PATH REDUCTION FACTOR FOR MICROWAVE TERRESTRIAL LINKS DERIVED FROM THE MALAYSIAN METEOROLOGICAL RADAR DATA

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DEDICATIONS

To Almighty ALLAH, Most Gracious, Most Merciful

إِيَّاكَ نَعْبُدُ وَإِيَّاكَ نَسْتَعِينُ ٱهْدِنَا ٱلصِّرَٰطَ ٱلْمُسْتَقِيمَ

To my parents

Haji Khamis bin Haji Othman

Hajjah Esah binti Haji Md Sab

To my dearest wife

Hajjah Aisyah binti Che Mat

To my children

Muhammad Khalid

Nurul Iman

Luqman Hamdani

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To all my teachers

To my brothers and sisters

For all the joy, love, understanding, and sacrifices.

Religion without science is lame, Science without religion is blind

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ABSTRACT

Attenuation due to rain is a major concern in transmission of microwave signals. The effect of rain attenuation is more pronounce when signals are being transmitted at higher frequencies. For tropical countries like Malaysia, rain occurs almost yearound and in most instances, much heavier than temperate region. Even rain itself, does not distribute evenly in a region experiencing precipitation. This gives rise to the need of a correction or reduction factor when calculating attenuation due to rain. This topic has been the focus of many researches. However, many of these researches were done in temperate regions, making it necessary for a study using local data. This study utilized the local weather radar data obtained from the Meteorological Department of Malaysia, and data from two rain gauge networks installed in UTM, Skudai campus. From the analysis of the radar data, a reduction factor is deduced. The reduction factor obtained in this study follows the same pattern as other models but has a lower value as the path link increases. This shows that attenuation due to rain is lower than as predicted using other models. Rain rate distribution and rain cell size distribution is also formulated from radar data. $R_{0.01}$ of 120.907 mm/hr agrees very well with the ITU-R and the Meteorological Department of Malaysia values. Using data from the rain gauge networks, the profile and the size of rain cells at different rain rates are determined. This study finds that most rain cells in Malaysia are highly convective with an average cell size of 1.2 to 1.5 km. All the information are important for attenuation predictions, link budget estimation, microwave system planning, slant path rain attenuation modeling and remote sensing of the earth's surface, and have important applications in attenuation mitigation techniques such as space diversity. Further study can be done with more precise, elaborate, and sophisticated measuring systems such as Doppler or polarimetric radar, complemented with microwave links and rain gauge networks.

ABSTRAK

Rosotan yang disebabkan oleh hujan adalah satu masalah yang besar di dalam penghantaran isyarat gelombangmikro. Kesan rosotan hujan adalah lebih ketara pada frekuensi yang lebih tinggi. Untuk negara-negara tropikal seperti Malaysia, hujan berlaku hampir sepanjang tahun dan adalah lebih lebat dari kawasan berhawa sederhana. Taburan hujan juga adalah tidak sekata di dalam kawasan hujan. Keadaan ini menjadikan keperluan faktor pengurangan dalam pengiraan rosotan hujan. Topik ini telah menjadi fokus untuk banyak penyelidikan. Walaubagaimanapun, kebanyakan penyelidikan adalah dalam kawasan berhawa sederhana, menjadikan satu kajian yang menggunakan data tempatan satu kepentingan. Kajian ini menggunakan data radar cuaca yang diperolehi daripada Jabatan Kajicuaca Malaysia dan rangkaian tolok hujan yang dipasang di UTM, Skudai. Penganalisaan data radar telah menghasilkan faktor pengurangan, taburan lebat hujan dan taburan saiz sel hujan. Faktor pengurangan daripada kajian ini mempunyai bentuk yang serupa dengan lain-lain model tetapi mempunyai nilai yang lebih rendah apabila jarak bertambah. Ini menunjukkan bahawa ramalan rosotan daripada model lain adalah lebih tinggi dari nilai sebenar. Nilai $R_{0.01}$ sebanyak 120.907 mm/jam adalah setara dengan ITU-R dan Jabatan Kajicuaca Malaysia. Daripada data tolok hujan, profil dan saiz sel hujan pada kelebatan hujan yang berlainan telah ditentukan. Kajian juga menunjukkan bahawa hujan di Malaysia adalah sangat konvektif dengan purata saiz sel hujan antara 1.2 hingga 1.5 km. Hasil kajian adalah sangat penting untuk jangkaan pelemahan, anggaran bajet rangkaian, dan perangkaan sistem gelombangmikro. Hasil kajian juga adalah berguna untuk teknik pengurangan seperti kepelbagaian tapak. Kajian selanjutnya boleh dilakukan dengan menggunakan teknik pengukuran yang lebih jitu dan canggih seperti penggunaan radar Doppler atau polarimetrik, dilengkapi dengan laluan jalurmikro dan rangkain tolok hujan.

