

LONG-TERM RAIN ATTENUATION PROBABILITY AND SITE DIVERSITY  
GAIN PREDICTION FORMULAS

KUSAY FAISAL A. AL-TABATABAIE

A thesis submitted in partly fulfillment of the requirements for the word of the  
degree of Master of Engineering (Electrical)

Faculty of Electrical Engineering  
Universiti Teknologi Malaysia

MAY 2007

DEDICATIONS

To

My beloved parents and brothers for their unwavering  
love, sacrifice and inspiration.

## ACKNOWLEDGEMENTS

First and foremost, I would like to express my utmost gratitude to my supervisor, Associate Professor Dr. Jafri bin Din for being a dedicated mentor as well as for his valuable and constructive suggestions that enabled this project to run smoothly.

Also, not forgetting my friends and classmates, I convey my full appreciation for their on-going support and contributions toward this project, whether directly or indirectly.

Last but not least, I am forever indebted to all my family members for their constant support throughout the entire duration of this project. Their words of encouragement never failed to keep me going even through the hardest of times and it is here that I express my sincerest gratitude to them.

## **ABSTRACT**

The increasing growth of wireless communication systems has caused the usage of higher frequencies in order to have wider bands. However the increase of frequency will lead to the degradation of satellite communication performance. Rain attenuation is one of the most fundamental reasons of the degrading quality of services. Thus fade mitigation techniques will be used in order to compensate for excessive attenuation such as diversity protection schemes, power control and adaptive processing techniques. Among these techniques the most efficient is site diversity (SD). The aim of this project is to determine the effect of SD under the rain conditions, combine both categories for the estimation of slant path rain attenuation and SD gain. It includes the designing of algorithm flow which incorporated into MATLAB programming software. Also, the SD gain calculation in Skudai – Malaysia is included too. It is hoped that with the availability of data, the design process of fade mitigation techniques is greatly simplified. The ITU-R study Group 3 database is used in this project.

## ABSTRAK

Pembangunan dalam teknologi sistem komunikasi tanpa talian telah menyebabkan penggunaan frekuensi yang lebih tinggi supaya lebar jalur yang lebih besar dapat diperolehi. Namun demikian, peningkatan frekuensi ini telah membawa kepada kemerosotan dalam prestasi komunikasi satelit. Pengecilan hujan merupakan salah satu faktor terpenting yang mengakibatkan berlakunya fenomena ini. Justeru itu, teknik mitigasi pemudaran seperti skema perlindungan kepelbagaian, kawalan kuasa, dan teknik pemprosesan penyesuaian digunakan untuk mengimbangi kelemahan tersebut. Di antara teknik-teknik tersebut, teknik yang paling berkesan adalah kepelbagaian tempat (SD). Objektif utama projek ini adalah untuk menentukan kesan SD dalam keadaan hujan, menggabungkan kedua-dua kategori untuk penganggaran pengecilan hujan laluan condong dan penggandaan SD. Ini termasuklah mereka aliran algoritma yang dimasukkan ke dalam perisian program MATLAB. Pengiraan peningkatan SD juga dilakukan di Skudai, Malaysia. Dengan tersedianya data tersebut, proses mereka teknik mitigasi pemudaran belaku dengan lebih mudah. Pangkalan data kajian kumpulan 3 ITU-R digunakan dalam projek ini.

**TABLE OF CONTENTS**

| <b>CHAPTER</b> | <b>SUBJECT</b>        | <b>PAGE</b> |
|----------------|-----------------------|-------------|
|                | DECLARATIONS          | iii         |
|                | DEDICATIONS           | iv          |
|                | ACKNOWLEDGEMENTS      | v           |
|                | ABSTRACT              | vi          |
|                | ABSTRAK               | vii         |
|                | TABLE OF CONTENTS     | viii        |
|                | LIST OF TABLES        | xii         |
|                | LIST OF FIGURES       | xiii        |
|                | LIST OF SYMBOLS       | xv          |
|                | LIST OF ABBREVIATIONS | xvii        |
|                | LIST OF APPENDICES    | xix         |
| <b>1.</b>      | <b>INTRODUCTION</b>   | <b>1</b>    |
|                | 1.1 Introduction      | 1           |
|                | 1.2 Problem Statement | 2           |
|                | 1.3 Objective         | 3           |
|                | 1.4 Scope of work     | 3           |
|                | 1.5 Methodology       | 4           |
|                | 1.6 Thesis Outline    | 6           |

