TIME DIVERSITY ANALYSIS BASED ON PREDICTED RAIN ATTENUATION AT KA AND V BANDS USING SYNTHETIC STORM TECHNIQUE

BY

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ABSTRACT

Future satellite communication services are moving towards higher frequency Ka and V-bands. The use of these frequency bands is limited by different propagation impairments in atmosphere. Rain fade is the main challenge to design reliable earth to satellite communication links above 10 GHz. The problem becomes severe in tropical regions because of high rainfall occurs most of the time in a year. Time diversity technique is one of the potential mitigation techniques because this technique is cost effective and efficient mitigation techniques to overcome the attenuation due to rain (Del Pino et al, 2005). For time diversity analysis, measured real-time rain attenuation data are needed to design. But the problem is in the higher frequency bands like Ka and V bands, those data are not available. Hence, Synthetic Storm Technique (SST) can be utilized because it can convert the measured real-time rain rate data to rain attenuation data. This thesis presents analysis of one year measured rain rate data with 1-minute integration time which has been collected at IIUM, Kuala Lumpur campus. One year measured rain rate data are converted into equivalent attenuation data using Synthetic Storm Technique (SST). The Cumulative Distribution function of all converted rain attenuation is calculated without time delay and with time delays of 1, 3, 5, 10, 20 and 30 minutes respectively for Ku, Ka and V-bands. Time diversity gain is also analyzed and found that gain is higher with the increasing of time delay. It has been also observed that improvement is higher at a lower percentage of outages. The gain at 0.01% are found 4.7 and 27.8 dB for Ku-band, 6.8 and 58.7dB for Ka-band and 10.5 and 94.2 dB for V-band with the time delays for 1 and 30 min respectively. For comparison, the gains predicted by Matricciani model are compared with SST predictions for Ku, Ka and V-bands for all percentages of outages and for 1, 3, 5, 10, 20 and 30 minutes delays. Since the analysis is done based on measurement in tropical region, it is very significant that Matricciani model gain is found comparatively much higher than SST predicted rain attenuation gain in all the frequency bands. For the purpose of validation, SST predicted gain has been compared with the available Kuala Lumpur measurement at Ku-band. After comparison, it has been found that the SST predicted gain is much closer to measured one than gain predicted by the Matricciani model. Hence, a model can be proposed to predict the time diversity gain using measured rain rate time series and Synthetic Storm Technique (SST) with a correction which depends on frequency and time delay. For Ku-band, the correction function is developed and presented. For any other bands, the functions can be developed using available measured gains.