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LIST OF SYMBOLS

α	regression exponential for specific attenuation
β	exponential in Moupfouma's model.
γ_s	specific attenuation due to rain (dB/km)
A	attenuation of radiowave propagating through free-space (dB)
a	excess attenuation due to water vapor
A_r	attenuation of radiowave due to rain (dB)
b	excess attenuation due to mist and fog; regression exponential for radar reflectivity
c	excess attenuation due to oxygen
D	diameter of rain cell (km)
d	absorption losses due to other gasses
dB	decibels
e	excess attenuation due to rainfall
dBZ	radar reflectivity factor in dB
F	Frequency (GHz)
k	regression coefficient for specific attenuation
L	path length (km)
m	exponential in Moupfouma's model.
n(r)	number of raindrops per unit volume per radius interval ($m^{-3}mm^{-1}$)
p	time percentage, percentage
$Q_t(r)$	total extinction cross-section (cm^2)
r	radius (cm), reduction factor
R	rainfall rate (mm/hr)
$R_{0.01}$	rainfall rate (mm/hr) for 0.01 % of the time

R_t	threshold values of a specific rain rate
Z	radar reflectivity factor (dBZ or mm^6/m^3)

LIST OF ABBREVIATIONS

3D-RAPIC	3 dimensional software to process and handle weather radar data
CETUC	Center for Telecommunication Studies of the Catholic University of Rio de Janeiro
CMOS	Complementary metal-oxide semiconductor
DAH	Dissanayake, Allnutt, Haidara
DSD, dsd	drop size distribution
EPROM	Erasable programmable read-only memory
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio communication Section
LOS	Line-of-sight
PPI	Pulse-Position Indicator
PPI	Pulse-position-indicator
r	Reduction factor
RGN-UTM 1	Rain Gauge Network in UTM no. 1
RGN-UTM 2	Rain Gauge Network in UTM no. 2
RHI	Rain Height Indicator
RHI	Rain height indicator
STC	Sensitivity Time Control
UTC	Universal Time Constant
UTM	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Overview

Radio link is very important in communication systems. Large number of parameters must be considered and optimized to build an efficient radio link. That is, radio signals must suffer minimum degradation possible. For reliable communication link, selection of operating frequency and possible atmospheric attenuation must be studied and understood. Since the governing body usually determines the operating frequency, attenuation, especially due to rain, has become the subject of numerous studies and researches. For good engineering and economic practice, it is always desirable to reduce cost of a system and avoid interference to other radio systems. Some factors which introduce attenuation to radio propagation are gaseous absorption, absorption and scattering due to clouds, fogs, precipitation, atmospheric turbulence and ionospheric effects. Since Malaysia is in the tropical region, studies of attenuation due to hydrometers are very important. Rain, hail, ice, cloud and snow are all types of hydrometers but raindrops cause the most attenuation by absorption and scattering of radio waves. Eventhough the International Telecommunication Union (ITU) recommends a technique to estimate rain attenuation, studies (Ajayi *et al*, 1988; Juy *et al*, 1990; Yagasena *et al*, 1995) have shown that results using this techniques does not agree with actual measurements done locally. This is understandable as the recommendation is meant to be applicable to wide area as possible and most studies were done using temperate region data. Thus, local studies are needed and based on these studies; a model for rain attenuation in Malaysia can be developed.

1.2 Problem Statement

Power budget and fade margin are important factors to be considered in designing microwave transmission systems. The world of telecommunication is very competitive such that when providing for a system, careful infrastructure planning is needed to avoid unnecessary costs.

Microwave links are designed to meet specific reliability factor. Reliability, or sometimes is known as availability of a system, is usually expressed as a percentage. It represents the percentage of the time the link is expected to operate without an outage caused by propagation conditions. It has been widely accepted that a good communication system must provide at least 99.99% reliability (IEEE, 2004; ITU-R SA 1414). In other words, the system can only be down for 0.01% of the time, which is usually referenced to a year. This means that the system can be unavailable for no less than 52.6 minutes per year [365.25*24*60*0.01/100]. (*For emergencies, call 999; for no emergency, it is 99.99%!*)

A very important factor that affects path reliability is rain attenuation. It also contributes in power budget and fade margin considerations. Thus, it is very important to properly quantify rain attenuation. Due to the nature of rain events, a reduction factor is needed in order to calculate rain attenuation.

A rain event occurring in an area is not constant. Rain does not distribute evenly in a region experiencing precipitation. Even though specific attenuation due to rain for a specific distance or per kilometer can be formulated; there arises a need to find a reduction factor to account for the non-uniformity of rain for larger distances. This is especially crucial in tropical regions as rain has been found to be more convective in nature rather than widespread. Tropical region also suffers heavier rainfall rates as compared to temperate regions.

To formulate the reduction factor, the experimental procedure would requires several links with different path lengths to be set up in close proximity. However, this would be very difficult to be constructed. An alternative approach is to use radar data to obtain attenuation statistics for simulated links of various lengths.

In addition, even after a proposed microwave link has been evaluated with regard to reliability, the calculations may show that it will not meet the required standards. Or a designer may want to improve the reliability of the telecommunication system. In this situation, mitigation techniques such as diversity may be employed.

