DEVELOPING A FREQUENCY DIVERSITY MODELS FOR RAIN FADE MITIGATION IN MALAYSIA

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science in Communication Engineering

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ABSTRACT

Microwave communication systems in tropical region like Malaysia, operating at higher frequency ranges, are degraded in its performance severely during rains. Hence, the rain fade must be taken in consideration for the microwave link design to track the service outage and quality. This research aims to develop and propose frequency diversity prediction models for rain fade mitigation from 5 – 40 GHz. The rain attenuation are predicted based on ITU-R rain attenuation prediction method using measured rain rate in Malaysia. The predicted data are analysed to develop and propose a prediction for the frequency diversity gain and improvement factor. The estimated gains are not uniform along the frequency range of 5 – 40 GHz, hence gain model is proposed for different frequency separation (5, 10, 15, 20 GHz) at 0.001 to 1% outages. A general model is also proposed for any path length at 0.01% outage only. An alternative approach named as frequency diversity improvement is also proposed. However this model is limited to 1 Km path length only. Proposed gain models are validated by comparing the measured rain attenuation data at 15, 23, 26, 38 GHz frequencies in UTM, Skudai. The difference varies from -2 to 2 dB. The effects of the frequency separation, the outage percentage and the path length on the gain models are discussed. The effect of fade margin on the improvement factor is also investigated. This analysis will help the designer to understand how these models can identify the best diversity frequency to use under rain fade.

ملخص البحث

نظم لاتصالات الميكروية في المناطق الاستوائية مثل ماليزيا التي تعمل ضمن مجالات ترددية عالية يكون أداؤها يتدهور بشدة نتيجة هطول الأمطار, و لذلك يجب الأخذ بعين الاعتبار الخبو الناتج عن المطر عند تصميم الوصلة المايكروية لمتابعة انقطاع الخدمة و جودتها. يهدف هذا البحث لتطوير و اقتراح نماذج تنبؤ للتعدد الترددي من أجل تخفيف الخبو المطري بين 5-40 GHz يتم تحديد التخميد الناتج عن المطر باستخدام نموذج توقع ITU-R باستخدام معدل أمطار مقاس في ماليزيا. يتم تحليل البيانات المتوقعة لتصميم و اقتراح نموذج للكسب الناتج عن التعدد الترددي و مقدار عامل التحسن. إن المكاسب المقدرة على كامل المجال الترددي بين 5-40 GHz ليست موحدة, وبالتالي تم اقتراح نموذج يختلف حسب فرق التردد (5,10,15,20 GHz)بين 0.001 و 1% من الانقطاع. تم اقتراح نموذج عام لأي طول مسار عند نسبة 0.01% من الانقطاعات. تم اقتراح نهج بديل تحت مسمى عامل التحسن للتعدد الترددي, لكن هذا النموذج محدد لمسافة 1كم فقط. تم التحقق من صحة النماذج المقترحة بمقارنة نتائجها مع النتائج المحصلة من معلومات التخميد المطري المقاسة في جامعة ماليزيا للتكنولوجيا في مدينة سكوداي,وأذهرت النتائج فرق بين ±2 dB. تم مناقشة تأثير الفرق الترددي و نسبة الانقطاع و طول المسار على نماذج الكسب, كما تم دراسة تأثير هامش الخبو على نموذج عامل التحسن.هذا التحليل سيساعد المصممين لفهم كيفية الحصول على أفضل تردد بديل لاستخدامه تحت تأثير الأمطار.

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 in Communication 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.

Mohamad Laith Altajjar

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In the name of Allah the most gracious, the most merciful and the master of all knowledge.

Praises to Allah, the Lord and the Creator, who give me this opportunity to complete this work with his guidance and grant, May Allah accept this humble work.

