EFFECTS OF INTEGRATION TIME ON RAIN RATE DISTRIBUTIONS FOR MICROWAVE LINK DESIGN BASED ON MEASUREMENT IN MALAYSIA

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Electronics Engineering)

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ABSTRACT

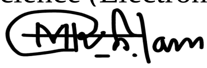
The demand for radio frequency spectrum is rapid since the most desirable frequency spectrum is congested; hence 5G and satellite communications are moving forward to the frequency band utilization above 10 GHz. Frequency higher than 10 GHz is subjected to impairment by rain. ITU-R has established rain attenuation prediction methods deduced from the measured rainfall rate with an integration time of 1-minute or less. However, recently, significant discrepancies in ITU-R prediction are found in the measurements of rain attenuation at mmWave bands for short-length propagation links. All researchers used rain intensity from 1- min integration time measurement, as not less than 1-minute data are unavailable. Therefore, this project aims to consider rain rate less than 1-minute integration time, investigate the effects of less than 1-minute integration time on rain rate distribution, and compare rain attenuation predictions using measured rain intensities with different integration times. A real-time rain gauge with a resolution of 10-secs integration time is installed in the International Islamic University Malaysia (IIUM) Gombak. A one-year measured rain rate data with integration times of 10-secs, 20-secs, 30-secs, 1- minute, and 2-minutes are utilized to analyze the effects of integration times on rain intensity distributions and rain attenuation predictions. From the analysis, it is found that at 0.01% probability, rain rates are 123 mm/hr and 191 mm/hr with 1-min and 10-secs integration times, respectively. At 0.1% and 0.001% probabilities, the differences increase to 80% and above. The rain attenuation measured at 26 GHz, 38 GHz, and 73 GHz terrestrial links with 300 m lengths and 12 GHz earth-to-satellite links in Malaysia are compared with those predicted by data from 5 integration times. Predicted attenuation with 10-secs is closer to measurement than 1-min integration time for all three terrestrial links and two satellite links. However, 30-sec integration time data was found close to the measurement for one satellite link. Hence mm-wave short paths in 5G, lower integration time-based rain rate measurement will provide more accurate prediction for path loss and high reliability in the tropical climate.

خلاصة البحث

الطلب على طيف الترددات الراديوية سريع لأن الطيف الترددي المرغوب فيه مزدحم ومن ثم ، فإن اتصالات G5 والأقمار الصناعية تتقدم إلى استخدام نطاق التردد فوق 10 جيجاهرتز. التردد الذي يزيد عن 10 جيجاهرتز يتعرض للانحطاط بفعل المطر. أنشأ قطاع الاتصالات الراديوية في قطاع الاتصالات الراديوية طرائق للتنبؤ بالتوهين الناجم عن المطر مستخلصة من معدل هطول الأمطار المقاس بوقت تكامل يبلغ دقيقة واحدة أو أقل. ومع ذلك ، ظهرت مؤخراً اختلافات كبيرة في تنبؤات قطاع الاتصالات الراديوية في قياسات التوهين الناجم عن المطر في نطاقات الموجات mmW لوصلات الانتشار قصيرة الطول. استخدم جميع الباحثين شدة المطر من قياس وقت التكامل لمدة دقيقة واحدة ، حيث لا تتوفر بيانات أقل من دقيقة واحدة. لذلك ، يهدف هذا المشروع إلى اعتبار معدل المطر أقل من دقيقة واحدة من وقت التكامل ، والتحقيق في آثار وقت التكامل أقل من دقيقة واحدة على توزيع معدل المطر ، ومقارنة تنبؤات التوهين بالمطر باستخدام شدة المطر المقاسة مع أوقات تكامل مختلفة. يتم تثبيت مقياس مطر في الوقت الفعلي بدقة تكامل مدتها 10 ثوانٍ في الجامعة الإسلامية العالمية ماليزيا IIUM) Gombak). يتم استخدام بيانات معدل المطر المقاسة لمدة عام مع أوقات تكامل تبلغ 10 ثوانٍ و 20 ثانية و 30 ثانية و 1 دقيقة و 2 دقيقة لتحليل تأثيرات أوقات التكامل على توزيعات كثافة المطر وتنبؤات التوهين بالمطر. من التحليل ، وجد أنه عند احتمال 0.01٪ ، تكون معدلات المطر 123 مم / ساعة و 191 مم / ساعة بأوقات تكامل مدتها دقيقة واحدة و 10 ثوانٍ ، على التوالي. عند احتمال 0.1٪ و 0.001٪ ، تزداد الفروق إلى 80٪ فما فوق. التوهين الناجم عن المطر المقاس عند 26 جيجاهرتز و 38 جيجاهرتز و 73 جيجاهرتز للوصلات الأرضية بطول 300 متر و 12 جيجاهرتز للوصلات من الأرض إلى الساتل في ماليزيا تتم مقارنتها مع تلك التي تنبأت بها البيانات من 5 أوقات تكامل. يكون التوهين المتوقع بـ 10 ثوانٍ أقرب إلى القياس من وقت التكامل لمدة دقيقة واحدة لجميع الوصلات الأرضية الثلاثة ووصلتي ساتلية. ومع ذلك ، تم العثور على بيانات وقت التكامل 30 ثانية بالقرب من قياس ارتباط ساتلي واحد. ومن ثم فإن المسارات القصيرة لموجة مم في الجيل الخامس ، فإن قياس معدل المطر على أساس التكامل المنخفض سيوفر تنبؤًا أكثر دقة لخسارة المسار وموثوقية عالية في المناخ الاستوائي.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Electronics Engineering).