One such technique is space diversity where an additional receiver may be constructed (Nor Hisham Khamis *et al*, 2000). By switching and/or combining the signals received by the two receivers, the reliability of the communication link is greatly increased. An important parameter to consider is site separation or the distance between the two receivers. When spacing is adequate between the two receivers, there should be little correlation between the two paths. Site separation or distance is used to determine the diversity improvement factor and diversity gain when employing diversity (ITU-R P.618-5, 1997). Knowing rain cell size distribution will help to determine site separation.

Thus, the aim of this thesis is to find the reduction factor to be used in rain attenuation calculation using radar data, and also to determine the rain cell size distribution needed for site diversity application using rain gauge networks.

1.3 Objectives

The objectives ensure that the aim of this study is achieved. These objectives are contributions accomplished during this study. The objective of this study are as follows.

To formulate a suitable reduction factor (r), to be used in the calculation of attenuation due to rain in the local Malaysian environment from the local weather radar data obtained from the Meteorological Department of Malaysia.

To estimate the attenuation due to rain using the formulated r and other models proposed by other researchers, and compare the results with measured values.

To find the profile of rain rate distribution inside a rain cell and to determine the rain cell size distribution of local rain.

1.4 Scope of Study

The scope of study indicates the basic guidelines and techniques that this study examined in achieving the objectives. It also ensures that the work done stays within the intended study.

There are two types of data that are utilized in this study, radar data and rain gauge network data.

Radar data gives the averaged rainfall rate for a range-bin size of 1-km each. This rainfall data is used to calculate the rain attenuation for ‘virtual’ microwave links of 1 to 10-km path lengths. Attenuation due to rain is then calculated using the rainfall rate from the radar data. Reduction factor is then deduced from the rain attenuation calculation. The radar data is obtained from the Kluang Radar Station of the Meteorological Department of Malaysia.

Rain cell size distribution is also obtained from radar data. However, rain cell size distribution from radar data is limited to 1-km integration size. This is due to the fact that the radar uses a range bin size of 1 km.

To determine the profile of rain rate distribution inside a cell, rain gauge networks were utilized. These rain gauge networks consisted of several rain gauges that were fixed in almost a single line. Rain gauge gives point rainfall rate values. Rain intensity profile inside a cell, and rain cell size are obtained from rain gauge networks. Two rain gauge networks have been set up in UTM, Skudai campus.

1.5 Outline of Thesis

The outline of this thesis indicates the organization of this thesis. This thesis is separated into 6 chapters.

Chapter One gives the introduction to this study, the problem statement, objectives, and the scope of this study.

Chapter Two focuses on the methodology that was used in this study. It discusses the feasibility of a study using radar data, some issues concerning radar, rain gauge networks and rain cell size.

Chapter Three goes through the theory on attenuation due to rain, and explained some parameters that important in propagation study. It also reviews a couple of rain models and some reduction factors models.

Chapter Four explains the rain gauge networks that were set up in this study. It also explains the data that were obtained from the Kluang radar, and how the data were retrieved.

Chapter Five is an important part of this project. It analyses both data that were utilized in this study. Results in this study are given in this chapter. The main contribution of this study which the formulation of a reduction factor, is also given in this chapter. Comparison with other models and actual measurement are also done.

Chapter Six concludes this study. It discusses the results of this study and shows that the objectives of this study are achieved. Future studies are also briefly given.

One of the most challenging tasks in this study is to determine the proper procedure in formulating the reduction factor. Eventhough there are many reduction factors that were proposed in the literature, none of them really give in detail how the reduction factors were obtained. Also, due to the large amount of data, a very long time is needed to process all the data. Eventhough a personal computer is adequate to do the processing, care must be exercise not to overload the memory of the computer. This means that the data have to be divided into several files and processed separately. A more powerful computing facilities will surely expedite in the processing of data and other works related to this study, such as larger data storage.

6.2 Future Studies

Eventhough ground based weather radar is widely used in many studies; Doppler radar and polarimetric radar have been developed and used (Hornbostel *et al*, 1997). These types of radars allow the determination of the shape, distribution, types of hydrometeors, and rain rate with more precision. Together with other types of data measurements such as rain gauge and beacon receiver, these data can be compared and checked out against each other (Hornbostel *et al*, 1995). This will raise the degree of confidence in outcomes of researches.

Radars of these kinds are not readily available in Malaysia. It is hoped that as a continuation to this study, using experience gained and expertise available, a radar system can be built here in UTM that employs such techniques so that the results found in this study can be refined. However, continuing studies are utilizing the TRMM radar project (Oki *et al*, 2000; Rincon *et al*, 2001). Furthermore, due to increasing popularity microwave communication using satellite, vertical path reduction factor must also be studied (Bandera et al, 1999), as a continuation of this study. Other factors that are to be considered are parametrization of dsd, and the relationship between dsd and rain rate.

Another important aspect of future studies is to have a longer period of measuring time. Also, different methods of measurements must be done concurrently to enable cross checking of data obtained. As new instruments and systems are being installed, greater accuracy and more reliable data will be available.

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