خلاصة البحث

تتجه خدمات وتطبيقات انظمة اتصالات الساتلايت المستقبلية نحو نطاقي Ka و V العالي التردد. هناك عدة عوائق انتشار مختلفة تحد من استخدام نطاقات التردد العالي في الغلاف الجوي. يعد التلاشي المطري هو التحدي الرئيسي لتصميم وصلات اتصالات موثوقة بالأرض إلى الأقمار الصناعية فوق 10 جيجا هرتز. تصبح هذه المشكلة اكثر حده في المناطق الاستوائية بسبب ارتفاع معدل هطول الأمطار على مدار السنه . يعتبر التنوع الزمني احدى التقنيات الفعاله من حيث التكلفة للتغلب على التوهين الناتج عن المطر.لتصميم و تحليل تقنية تنوع الوقت ، يلزم استخدام بيانات حقيقيه مقاسة لتوهين الاشارة الناجم عن المطر في الوقت الفعلي. ولكن المشكلة هي في نطاقات التردد الأعلى مثل نطاقي Ka و V ، فهذه البيانات غير متوفرة. وبالتالي , يمكن استخدام تقنية العاصفة الاصطناعية (SST) لأنها يمكن أن تحول بيانات معدل المطر في الوقت الفعلي إلى بيانات التوهين بالمطر. تقدم هذه الأطروحة تحليلًا لبيانات معدل المطر المقاسة لمدة عام واحد مع وقت تكامل مدته دقيقة واحدة تم جمعها في الحرم الجامعي IIUM كوالا لمبور. تم تحويل بيانات معدل المطر المقاسة لمدة عام إلى بيانات توهين مكافئة باستخدام تقنية العواصف الاصطناعية (SST). تم حساب دالة التوزيع التراكمي لجميع التوهين الناجم عن المطر دون تأخير زمني، كذالك بتأخير زمني قدره 1 , 3, 5 , 10 , 20 , 30 دقيقة على التوالي لنطاقات Ku و Ka و V. أيضًا تم تحليل كسب التنوع الزمني ووجد أن الربح أعلى كلما زاد التأخير الزمني. وقد لوحظ أيضا أن التحسن في الأداء أعلى كلما انخفضت نسبة الانقطاع . تم العثور على المكاسب عند 0.01٪ 4.7 و dB 27.8 للنطاق Ku و 6.8 و dB58.7 للنطاق Ka و 10.5 و dB 94.2 للنطاق V مع التأخير الزمني لمدة 1 و 30 دقيقة على التوالي. لمقارنة النتائج ، تمت مقارنة المكاسب التي تنبأ بها نموذج Matricciani مع تنبؤات SST لنطاقات Ku و Ka و V لجميع نسب الانقطاعات والتأخير لمدة 1 و 3 و 5 و 10 و 20 و 30 دقيقة. نظرًا لأن التحليل يتم على أساس القياس في المنطقة المدارية ، من المهم جدًا أن يكون كسب نموذج Matricciani أعلى نسبيًا من كسب التوهين الناجم عن المطر الذي تنبأ به SST في جميع نطاقات التردد. لغرض التحقق من دقة النتائج ، تمت مقارنة الكسب المتنبأ به من SST بقيم مقاسه في كوالالمبور في نطاق Ku. بعد المقارنة ، وجد أن الربح المتوقع من SST أقرب بكثير إلى القياس من المكسب الذي تنبأ به نموذج Matricciani. ومن هنا يمكن اقتراح نموذج للتنبؤ بكسب التنوع الزمني باستخدام السلاسل الزمنية لمعدل المطر المقاسة وتقنية العاصفة الاصطناعية (SST) مع تصحيح يعتمد على التردد وتأخر الوقت. بالنسبة إلى Ku-band ، تم تطوير وظيفة التصحيح وتقديمها. لأي نطاقات أخرى ، يمكن تطوير الدوال الحسابيه باستخدام القيم المتاحه للكسب المقاس .

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it confirms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Computer and Information 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 ABBREVIATIONS

CDF	Cumulative Distribution Function
IIUM	International Islamic University Malaysia
ITU- R	International Telecommunication Union - Radio communication
SST	Synthetic Storm Technique
TD	Time Diversity
G_{TD}	Time Diversity Gain
min	Minute
Td	Time Delay

LIST OF SYMBOLS

A	Attenuation
dB	A unit of power in decibel scale
f	Frequency (GHz) in operating
h_0	Height of 0°C isotherm
h_r	Effective height of rain (km)
h_s	Height of the earth station (km) above mean sea level
I	Diversity improvement factor
k and α	Coefficients related with frequency and polarization that given
L_{eff}	Effective Length
L_s	Length of the slant path
R	Rainfall rate
$R_{0.01}$	Rain rate for the location for 0.01% of an average year (mm/h)
R_A	Rain rate of rain layer
R_B	Rain rate of melting layer
T	Time duration
β	Baseline angle
δt	Time delay
θ	Elevation angle (deg.) of the satellite -Earth link
σ	Standard deviation

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

C and Ku bands are congested for the satellite communication services(Space & Company, n.d.). Hence, the future direction of satellite communication system is going away to higher frequencies such as at the Ka-and V-bands. Higher frequencies band are of preliminary interest in satellite communication systems, since they provide sufficient transmission bandwidth and higher data rate. However, higher frequencies are severely affected by different propagation deprivations in atmosphere, such as rains, cloud, snowfall, fog etc. But the rain is one of the main challenges to design reliable earth to satellite communication links for higher frequencies. Rain fade is more severe in tropical regions(Yussuff, 2016). Therefore, to overcome the rain fade, several mitigation techniques have been proposed such as site diversity(Panagopoulos, Arapoglou, & Cottis, 2004)(Castanet, Bolea-Alamañac, & Bousquet, 2003),frequency diversity(Capsoni, D'Amico, & Nebuloni, 2009), and time diversity(Ismail & Watson, 2000) and all the techniques show promising results.