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LIST OF ABBREVIATIONS

AC	Adaptive Coding
dB	Disable
DPC	Downlink Power Control
FD	Frequency Diversity
FEC	Forward error correction
FMT	Fade Mitigation Technique
GHz	Gega Hertz
GSM	global system for mobile communications
ITU-R	International Telecommunication Union-Radio
LOS	LINE OF SIGHT
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MW	Microwave
SBS	Spot Beam Shaping
SD	Site Diversity
TD	Time Diversity
UPC	Uplink Power Control
UTM	University of Technology Malaysia
WGS	Wideband Global Satellite

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The evolution of communication systems and the enormous increase in the user's numbers require a large bandwidth, high speed and reliable system designs. These demands resulted in highly saturated lower frequency bands together with the fast growth in capacity requirements pushing the frequency range limits into higher bands, which have enough band-widths to support these needs. Above a certain threshold of frequency, attenuation due to rainfall becomes one of the most important limits on the performance of line-of-sight (LOS) microwave links especially in tropical regions like Malaysia which experience heavier rainfall intensities, so the link quality and availability may be affected, To counteract this degradation and make efficient and economic use of these bands, different techniques have been proposed which are called fade mitigation techniques (Freeman, 2007).

Fade mitigation technique (FMT) defined as an adaptive communication systems that compensate tropospheric attenuation effects affecting the signal quality in real time. Designing a fade mitigation technique to countermeasure the rain attenuation requires analysing the effect of the rain rate on the microwave link using a prediction models. ITU proposed prediction model used to estimate the rain attenuation level related with each frequency, hence the fade mitigation technique is based on these estimations to meet specific quality of service requirements (Yussuff, 2005).

Improving the reliability and quality of the transmission system by using diversity schemes is considered the most effective technique in rain fade mitigation where two or more communication channels with different characteristics are used to deliver the signal through faded channels and decreases the outage percent of time of the link. Frequency diversity scheme uses multiple frequencies as different communication channels, under the condition that each frequency is uncorrelated with others in term of propagation effects. Thus, rain attenuation estimation by ITU used to define the best frequencies to consider as diversity frequencies for the system base frequencies (Nitika, Deepak, 2012).

1.2 PROBLEM STATEMENT

Rain fade is considered as the major problem facing microwave links design in tropical climate country like Malaysia where the rain intensity is very high, but telecommunication development demands higher frequency bands where rain has larger fade attenuation effect on the microwave frequencies.

Many researches provided rain fade mitigation technics models for such a climate, however, frequency diversity technique was not much investigated properly and no model was found for Malaysia's rain rate. Frequency diversity fade mitigation technique is considered a very reliable technique to be used, since it utilizes transmission of the same information at two different frequency carriers achieving high data rate at higher frequencies and low rain attenuation with lower frequencies.

1.3 RESEARCH OBJECTIVS

The main objectives of this research are:

- To investigate rains fade at different frequencies using ITU prediction model.

- To analyse the frequency diversity technique.
- To develop and propose a model of frequency diversity for rain fade mitigation in Malaysia based on the measured data.
- Validate the proposed model using the measured data.

1.4 RESEARCH METHODOLOGY

The research followed a steps methodology to achieve the required objectives; each step leads to the next one as:

- **Step 1:**

  Study the available frequency diversity model provided by the ITU-R recommendation for rain fade mitigation .

- **Step 2:**

  investigate rain rate effect for Malaysia using ITU-R prediction model for terrestrial microwave link .

- **Step 3:**

  Process the resulted data using MATLAB as a software tool for calculations and plotting the required graphs.

- **Step 4:**

  Analyze the processed data for each frequency and discuss the comparison to build up the frequency diversity model

- **Step 5:**

  Propose a new frequency diversity model based on the data analysis and compare it with the available model.

- **Step 6:**

  Validate the proposed model using measured data in Malaysia.

1.5 DISSERTATION ORGANIZATION

This thesis is structured of five (5) chapters. The intent of this thesis is to propose a frequency diversity model for rain fade mitigation in tropical country like Malaysia and to compare the resulting approaches to the standards.