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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF SYMBOLS

λ	Wavelength
f	Frequency
c	Speed of light
f	Frequency
a	Excess attenuation due to water vapour
b	Excess attenuation due to mist and fog
c	Excess attenuation due to oxygen
d	Sum of the absorption losses due to other gases
e	Excess attenuation due to rainfall
N(d)d(d)	Number of drops per unit volume
N(d)Δd	Drop size distribution per cubic meter
Re[SH, V(O)]	Real part of forward scattering amplitude function
$R_{\%P}$	Rainfall rate statistics
L	Path length
r	Reduction factor
A_i	Real part of forward scattering amplitude function
V	Terminal velocity
D	Diameter of rain drop
Δt	Time between tips
R	Rain rate
ρ60 (P)	Mixed Power – Exponential Law
$\boldsymbol{\theta}$	Elevation angle
Φ	Latitude of the ground station
τ	Polarization tilt angle
h_s	Altitude of ground station above sea level
L_s	Length of the satellite-to-ground path
γ_R	Specific attenuation
r_τ	Cumulative rain volume

LIST OF ABBREVIATIONS

ITU-R	International Telecommunication Union Radio Propagation
CDF	Cumulative Distribution Function
CCDF	Complementary Cumulative Distribution Function
DSD	Drop Size Distribution
5G	Fifth Generation
ETRI	Electronics & Telecommunications Research Institute (Korea)
R-H	Rice and Holmberg
IIUM	International Islamic University Malaysia
UTM	Universiti Teknologi Malaysia
USM	Universiti Sains Malaysia

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The demand for radio frequency spectrum is rapidly increasing to serve many customers in the business, government, and private sectors. Since the most desirable frequency spectrum to satisfy this demand is the 1 to 10 GHz band, apparent congestion occurs within this band, and telecommunication engineers are forcibly looking forward to utilizing the frequency band above 10 GHz. Around the same time, it is therefore vital to consider the exploration and use of higher frequencies, reaching deep into the millimeter-wavelength regions of the electromagnetic spectrum, to promote the growing need for modern communication networks with higher data speeds and hence broader bandwidths. With recent advancements and innovations in component and machine technology, these region spectrums are now becoming more available for communications networks, increasing the availability of cost-effective, stable, and lightweight hardware and thereby providing new prospects and possibilities that are currently not achievable or not feasible at lower frequencies.

