjang gelombang 1550nm dipilih kerana tidak mendatangkan kesan bahaya pada mata, tidak berbahaya pada persekitaran dan perlaksanaan yang lebih baik.

Kesan perlemahan atmosfera bergantung pada penyelerakan pemalar adalah lebih besar pada hari berjerebu berbanding dengan hari hujan. Daripada keputusan analisis, didapati penghantaran pada Ruang Bebas Optik boleh dioptimakan dengan mengunakan sinaran sudut yang kecil, diameter apertur alat pemacar yang kecil , dimater apertur penerima yang luas dan jarak pendek antara pemancar dan penerima.

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Last but not least I would like to express my sincere thanks to my family for being patient and supported me throughout my study. Without their for being patient and support I would not have made it till to the end.

I certify that an Examination Committee met on 29 October 2004 to conduct the final examination of Bibi Sarpinah Sheikh Naimullah on her Master of Science thesis entitled “The Effect of Rainfall Rate and Visibility on Free Space Optical Communications in Malaysian Environment” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

BIBI SARPINAH SHEIKH NAIMULLAH

Date:

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LIST OF ABBREVIATIONS

CLEC	-	Competitive Local Exchange Carrier
CO_2	-	Ground State Absorption
FCC	-	Federal Communications Commission
FIR	-	Far Infrared
FSO	-	Free Space Optical
GL	-	Geometric Loss
H_2O	-	Water
IEC	-	International Electrotechnical Commission
IR	-	Infrared
IP	-	Internetworking Protocol
ITU-R	-	International Telecommunications Union – Radio Communications
LASER	-	Light Amplified Spontaneous Emission
LAN	-	Local Area Network
LOS	-	Line Of Sight
MIR	-	Middle Infrared
MPE	-	Maximum Permissible Exposure
MST	-	Malaysian Station Time
NIR	-	Near Infrared
OSI	-	Open System Interconnect
PCS	-	Personal Cellular Service
RF	-	Radio Frequency
SONET	-	Synchronous Optical NETwork
ST	-	Station Time

US	-	United State
WDM	-	Wavelength Division Multiplexing
XIR	-	Extreme Infrared

CHAPTER 1

INTRODUCTION

1.1 Introduction

Transmission through light has been developed since the nineteenth century. In 1880, Alexander Graham Bell expanded optical communications with his ‘photo-phone’ that modulated sunlight for communication. In the early 1960’s, scientists have successfully developed Light Amplification by Stimulated Emission of Radiation (LASER) technology. Finally, optical communication was shortly discovered after the development of LASER technology (FSO, 2003 & Johnson, 2002).

1.2 Background

There are several options for data communication in the existing technology today. First is fiber optic cable technology. It is the best choice in the telecommunications industry. Fiber is the most reliable for many applications in various areas in communication connectivity. However, using fiber optic is extremely uneconomical. This is because the costs of trenching street to lay fibers are excessively high.

Another option is radio frequency (RF) technology. RF is a mature technology, but is limited in data rate, requires FCC licensing and is costly relative to other access. RF technology cannot scale to 2.5Gbps. The current RF bandwidth ceiling is 622 Megabits. When compared to Free Space Optical, RF does not make economic sense for service providers looking to extend optical networks (Rockwell, 2001).

The third alternative is wire and copper based technologies. The percentage of copper technology use is higher than fiber, but it does not solve the bottleneck of connectivity problem and bandwidth capability limitation. Losses in copper cables increase with the frequency, the more information carried in copper conductors, the higher the losses.

The fourth and often most popular alternative is Free Space Optical (FSO). FSO provides higher bandwidth to the end user at a faster speed. Because of high bandwidth availability (currently capable of up to 2.5Gbps), a large amount of data can be transmitted through a narrow laser beam. FSO is also portable, quickly deployable and cost effective, costing on average one-fifth the cost of installing fiber optic cable (Willebrand, 2001).