|           |   |           |
|-----------|---|-----------|
|           | <b>SATELLITE COMMUNICATION AND RAIN</b>       |           |
| <b>2.</b> | <b>ATTENUATION EFFECT</b>                     | <b>7</b>  |
| 2.1       | Introduction                                  | 7         |
| 2.2       | Satellite Communications                      | 8         |
| 2.3       | Satellite System Fundamentals                 | 9         |
| 2.4       | Frequency Spectrum                            | 9         |
| 2.5       | Rainfall Impact on Satellite Link             | 10        |
| 2.6       | Rainfall Structure and Types                  | 12        |
| 2.6.1     | Principal Sources of Rainfall Data            | 13        |
| 2.6.2     | Malaysia Climate and Rainfall Distribution    | 13        |
| 2.6.2.1   | ITU-R Rainfall Rate Model                     | 14        |
| 2.7       | Rain Vertical Profile                         | 15        |
| 2.8       | Development of Rain Attenuation Studies       | 15        |
| 2.9       | Specific Attenuation                          | 20        |
| 2.9.1     | ITU-R Model for Specific Attenuation          | 21        |
| 2.10      | Effective Path Length                         | 22        |
| 2.10.1    | Effective Terrestrial Path                    | 23        |
| 2.10.2    | Slant path prediction models                  | 24        |
| 2.10.2.1  | ITU-R prediction model                        | 24        |
| 2.11      | Summery                                       | 27        |
| <b>3.</b> | <b>Fading duration effect</b>                 | <b>28</b> |
| 3.1       | Introduction                                  | 28        |
| 3.2       | Fade Durations in Tropical Climates           | 30        |
| 3.3       | Number of Events and Fade Duration Statistics | 30        |
| 3.4       | Fade Duration Modeling                        | 31        |
| 3.5       | Importance of Fade Duration Information       | 34        |
| 3.6       | Overview of Fade Mitigation Technique         | 35        |
| 3.6.1     | Power Control                                 | 36        |

|           |  |           |
|-----------|--|-----------|
| 3.6.2     | Adaptive Waveform                                      | 36        |
| 3.6.3     | Diversity  | 37        |
| 3.7       | Accumulative Distribution Functions                    | 37        |
| 3.8       | Summery  | 38        |
| <b>4.</b> | <b>SITE DIVERSITY EQUATIONS</b>                        | <b>39</b> |
| 4.1       | Introduction   | 39        |
| 4.2       | Diversity improvement factor                           | 40        |
| 4.3       | Site Diversity Attenuation                             | 41        |
| 4.3.1     | Single site attenuation                                | 41        |
| 4.3.2     | Diversity time percentages                             | 41        |
| 4.4       | Site Diversity Gain                                    | 42        |
| 4.5       | Summery  | 44        |
| <b>5.</b> | <b>THE METHODOLOGY AND RESULTS</b>                     | <b>45</b> |
| 5.1       | Introduction   | 45        |
| 5.2       | The overall Project Methodology                        | 46        |
| 5.3       | ITU-R Study group Three Data Bank                      | 47        |
| 5.4       | Rainfall rate data                                     | 48        |
| 5.4.1     | Rainfall Rate Data at UTM-Skudai site                  | 48        |
| 5.4.2     | Rainfall Rate Data Various Locations in<br>Malaysia    | 50        |
| 5.5       | Slant Path Calculations                                | 51        |
| 5.6       | Attenuation versos single site time percentage         | 53        |
| 5.7       | Fade duration statistics calculations                  | 56        |
| 5.7.1     | Data Collection  | 57        |
| 5.7.2     | Designing the Algorithm Flow                           | 57        |
| 5.7.3     | The Program Development for Fade Duration<br>Statistic | 59        |



|           |  |           |
|-----------|--|-----------|
| 5.7.3.1   | Loading the data into MATLAB   | 59        |
|           | 5.7.3.1.1 Sub-Program in MATLAB  | 60        |
| 5.7.3.2   | Conversion of Voltage to dBm   | 61        |
|           | 5.7.3.2.1 Sub-Program in MATLAB  | 62        |
| 5.7.3.3   | Analyzing the Database   | 62        |
|           | 5.7.3.3.1 Sub-Program in MATLAB  | 63        |
| 5.7.3.4   | Obtaining the Fade Duration  | 63        |
| 5.7.3.5   | Compiling the Number of Fade<br>Events                                 | 66        |
|           | 5.7.3.5.1 Sub-Program of MATLAB  | 67        |
|           | 5.7.3.5.2 Graph of Number of<br>Events and fade duration<br>statistics | 68        |
| 5.7.3.6   | Comparison of the ITU-R model and<br>the obtain result                 | 70        |
| 5.8       | Attenuation versos diversity time percentage                           | 71        |
| 5.9       | Site Diversity Gain  | 75        |
| 5.9.1     | Without diversity at A0.01   | 75        |
| 5.9.2     | With 10 Km distance diversity at A0.01                                 | 75        |
| 5.10      | Summary  | 76        |
| <b>6.</b> | <b>CONCLUSION AND RECOMMENDATIONS</b>                                  | <b>77</b> |
| 6.1       | Conclusion   | 77        |
| 6.2       | Future of work and recommendations                                     | 79        |
|           | REFERENCES   | 81        |
|           | APPENDICES A – X   | 85        |