Radio wave propagation through the earth's atmosphere is a persistent problem in the efficiency of communication systems. Uncontrolled changes in signal amplitude, phase, polarization, and angle of arrival can be caused by atmospheric conditions, resulting in a decrease in the performance of wireless communication systems. Consequently, statistical tests and procedures are typically most helpful in determining propagation impairments on communication links.

Rain is the primary source of impairments for the radio wave when the frequency is higher than 10 GHz. Hence the future millimeter-wavelength regions will be highly affected by rainfall and will degrade the performance of wireless communication systems (Abdulrahman et al., 2012). The problem is severe in tropical regions where the intensity of rain is very high and frequent. Raindrops consume and spread radio wave energy, resulting in rain attenuation that can degrade the contact link's stability and performance. Thus, the raindrops are believed to be spherical drops of vapor, which disperse and absorb energy from the incident radio signal. However, the non-spherical configure ratio of raindrops can also affect the signal's polarization properties, resulting in rain depolarization (a transfer of energy from one polarization state to another). Hence the effects of rain are frequency-dependent, and each drop's contributions are proportional and distinct from the other drops. This means a 'simple dispersion' of energy; however, specific 'multiple scattering' effects must be considered for attenuation and loss estimation.

As the frequency increases, the size of wavelength decreases that approaches the size of raindrops, which scatters and absorbs the radio wave's energy.

The wavelength of a radio wave is $\lambda = \frac{c}{f}$ (1.1)

Where, λ= wavelength in m, f= frequency in Hz and c= 3x10^8 m/s If the frequency of a wave is 10GHz, then the wavelength is 3cm from equation (1.1), which is closed to raindrop size, and the wave is highly attenuated during propagating through the rain (Kotamraju & Korada, 2019). Thus, the study of raindrop size distributions is essential to know the rain effects on microwave propagation.

A significant challenge for the designer is to evaluate the excess path attenuation due to rainfall when constructing millimeter-wave connections. Rain attenuation can be obtained directly from measurement or predicted from a knowledge of the rain rate. The rain attenuation prediction utilizing indirect measurement is based on the multiplication of specific attenuation (attenuation per unit length), propagation path length, and a path length reduction factor. The horizontal reduction factor accounts for the inhomogeneity of rain along the propagation path for a terrestrial microwave link. The relationship between the specific attenuation and the rain rate is established by modeling two regression parameters. These parameters depend on frequency, drop size distribution, shape, temperature, and radio-wave polarization. It has been standard practice as a function of precipitation intensity to express rainfall depletion. The intensity depends on the content of liquid water and the drop velocity of the drops (Emiliani et al., 2009). The statistical distribution of rain attenuation is, thus, obtained from the rain rate distribution for the region concerned. In its recommendation ITU-R P.618-13-2017/12, International Telecommunication Union describes a procedure to predict rain attenuation for earth-to-satellite microwave links. By considering IIUM, Gombak campus as a location of satellite earth station and MEASAT3A as satellite rain attenuation is predicted using ITU-R P.618-13-2017/12 for C-band (4 GHz), Ku-band (12 GHz), Ka-band (20 GHz), and V-band (40 GHz) downlinks and presented in Figure. 1.1. Figure 1.1 shows how severe the problem is to design reliable links in Malaysia. It requires about 20 dB, 40 dB, and 120 dB extra fade margins to achieve 99.99% availability for Ku, Ka, and V-bands systems in Malaysia.