Chapter one is an introduction to the research. It gives a background on the research topic, the statement of the problem and its significance is outlined. The chapter also covers the research objectives as well as the methodology of the research.

Chapter two provides a literature review on the basic information about the research defines main concepts in rain attenuation prediction models and fading mitigation techniques that are used in the later chapters and discusses some related work.

Chapter three presents the frequency diversity modelling, discusses specific rain attenuation prediction model by ITU-R, frequency diversity gain and improvement factor and how to include distance factor in the model.

Chapter four investigates the validity of the proposed models using data from UTM research group and discusses the effect of the frequency separation, path length, fade margin effects on the models.

Finally, Chapter five includes a conclusion summarizing the outcomes and some recommendations for future developments on the topic.

CHAPTER TWO

LITERATURE REVIEW

2.1 ATMOSPHERIC EFFECTS ON MICROWAVES

Microwave communication links, including terrestrial and satellite links operating at 3 GHz to 300 GHz frequency ranges, it is a form of line of sight communication because it requires the obstruction less transmission between the receiving and transmitting sites for signals to be connected properly at both ends, this make the transmission quality depends mainly on the medium of propagation, which is the earth's atmosphere (Seybold, 2005).

Microwaves propagation through atmosphere suffers from many effects caused by each layer of the atmosphere, where each layer considered as a medium for different waves and thus different types of communication as shown in Figure 2.1.

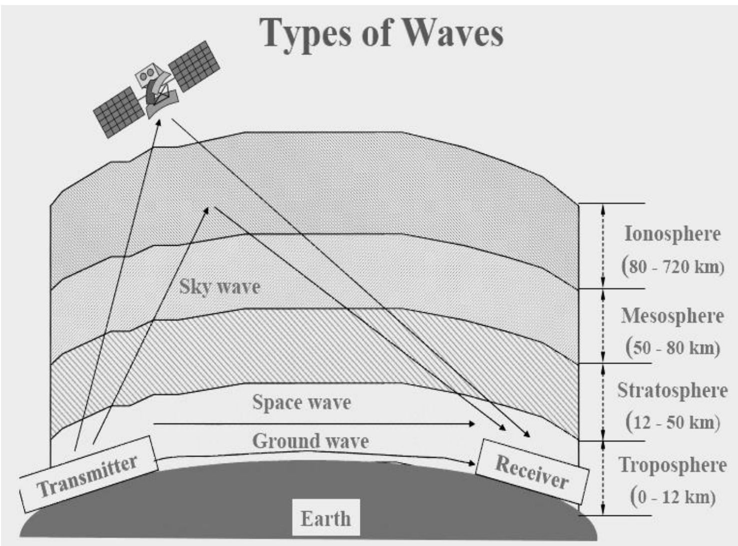

Figure 2. 1 Communications through Atmosphere

The atmospheric effects are frequency dependant, where in general high frequency associated with higher losses. Rain attenuation is the main attenuation mechanism on terrestrial links operating above 5 GHz. Other effect such as cloud, fog and snow attenuation, absorption by atmospheric gasses, and multipath effects such as refractivity and reflection also have important effects to consider.

Atmospheric absorption is the reduction in the signal strength caused by the contact between the microwaves and the gasses in the atmosphere mainly as water vapour and oxygen molecules, where these gasses have resonant frequency at which they absorb the radio waves causing high attenuation as shown in Figure 2.2 (ITU-R, 2009)