## LIST OF TABLES

| <b>TABLE</b> | <b>TITLE</b>   | <b>PAGE</b> |
|--------------|--|-------------|
| 2.1          | Satellite frequency spectrum   | 10          |
| 2.2          | ITU-R Annual rain rate cumulative distributions for region P   | 15          |
| 3.1          | 38 GHz Links Under Examination in the MilliProp Countries  | 38          |
| 5.1          | Rainfall measurement specifications at UTM-Skudai  | 49          |
| 5.2          | The average one year cumulative distribution at UTM-Skudai   | 50          |
| 5.3          | Rainfall measurements at various sites at Malaysia   | 51          |
| 5.4          | The specific rain and reduction factor results according to ITU-R data for MEASAT1 at 12 GHz                                 | 52          |
| 5.5          | The specific rain and reduction factor results according to experimental data for MEASAT1 at 12 GHz                          | 53          |
| 5.6          | The estimated attenuation to be exceeded for percentage of an average year for Skudai according to ITUR                      | 54          |
| 5.7          | The estimated attenuation to be exceeded for percentage of an average year for Johor Bahru according to ITUR                 | 54          |
| 5.8          | The estimated attenuation to be exceeded for percentage of an average year for Skudai according to data collected in WCC     | 55          |
| 5.9          | The Investigated 38 GHz Links Connected to Measuring Nodes Located in WCC, UTM, Malaysia                                     | 57          |
| 5.10         | Example of Converting Time Given to Accumulate Time  | 63          |
| 5.11         | Average Fade Durations   | 65          |
| 5.12         | Number of Fade Events Exceeding Duration Thresholds  | 68          |
| 5.13         | Percentage of time for two sites (P2) in Horizontal with different distance for Skudai experimental using diversity formulas | 72          |

## LIST OF FIGURES

| FIGURE | TITLE  | PAGE |
|--------|--|------|
| 1.1    | The methodology diagram of overall project   | 4    |
| 2.1    | Hydrometeor effects over the satellite path  | 11   |
| 2.2    | The climatic zones and rainfall rate (ITU-R, 1997)   | 14   |
| 2.3    | The three rain height terms  | 16   |
| 2.4    | Volume of spherical, uniformly distributed Raindrops   | 18   |
| 2.5    | Shows this phenomenon using the three drop size  | 20   |
| 2.6    | Shows this phenomenon using the three drop size distributions  | 25   |
| 3.1    | Features characterizing the dynamics of fade events  | 29   |
| 3.2    | Fade Duration on Link HU01 2004  | 31   |
| 3.3    | Graph of Probability of Fade Events versus Duration  | 33   |
| 3.4    | Graph of Fraction of Time versus Duration  | 33   |
| 4.1    | Two earth terminals to provide path diversity  | 40   |
| 4.2    | Geometrical configuration of a site diversity scheme   | 44   |
| 5.1    | Screen shoot of the user graphical interface window of DBSG5.exe program   | 45   |
| 5.2    | The rainfall and rain attention data conducted at UTM companied using computer program                                     | 49   |
| 5.3    | Several years measurement of rainfall rate at UTM-Skudai   | 50   |
| 5.4    | Cumulative distribution for horizontal coefficient at 12GHz  | 55   |
| 5.5    | Cumulative distribution for vertical coefficient at 12GHz  | 56   |
| 5.6    | Ericsson Microwave Link at 38 GHz in Wireless Communication Centre (WCC) University Technology of Malaysia M. Karim (2000) | 57   |