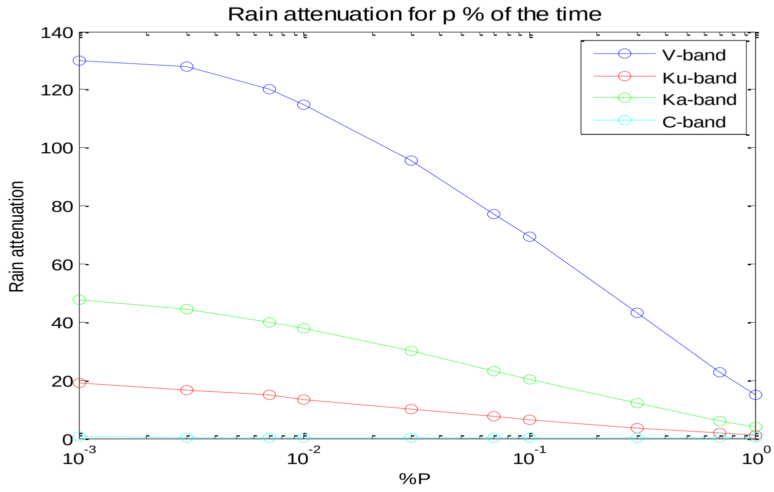

Figure 1.1: Predicted rain attenuation in vertical polarization using rain intensity for Malaysia. (ITU-R P.618-13-2017/12)

In Malaysia, two monsoon wind seasons occur, which are southeast monsoon and northeast monsoon. The southeast monsoon happens from May to September and the northeast monsoon from November to March. During the monsoon season, the rain occurs most heavily. According to Malaysian Meteorological Department, different parts of Malaysia have different rainfall, for example, the lowest rainfall is in Jelebu, Negeri Sembilan and the highest rainfall is in Bukit Larut, Perak.

The Malaysian Meteorological Department has defined the monsoon based on total rainfall in mm, not based on rain intensity. However, ITU-R and all other prediction methods need the intensity of rain in mm/hr. The rain intensity data can only be measured by the real-time rain gauge and being analyzed to get the rain distribution for one year of data. The rain rate distribution is also known as cumulative distribution, is a measure of rain intensity in mm/hr. Many rain rate distribution models are widely being used and acceptable for the whole world, which are Moupfouma Model, Crane Model, Modified Crane Model, and ITU-R Model.

In Bell System Technical Journal, S. H. Lin proposed that rain intensity must be used as mm/hour to cover geographical variations of 1 km to predict specific rain attenuation dB/Km. In his analysis of the dependence of rain rate distributions on rain gauge integration time, he used 5-min, 10-min, 15-min, 30-min, and 60-min integration times and found that the lower integration times showed higher rain intensity. ITU-R has recommended that the rain intensity or rain rate be deduced from the observed rainfall rate with an integration time of 1-minute or less. However, the lowest integration time in measurement was reported with 30-secs and distribution was found higher than 1-min with more accurate prediction was achieved.

Since the rain attenuation is one of the major challenges for current mmWave propagation for 5G in the tropical climate, it is high time to analyze the intensity measurement based on lower than 1-min integration time to predict more accurately. This research aims to collect rain rate data with 10-sec integration time in the International Islamic University Malaysia (IIUM) Gombak campus and analyze its effects on rain intensity distributions and rain attenuation predictions.

1.2 PROBLEM STATEMENT

Fifth-generation mobile and future satellite communications all move towards the utilization of higher and higher frequencies. However, rain is the most critical factor above 10 GHz frequency for severe signal attenuation in open space propagation. All system designers depend on rain attenuation prediction models to design reliable systems for 5G and other links. All prediction models use rain intensity data in mm/hr measured with 1-min integration time or less as recommended by ITU-R. Recent measurements of rain attenuation at mmWave bands for short length propagation links are found significant discrepancies from ITU-R predictions as reported by many researchers. All researchers used rain intensity from 1-min integration time measurement, as not less than 1-minute data are unavailable. As rain gauge integration time impacts rain intensity distribution and eventually on rain attenuation prediction, the fact has not been investigated yet. A rain gauge with a 10-seconds integration time was installed on Satellite Lab Rooftop, and this project has presented the analysis of the effects of integration time on rain intensity distributions and rain attenuation prediction based on one-year measurement.

1.3 OBJECTIVES

The study to achieve the following objectives:

1. To investigate the effects of 10-s integration time on rain intensity distributions based on measured data using real-time rain gauge.
2. To compare the predicted rain attenuation for mm Wave bands with different integration times with those of available rain attenuation measurements.
3. To predicted rain attenuation for mmWave bands using measured rain intensities with different integration times.