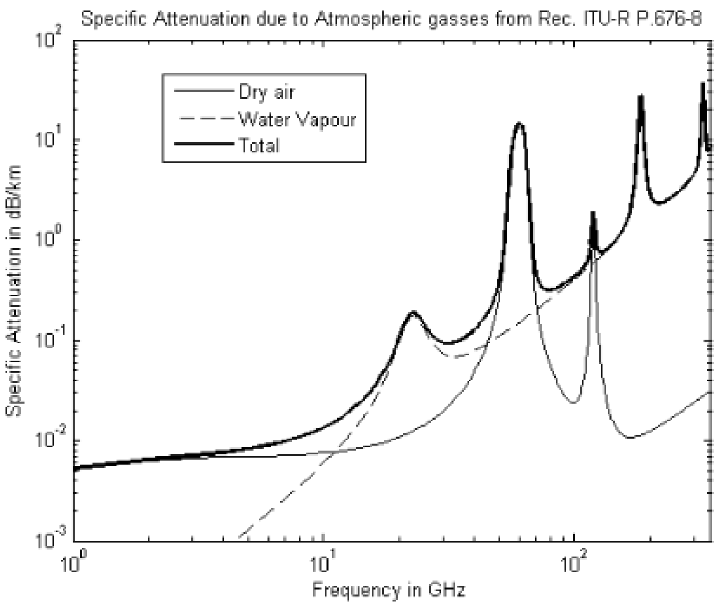

Figure 2. 2 Specific attenuation due to atmospheric gasses (ITU-R, 2009)

Refractivity is the variation in the atmospheric refractivity index; that is due to of the atmosphere in homogeneity, which encounters the microwave beam along its path of propagation, causing the waves path to become curved (Ippolito, 2008).

Another factor related to the curvature of the wave beam to consider is the K-factor that helps to calculate the beam curve with respect to the radio horizon, where a horizontal wave is bent downward beyond the straight line-of-sight horizon or the optical horizon as illustrated in Figure 2.3 (Roddy, 2006).

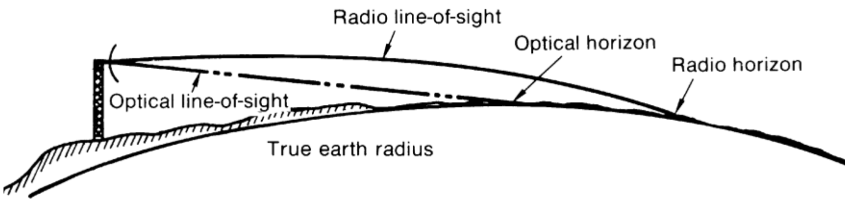

Figure 2. 3 radio horizon and the LOS horizon (Roddy, 2006)

Hydrometeors are classified into two parts according to their effect on the microwave beam, fog, haze and clouds are the first class where they generally consist of water droplets of less than 0.1mm diameter suspended in the atmosphere causing absorption and scattering of the microwave beam.

The effect of clouds mainly acts on satellite or high altitude communication rather than terrestrial microwave links, but the attenuation caused by fog and haze on the other hand, is determined by the amount of water per unit of volume and it varies with the atmospheric temperature, the fog’s effect is considered similar but very small compared with precipitation effect as shown in Figure 2.4 (Karmakar, Sengupta, Maiti, and Angelis, 2010) (ITU-R, 2009).

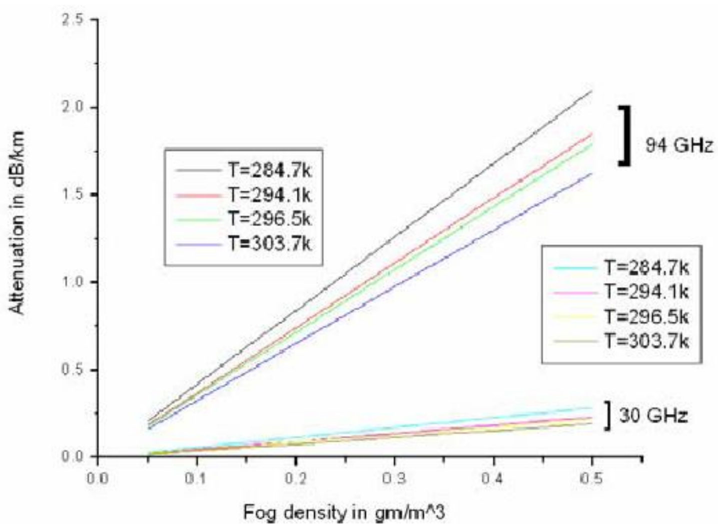

Figure 2. 4 Fog density and attenuation (Karmakar, 2010)