1.3 Statement Of Problems And Motivation

FSO systems are sensitive to poor weather conditions such as fog, haze and rain. All of these conditions act to attenuate light and could block the light path in the atmosphere. As a result, interruption and disturbance could occur in the communication process.

Before the installation process of FSO on tall buildings, detailed investigation of weather conditions have to be carried out. This is to ensure FSO will operate with sufficient transmission power and minimal losses, even during bad weather conditions.

This project is a FSO system propagation study on atmospheric effect in the Malaysian weather environment. The study focused more on rain and haze effects, on the FSO system. The selection of wavelengths, divergence angle, receiver area, transmitter area and distance between transmitter and receiver can be adjusted to minimize the attenuation effect on FSO. Further discussion will be elaborated later in this project.

1.4 Objectives

The main limitation in FSO is proper understanding of weather effects on its signal propagation. The analysis based on weather statistics should be conducted at a specific location to estimate the link availability. Therefore the main objectives of this project are stated below:

a) To study the propagation of infrared signals in rain and haze conditions.
b) To determine the scattering coefficient, atmospheric attenuation and total attenuation due to rainy and hazy days by using Stroke Law and Beer's Law
c) To study the performance of FSO under different wavelengths, beam angles, diameters of receiver and transmitter apertures and link range.

1.5 Scope of Works

1.5.1 Study Model Description

FSO is an independent protocol that can be fixed to any network topology. The Open System Interconnect (OSI) for FSO is under physical layer. The scope of this project is shown clearly under study model in Figure 1.1. Generally, FSO system is divided into two categories: indoor system and outdoor system. This study concentrated on propagation study of FSO under Malaysian weather environment for outdoor system, especially dealing with atmospheric effect and total attenuation.

The atmospheric effect can be divided into 2 categories: atmospheric attenuation and atmospheric turbulence. Scattering due to water droplets (rainfall) effect is called non-selective scattering. This scattering is a wavelength independent process. Mie scattering dominates total scattering coefficients on haze days. Attenuation due to

Mie scattering is a function of the visibility and laser wavelength. Mie scattering effect depends on wavelength.

In examining FSO performance, it is important to take several system parameters into consideration. This project concentrated on rain and haze conditions. The parameters can be divided into 3 categories: design, uncontrollable performance parameters. Design parameters are related to design of the FSO system such as wavelength, aperture size, beam divergence and link range. Uncontrollable parameters are related to weather conditions. Uncontrollable parameters on rain conditions include rainfall rate and radius of raindrop. The uncontrollable parameters of hazy conditions are related to visibility. Performance of rain and haze conditions can be evaluated from scattering coefficient effect, atmospheric attenuation and total attenuation.