Time diversity technique is one of the potential mitigation techniques because this technique is cost effective and efficient mitigation techniques to overcome the attenuation due to rain (Del Pino et al., 2005) and this technique is also used in satellite communication to improve the performance over a link with fading. For time diversity, measured rain attenuation data are needed otherwise the gain and improvement of the time diversity cannot be estimated. However recent studies show that in tropical climate, melting layer is disappeared during convective type of rains (Azlan, et al,2011).The Synthetic Storm Technique (SST) is a suitable method to convert the instantaneous rain rate measurements to rain-attenuation time series for Ku, Ka and V bands (Kadhim, 2017).

In present communication system measured rain attenuation data are not available at the higher frequency bands but measured rain rate data are available in many locations. By using SST rain rate data are converted into equivalent measured rain attenuation data as a result we can check the time diversity for higher frequency bands. SST was developed based on data collected from temperate regions (Sánchez-Lago et al, 2007)

An epitome of the fundamentals of the SST developed by Matricciani, (1996) is converting a rain rate time series, which is measured using a rain gauge at a point for 1-minute integration time, to a rain rate space series along a line, using an estimate of the storm translation speed to transform time to distance. Mathematically, this is carried out by convolution. The SST is also called physical-mathematical radio propagation method. This process requires knowledge about the length of the signal path through the rain cell, the rain cell velocity and the rain rate at the site under investigation(E Matricciani, 2006). Moreover, by applying the SST can generate rain attenuation time series at any frequency and polarization and for any slant path above approximately 10° as well as Matricciani et al (Matricciani et al, 2006) stated that the SST can be used to generate rain attenuation time series to slant paths of very low elevation angle with caution and a number of restraints. As a result, the SST is one of the most authentic methods to estimate rain attenuation time series and consequently long-term rain attenuation expedience probability, diurnal and service-oriented statistics (Kanellopoulos et al, 2006). The SST is very feasible for designing communications satellite systems and improves its performance(E Matricciani, 2006).

Sánchez-Lago et al (Sánchez-Lago et al, 2007) referred to use of the SST model to generate time-series of signal attenuation on satellite links in system simulation studies is quite safely. This research has focused on the one year rain rate data measured at IIUM in Malaysia converted by the Synthetic Storm Technique.

After conversion of rain rate data, equivalent measured rain attenuation data are obtained. By using equivalent measured rain attenuation data cumulative distribution function is generated to get the gain with different time delays from 1 to 30 minutes. After that gain has been obtained at Ku-, Ka- and V-bands and has also been compared to Matricciani's proposed model gain and local measured gain. Time diversity with SST at higher frequencies and refers to performance has been analyzed and presented in this dissertation.

1.2 PROBLEM STATEMENT

Rain is a problem at the higher frequency especially in tropical regions due to heavy rainfall with different characteristics (Dao et al, 2013; Das, et al, 2013). Future direction of satellite communication systems is moving towards Ka- and V- bands in which rain attenuation is main challenge to design reliable links. To mitigate this problem, time diversity technique is proposed as one of the potential methods. However, measured rain attenuation data is required to evaluate time diversity improvement which is not available in tropical region, especially at Ka- and V- bands. In this situation Synthetic Storm Technique is proposed as a good solution because SST can convert the rain rate time series into a rain attenuation time series which can be utilized to predict time diversity gain.

1.3 OBJECTIVES OF THE RESEARCH

The main objectives of this research are:

1. To predict and analyze rain attenuation at Ku-, Ka- and V-bands using SST based on one year rain rate data measured in Malaysia.
2. To investigate time diversity improvement based on converted rain attenuation series at Ku-, Ka- and V- bands.
3. To compare predicted time diversity gain with those predicted by Matricciani's model as well as available measurements.

1.4 RESEARCH METHODOLOGY

For obtaining the desired objectives stated above, the following steps are taken into consideration:

Step 1: Rain rate data collection

1 year rain rate data has been collected at IIUM engineering faculty from 1st January 2014 to 31st December 2014.

Step 2: Rain rate data processing

Data have been processed from 10 seconds integration time into 1 minute.

Step 3: Conversion

Rain rate time series data have been converted into rain attenuation time series data at Ku-, Ka- , V- bands using Synthetic Storm technique where MATLAB software has been used.