|      |   |    |
|------|---|----|
| 5.7  | Example of Data Collected   | 60 |
| 5.8  | Graph of dBm versus Voltage   | 61 |
| 5.9  | Graph of Attenuation Threshold (dB) versus Time (hour)  | 62 |
| 5.10 | Illustration for Lagrange Method  | 64 |
| 5.11 | Graph Model of Number of Events above a Given Attenuation Threshold and Longer than a Given Fade Duration   | 65 |
| 5.12 | Illustration of How the Number of Events Longer than a Given Fade Duration is Compiled  | 66 |
| 5.13 | Graph of Number of Events above a Given Attenuation Threshold and Longer than a Given Fade Duration   | 69 |
| 5.14 | Comparison of Fade Duration Statistics for Obtained Results and Model   | 70 |
| 5.15 | Relationship between percentages of time with and without diversity for the same attenuation according to improvement factor formula                        | 71 |
| 5.16 | The relationship between attenuation and percentage of time for two sites in different distance according to improvement factor and site diversity formulas | 73 |
| 5.17 | An practical example for Cumulative distribution at 11.198 GHz  | 74 |

## LIST OF SYMBOLS

|             |  |
|-------------|--|
| $A$         | Attenuation  |
| $A_{0.01}$  | Attenuation at 0.01% of time                                   |
| $A_m$       | Measured attenuation   |
| $A_p$       | Predicted attenuation  |
| dB          | Decibel unite  |
| $d$         | Separation (km) between the two sites                          |
| $f$         | Frequency  |
| GHz         | Giga Hertz   |
| $h_o$       | Rain freezing height   |
| $H_R$       | Rain height (km)   |
| $H_s$       | Height above mean sea level of the earth station (km).         |
| $k, \alpha$ | Regression coefficients  |
| km          | Kilometer  |
| $L_{eff}$   | Effective Path length  |
| LG          | Horizontal projection of the slant path                        |
| $L_o$       | Rain cell diameter   |
| L           | path length  |
| m           | Meter  |
| $mm$        | Millimeter   |
| $P$         | Probability  |
| P (%)       | Percentage in time of the year                                 |
| P1          | percentages of time for an average year with no site diversity |
| P2          | percentages of time for an average year with site diversity    |
| $R_{(p)}$   | Rain rate at percentage in time of the year                    |
| $r(P)$      | Horizontal reduction factor of percentage in time of the year  |
| $r_{0.01}$  | Horizontal reduction factor for 0.01% time of the year         |
| $R_{0.01}$  | Rain rate at 0.01% of time of the year                         |
| $v_{0.01}$  | Vertical reduction factor for 0.01% time of the year           |
| $\gamma_R$  | Specific attenuation   |

|          |                               |
|----------|-------------------------------|
| $\theta$ | Elevation Angle               |
| $\psi$   | baseline-dependent angle      |
| $\Phi$   | Latitude of the earth station |

## LIST OF ABBREVIATIONS

|            |  |
|------------|--|
| AC         | Adaptive Coding  |
| AGCV       | Automatic Gain Control Voltage                           |
| AM         | Adaptive Modulation                                      |
| C          | Centigrade   |
| dB         | Decibel  |
| dBm        | Decibel mili watt  |
| DBSG5      | ITU-R Study Group Three Data Bank                        |
| DDR        | Data Rate Reduction                                      |
| DLPC       | Down-Link Power Control                                  |
| DTH        | Direct to Home   |
| EEPC       | End-to-End Power Control                                 |
| EHF        | Extremely High Frequency                                 |
| EIRP       | Effective Isotropic Radiating Power                      |
| FMT        | Fade Mitigation Technique                                |
| FSS        | Fixed Satellite Service                                  |
| $G_d$      | gain contributed by the spatial separation               |
| GEO        | Geosynchronous Earth Orbit                               |
| $G_f$      | frequency gain   |
| GHz        | Giga Hertz   |
| $G_{SD}$   | site diversity gain                                      |
| GUI        | Graphical User Interface                                 |
| $G_\theta$ | gain term dependent on elevation angle                   |
| $G_\psi$   | baseline-dependent gain                                  |
| IEEE       | Institute of Electrical and Electronic Engineering       |
| ITU-R      | International Telecommunication Union Radio-Broadcasting |
| LEO        | Low Earth Orbit  |
| MEO        | Medium Earth Orbit                                       |

|      |                                     |
|------|-------------------------------------|
| mm/h | milimetre per hour                  |
| MMS  | Malaysia Metrological Services      |
| OBBS | On-Board Beam Shaping               |
| RF   | Radio Frequency                     |
| RMS  | Root Mean Square                    |
| S    | second                              |
| SD   | Site Diversity                      |
| SHF  | Super High Frequency                |
| TRMM | Tropical Rainfall Measuring Mission |
| ULPC | Uplink Power Control                |
| U.S  | United State of America             |
| UTM  | Universiti Teknologi Malaysia       |
| VSAT | Very Small Aperture Terminal        |