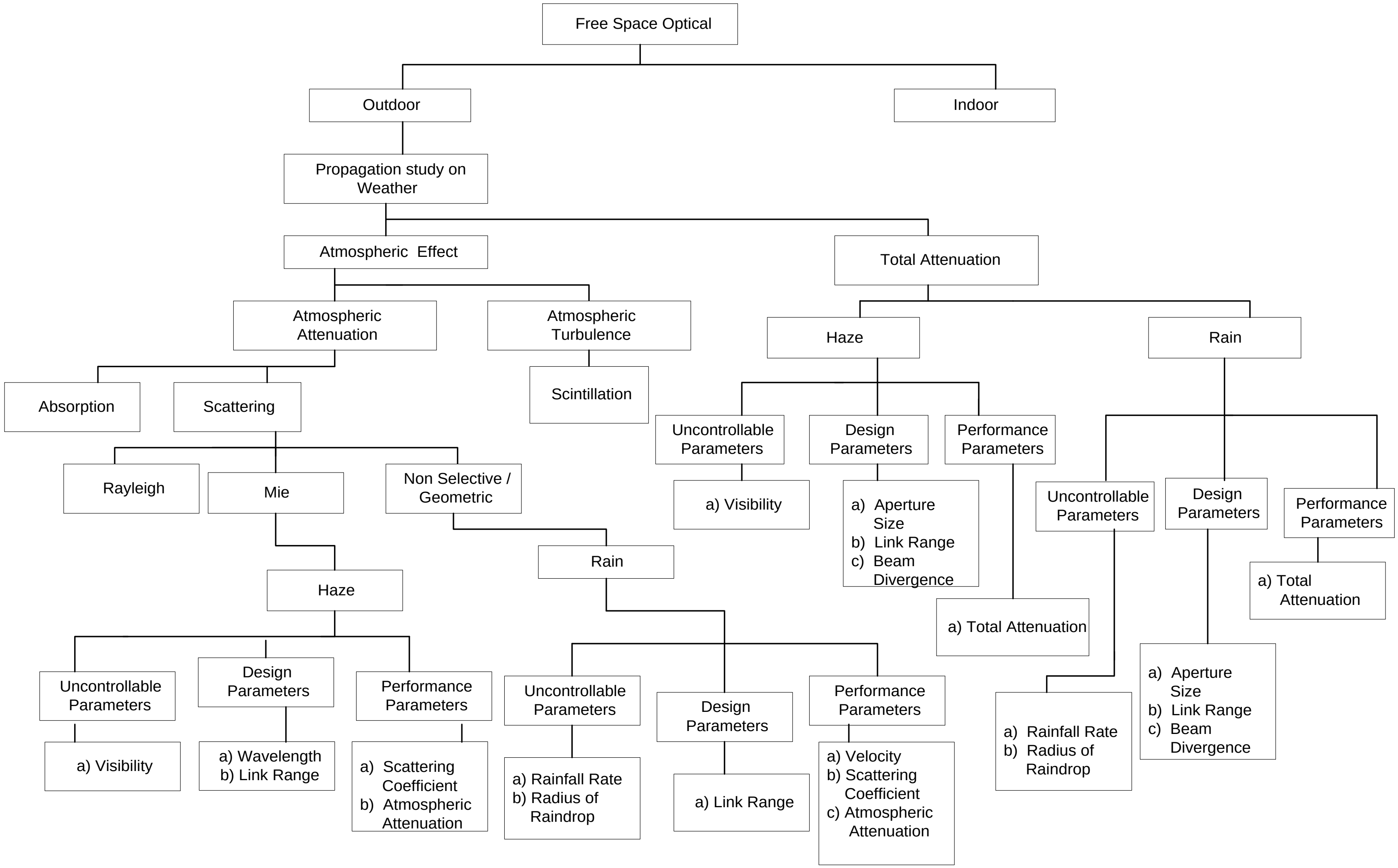

Figure 1.1: Study Model Showing the Scope of Study

1.5.2 Assumptions

There are a few assumptions made in this project. The effect of aerosol absorption, Rayleigh scattering, scintillation fluctuation and background noises are assumed to be negligible. There are some reasons of ignoring these effects as stated below. The detailed explanation is given in Chapter 2.

The laser wavelengths of 780nm, 850nm and 1550nm fall inside the transmission windows within the absorption spectra and the contributions of absorption to the total attenuation coefficient are very small; thus absorption effect is negligible (as shown in Figure 2.13). FSO systems are operated in the longer wavelength near infrared wavelength range so the impact of Rayleigh scattering on the transmission signal can be ignored (Chu, 2002).

Using either multiple beams or larger receiver apertures could reduce scintillation fluctuations. However, the large receiver aperture approach is more effective for scintillation reduction than multiple smaller apertures. Besides that, the longer wavelength is less susceptible to scintillation. At ranges less than 1km, most FSO systems have enough dynamic range or margin to compensate for scintillation effects (Kim, 2001, Achour, 2001 & Bloom, 2003). In this project a larger receiver aperture is used, wavelength of 1550nm is considered and link range is only 1km. Therefore effect of scintillation is ignored.