Step 4: Analysis

Using converted data, attenuation time series with 1, 3, 5, 10, 20, 30 minutes time delay has been presented at Ku-, Ka- and V- bands.

Step 5: Cumulative Distribution Function (CDF)

CDF has been calculated at Ku-, Ka- and V- bands without delay and with delay of 1, 3, 5, 10, 20, 30 minutes at 0.001%, 0.01% and 0.1% .

Step 6: Attenuation Gain

Gain has been calculated using CDF at Ku-, Ka- and V- bands without delay and with delay of 1, 3, 5, 10, 20, 30 minutes. SST predicted gain has been validated with Matricciani model gain and available measured gain.

1.5 THESIS LAYOUT

Overall preview of the research has been summarized in chapter1.Chapter 2 covers the literature related with rain attenuation and time diversity. Chapter 3 describes about the data process and methodology. All results are discussed in chapter 4 and conclusion is in chapter 5.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

Propagation effects such as rain effects and its prediction models are elaborated in this chapter. Statistical model like ITU-R and real-time model like Synthetic Storm Technique (SST) are presented in details. The different mitigation techniques are introduced and time diversity is discussed thoroughly. Several previous works related with time diversity have also been presented in this chapter.

2.2 RAIN EFFECT

Rain attenuation, caused by scattering and absorption by water droplets, is one amongst the foremost elementary limitations to the performance of satellite communication links within the microwave region, inflicting giant variations within the received signal power with very little sure thing and lots of abrupt changes. The prevailing propagation impairment at radio frequencies higher than 10 GHz is that the rain attenuation and this can be even a lot of obvious within the tropical regions (Mandeep et al, 2006). There are several factors like frequency, elevation angle, polarization angle, rain intensity, driblet size distribution and driblet temperature that directly contributed to rain attenuation.

There are many prediction models accustomed estimate the rain attenuation. Most of those models are supported applied mathematics information of rain rate like ITU-R model, Crane model and Garcia-Lopez model. The Synthetic Storm Technique (SST) may be a technique which might rework a precipitation rate statistic directly into a rain attenuation statistic. The SST is one amongst the most effective dependable techniques to estimate rain attenuation statistic.

2.3 RAIN ATTENUATION PREDICTION MODEL

Rain attenuation prediction models have been discussed here. There are two rain attenuation prediction models are presented that have performed well for many diverse regions and types of rain: the ITU-R Rain Attenuation Prediction Model and SST (Synthetic Storm Technique). The ITU-R model is semi-empirical in nature and this is based on the relationship relating the specific attenuation $\gamma = aR^b$ (dB/km) to the rain rate R (mm/hr) through the parameters a and b. The SST is a technique which can convert a rainfall rate time series directly into a rain attenuation time series.

2.3.1 Statistical Model: ITU-R

The model differs in the method used to convert the specific attenuation to total attenuation over the path of the rain. There are 3 commercial frequencies band that has been used for this chapter. These are Ku-Band (12 GHz), Ka-Band (20GHz) and V-Band (40GHz). It has been analyzed about the effect of polarization on attenuation for every frequency band. There are 3 polarizations which are vertical, horizontal and circular polarization. The most commonly implemented model from the international propagation community is the ITU-R rain attenuation model. The model was first admitted internationally in 1982 and is continuously updated.

The input parameters are required for the ITU-R Rain Model are the frequency of operation, in GHz, the elevation angle to the satellite, in degrees, the latitude of the ground station, in degrees N or S and the altitude of the ground station above sea level, in km (ITU-R P.618-13, 12/2017). In order to obtain the rainfall rate, $R_{0.01}$, exceeded in 0.01% of an average year, it can be obtained from the map of rainfall rate given recommendation ITU-R P.837 (Fig.1 in Appendix) (ITU-R P.837-7, 06/2017). To obtain the specific attenuation, γ_R using the frequency-dependent coefficients (K and α, these parameters are dependent on frequency, rain temperature, rain drop size distribution, and polarization) given in Recommendation ITU-R P.838 (ITU-R P.838-3, 2005) and γ_R can be determined by

$$\gamma = K\,(R_{0.01})^{\alpha} \qquad (2.1)$$

In order to predict attenuation exceeded in 0.01% of an average year, the following formula is used:

$$A_{0.01} = \gamma_R L_E \quad (L_E \text{ is effective path length}) \qquad (2.2)$$

$$\text{Where } L_E = L_R V_{0.01} \qquad (2.3)$$

To calculate the vertical adjustment factor, V0.01 for 0.01% of the time:

$$\xi = \tan^{-1}\left(\frac{h_R - h_S}{L_G r_{0.01}}\right) \quad (h_R \text{ is the height of the rain}) \qquad (2.4)$$