1.4 RESEARCH METHODOLOGY

Phase I: Literature Review

Investigation of the dependence of Rain Intensity Distribution in mm/hr on rain gauge resolution and integration time of measurement from related literature.

Phase II: Rain Intensity Data Collection

1. Collection of one-year rain-intensity data time series using real-time rain gauge with 10-secs integration time at IIUM.

2. Availability analysis of data

Phase III: Data Processing

1. Processing the data with a 10-sec integration time.
2. Conversion of the data to 20-seconds, 30-seconds, 1- minute, and 2-minutes of rain intensity time series.
3. Analysis of cumulative distribution function (CDF) for rain intensity distributions using measured 10-seconds, 20-seconds, 30-seconds, 1-minute and 2-minutes data.

Phase IV: Data Analysis

1. Analysis of rain intensity distributions for monthly and yearly with five integration times.
2. Compare yearly distributions with different prediction models for rain intensity distribution.

Phase V: Rain Attenuation Predictions

1. Prediction of rain attenuation using ITU-R REC-P.530-17-2017 and P.618-13-2017 for terrestrial and satellite links.
2. Analyze the effects of rain intensity with different integration times.

Phase VI: Compare the predicted attenuation with available measurements.

1.5 SCOPE OF THE RESEARCH

The rain intensity data used for research is the one-year measurement with a 10-seconds integration time at IIUM, Gombak campus.

The other five integration times are utilized to analyze the effects of integration times on rain intensity distributions and rain attenuation predictions. The rain attenuation measured at 26 GHz, 38 GHz, and 73 GHz terrestrial links and 12 GHz earth-to-satellite links in Malaysia are used for comparison and validation of findings.

1.6 THESIS LAYOUT

This research dissertation consists of five chapters. The chapters are arranged as follows:

Chapter 1: Introduction

Background, problem statements, objectives, methodology, and scopes are included in chapter 1.

Chapter 2: Literature Review

The significance of rain intensity measurement, distributions, prediction models is described in this chapter. Significance and literature related to integration time, rain attenuation prediction, and measurements are also included in chapter 2.

Chapter 3: Data Collection and Data Processing

This chapter presents rain gauge setup, rain intensity data collection, availability analysis, conversion to different integration times, and monthly and yearly distributions.

Chapter 4: Results and Analysis

This chapter presents the effects of integration time on rain intensity distributions, rain attenuation predictions and compares them with the available measurements.

Chapter 5: Conclusions

This chapter summarizes the findings and recommends further works for future researchers to conduct future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the basic concepts of rain-caused effects on wave propagation. It describes the relation between rain attenuation and rain intensity. This chapter also presents how rain intensity is derived from the rain gauge data with different integration times. The effects of integration time on the rain rate distributions are also presented and reviewed. Available prediction models for rain rate distributions are described briefly. Rain attenuation predictions by ITU-R for Earth-to-satellite (ITU-R P.618-13) and terrestrial (ITU-R P.530-17) links are explained in detail. Finally, few rain attenuation measurements are presented for comparisons.

2.2 EFFECTS OF RAIN

Above 10 GHz, radio waves are propagated through the atmosphere not just due to free space loss but also due to a variety of other meteorological factors. The gaseous contribution of the homogeneous atmosphere due to resonant and non-resonant polarization parameters, the contribution of atmospheric inhomogeneities, and the contribution from fog, mist, and rain are all included. In radio connection design for frequencies above 10 GHz, excessive attenuation due to rainfall and atmospheric absorption can play a major role. The general formula derived(Freeman & Freeman, 2005) for the calculation of total transmission loss in a given radio link is

$$\text{Attenuation (dB)} = 92.45 + 20 \log F_{GHz} + 20 \log D_{Km} + a + b + c + d + e \qquad (2.1)$$

where F is in gigahertz and D is in kilometers,
a = excess attenuation due to water vapour
b = excess attenuation due to mist and fog