The major atmospheric effect on microwave terrestrial links comes from precipitation; rain and snow in general, the attenuation of microwaves due to snow is mainly a function of the moisture content of the particles. For this reason, the attenuation effects are expected to be less than those due to rain (Tjelta, and Bacon, 2010).

2.2 RAIN EFFECTS ON MICROWAVES

The main obstacle that faces a microwave communication system in tropical region is rain; it has two main effects on the microwave signal, one that has an effect on the signal amplitude, the other affects the polarization status.

Rain depolarization is the transfer of energy from one polarization state to another due to the none spherical shape of the rain drops changing the polarization characteristics of the signal (Chen, Chu and Tzeng, 2011).

Rain attenuation due to the scattering and absorption by the water droplets, is one of the most effecting factors that limit the performance of microwave communication systems operating in the frequency bands above 5 GHz especially in tropical countries.

Rain fade is defined as the reduction of the signal power in dB due to rain rate resulting in degradation in the system quality; the rain rate is the rate of the accumulated rainwater in a rain gauge measured in mm/hr.

Specific attenuation is the estimated attenuation exceeded for a percentage of time at 1 Km distance, calculated using the imperial equation that relates the rain rates at P% outage and frequency as:

$$\gamma_R = k * R_P^{a} \tag{2.1}$$

Where γ_R represents the specific attenuation at P outage of time, measured in dB/Km. k and a are frequency, polarization and temperature related coefficients and R is the predicted rain rate (ITU-R, 2005).

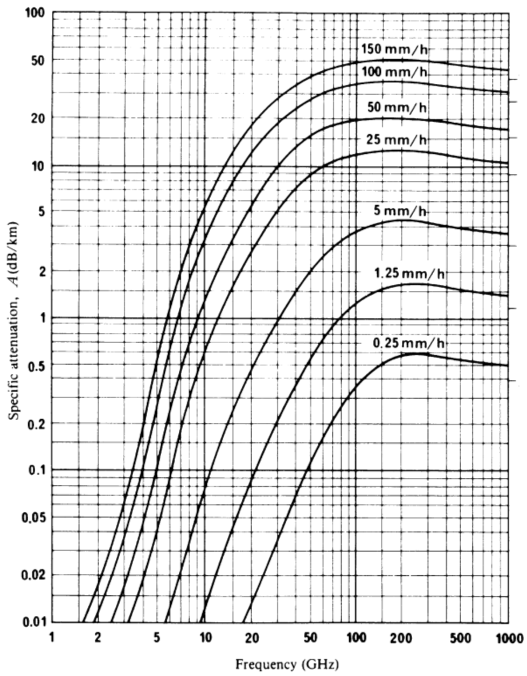

Figure 2.5 Attenuation With Frequency For Different Rain Rates (Freeman, 2007)