Mean rain height above mean sea level, h_r can be obtained from 0° isotherm h_0 is given:

$$h_r = h_0 + 0.36 \text{ km}$$

Where slant path is expressed in km is determined from

$$L_S = \frac{(h_R - h_S)}{\sin\theta} \quad \text{for } \theta \geq 5° \qquad (2.5)$$

Where h_s is the altitude from the receiver site of the sea level and θ is the elevation angle. The horizontal projection of L_G of the slant path length is calculated:

$$L_G = L_S \cos\theta \qquad (2.6)$$

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G \gamma_R}{f}} - 0.38(1 - e^{-2L_G})} \qquad (2.7)$$

For ζ >θ, $L_R = \frac{L_G r_{0.01}}{\cos\theta}$ km

Else, $L_R = \frac{h_R - h_S}{\sin\theta}$ km

If $|\varphi| < 36°, x = 36° - |\varphi|$ degrees

Else x=0

$$V_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{\frac{-1}{1+x}}\right)\frac{\sqrt{L_R \gamma_R}}{f^2} - 0.45\right)} \quad (2.8)$$

φ is the latitude of the earth station (Degrees)

Estimated attenuation to be exceeded for other percentages of an average year in the range 0.001% to 5%, is determined from the attenuation to be exceeded

If p≥ 1% or $|\varphi|$≥ 36° β = 0

If p<1% or $|\varphi|$ <36° and θ≥25° β = - 0.005($|\varphi| - 36°$)

Otherwise β = - 0.005(|φ|-36°) + 1.8- 4.25sin θ

$$A_P = A_{0.01}\left(\frac{P}{0.01}\right)^{-(0.665+0.033\ln(P)-0.045\ln(A_{0.01})-\beta(1-P)\sin\theta)} \quad (2.9)$$

A new rain attenuation prediction model tropical region was proposed by (Badron,)

as shown in equation (2.10).

$$A_P\ (new) = A_{0.01} * \left(\frac{P}{0.01}\right)^{-(0.665+0.033\ln(P)-0.045\ln(A_{0.01})-\beta(1-P)\sin\theta)} + C \quad (2.10)$$

The multiplication sign (*) is used to distinguish this model from ITU-R model. Since this model was developed using tropical measurement. Therefore, the correction factor C was added to the equation. C is calculated using the regression analysis for the local measurements of rain height, rainfall rate and specific attenuation(Badron et al., 2011)which is shown in equation of 2.10.

2.3.2 Synthetic Storm Technique (SST)

A summary of the fundamentals of the SST as developed by Matricciani, (2006) is converting a rain rate time series, which is measured using a rain gauge at a point for 1 minute and the average value is taken, to a rain rate space series along a line, using an estimate of the storm translation speed v to transform time to distance. Mathematically, this is carried out by convolution. The SST is used to generate reliable rain attenuation time series by converting a rain rate time-series at any frequency and polarization for any slant path above approximately 10°, as long as the hypothesis of isotropy of the rainfall spatial field holds, in the long term. The SST is also called physical-mathematical radio propagation method.

This process requires knowledge about the length of the signal path through the rain cell, the rain cell velocity and the rain rate at the site under investing (E Matricciani, 2006)as well as (Kanellopoulos et al., 2006) stated that the Synthetic Storm Technique can be used to generate rain attenuation time series to slant paths of very low elevation angle with caution and a number of restraints. As a result, the SST is one of the most reliable methods to estimate rain attenuation time series and consequently long-term rain attenuation expedience probability, diurnal statistics and service-oriented statistics (Kanellopoulos et al., 2006).The SST is very useful for designing communications satellite systems and improves its performance (Matricciani et al., 2006). Sánchez-Lago et al., 2007 referred to use of the SST model to generate time-series of signal attenuation on satellite links in system simulation studies is quite safely