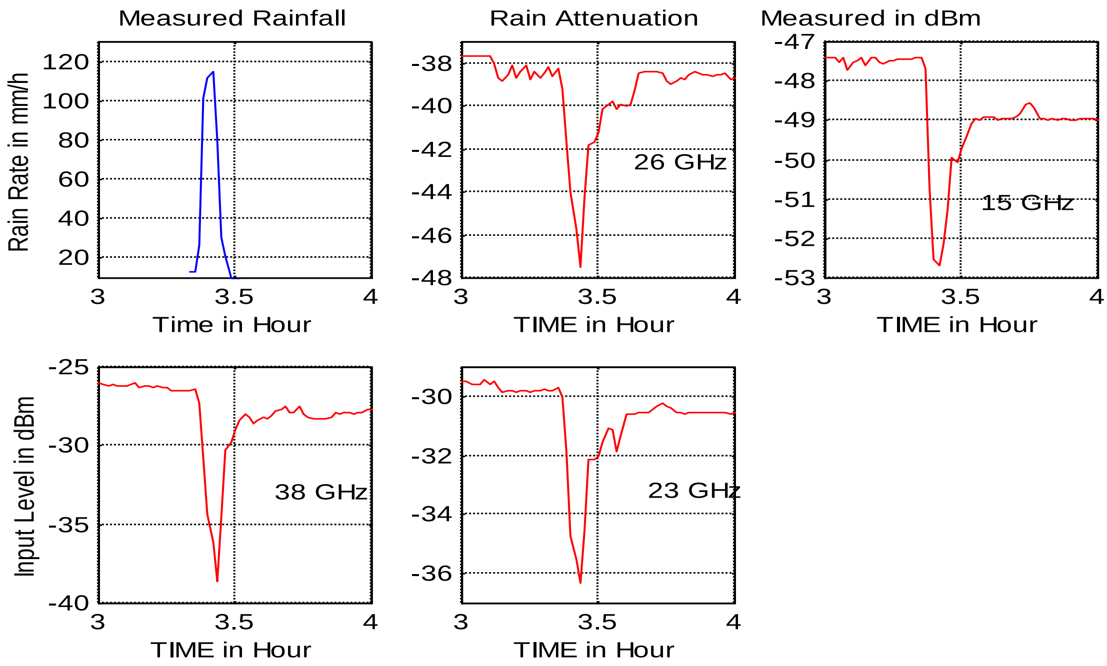

Figure 2. 6 UTM Rain Rate Measurements and Attenuation for Different Frequencies (Research Group, 2000)

The frequency relationship with the rain rate in equation 2.1 can be shown as in Figure (2.5), where the specific attenuation increases as the frequency of operation goes higher and the higher the rain rate. This conclusion is proofed by UTM (Research Group, 2000) when they measured the rain rate for specific time and measured the attenuation on four different frequency as explained in Figure (2.6).

2.3 RAIN ATTENUATION PREDICTION

Attenuation due to rain restricts the system performance of microwave communication and limits the usage of higher frequencies for terrestrial point-to-point links.

Evaluating the rain fade on the microwave signal is a fetal step in the design process of a terrestrial link especially in tropical countries, thus a few models are used to predict rain attenuation value depending on equation (2.1).

Robert Crane (Crane,1996) and ITU (ITU-R, 2012a) provided the most used rain fade prediction model depending on the rain rate and based on large amount of empirical data.

2.3.1 ITU-R Rain Attenuation Model

The model provided by ITU-R (ITU-R, 2012a) is the most accepted international method for predicting the rain effects on a communication system; this recommendation provides a prediction method for the propagation effects that should be taken in consideration in the design of the communication system.

The ITU-R model follows a steps methodology as:

- Estimate the rain rate R (mm/hr) for 0.01% outage of time from local measurements or can be estimated from ITU recommendation (ITU-R, 2012b).
- Calculate the specific attenuation γ_P (dB/Km) for the rain rate R using the power –law equation:

$$\gamma_P = k * R_P^{\alpha} \tag{2.2}$$

  Where (k, α) are determined as a function of frequency f (GHz) for horizontal and vertical polarization as:

$$k = [\, k_H + k_v + (k_H - k_v)cos^2\theta * cos2\tau]/2 \tag{2.3}$$

$$a = [\, k_H\, a_H + k_v a_v + (k_H a_H - k_v a_v)cos^2\theta * cos2\tau]/2k \tag{2.4}$$

  Where k_H, k_V and α_H, αV are horizontal and vertical coefficients, which values are provided by ITU (ITU-R, 2005), θ is the elevation angle and τ is the tilt angle.

- Calculate the effective path length d_{eff} (Km) of the link by the use of the distance reduction facto r as :