**LIST OF APPENDICES**

| <b>APPENDIX</b>   | <b>TITLE</b>   |
|-------------------|--|
| <b>Appendix A</b> | Rain station with mean annual rainfall in Malaysia                               |
| <b>Appendix B</b> | The ITU-R specific attenuation parameters<br>(ITU-R, P. 838-3)                   |
| <b>Appendix C</b> | The experimental specific attenuation parameters<br>UTM-Skudai. Feb 2001-Feb2002 |
| <b>Appendix D</b> | MATLAB Program for rain fall rate.   |
| <b>Appendix E</b> | MATLAB Program for effective horizontal path.                                    |
| <b>Appendix F</b> | Flow Chart to Calculate the Time   |
| <b>Appendix G</b> | Flow Chart to Calculate the Fade Duration  |
| <b>Appendix H</b> | Flow Charts to compile the Number of Events above a<br>Given Duration            |
| <b>Appendix I</b> | Sub-Program to Calculate Time  |
| <b>Appendix J</b> | Sub-Program to Obtain the Fade Duration  |
| <b>Appendix K</b> | Sub-Program to Calculate the Number of Fade Events                               |

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

The increasing growth of wireless communication system has caused the usage of higher frequencies in order to have wider band. However the increase of frequency will lead to the degradation of satellite communication performance. To combat rain attenuation, several fade mitigation techniques have been developed the most efficient one is the site diversity (SD) ESA Publication (2002).

Rain attenuation is one of the most fundamental limitations to the performance of satellite communication links, causing large variations in the received signal power. Although a lot of research has been conducted overseas to reduce the effect of rain fading such as investigation in fade duration statistics, these research efforts are really carried out in tropical countries, especially in the frequency 38GHz radio link communication.

Fade duration indicates the time length between two consecutive crossings of the received signal on the same attenuation threshold. This parameter is important for communications systems where length of time is a critical parameter. The fade duration is usually presented as statistics of the number of fade events at a given fade duration which is useful for the design of fade mitigation techniques.

SD (Site Diversity) takes advantage of the spatial characteristics of the rainfall medium by using two earth stations to exploit the fact that the probability of attenuation due to rain occurring simultaneously on the alternative Earth-space paths is significantly less than the relevant probability occurring on either individual path. Though the cost effectiveness of SD remains questionable, the interest on SD has been renewed, due to the significant reduction of ground terminal antennas and other hardware sizes. Nowadays, terminals can be installed in customers' premises and the use of public terrestrial networks to carry out signaling seems possible ESA Publication (2002). Moreover, SD is considered for alternative feeder links of a satellite network.

## **1.2 Problem Statement**

The problem statement of this project is stated in the following points:

- i- The incapability of the published prediction models to be sensitive of the available knowledge of rainfall on Malaysia climate.
- ii- The lakes in the dynamic fade information (fade duration, depth, slop and interfade).
- iii- The lack of satellite propagation studies in Malaysia, especially for higher frequency band.
- iv- A diversity control unit coordinating the signal flow and a signal processing unit must be incorporated at the master and the other earth station, respectively.
- v- There is no previous calculation for diversity gain in Malaysia.

### 1.3 Objective

The objectives of this project is to determine the effects of site diversity under the rain conditions and calculate the diversity gain. will be done by using experimental data as well as ITU-R study group 3 databank, and analyze in an easy to use environment features by using Mat-lab program.

The objective main approach is to enhance the existing satellite services at Ku-band under the rain conditions, study the rain and fade effect on the satellite, then the site diversity and try to get a new parameter for future satellite site diversity systems to get the data from higher frequency band such as Ka-band and above then transfer it to other satellite. The local experimental data will be used as function to enhance the prediction techniques for satellite path instead of using the theoretical models, which mainly based on experimental data of temperate regions.

### 1.4 Scope of work

- Specify rain attenuation data collected from Ericsson Microwave Link in (WCC) at UTM.
- Conversion of the terrestrial rain attenuation data for satellite application.
- Perform the Site Diversity based on available collective data.
- Obtain Similar profile from ITU-R group 3 databank.
- Calculate the fade duration statistics.
- Evaluate the effect of SD and compare it with various SD equations [1].
- Diversity improvement factor and diversity gain calculation.

- Calculate the site diversity gain.

## 1.5 Methodology

The main contribution of this project is to propose of combine the estimation of slant path rain attenuation and SD gain. It includes the designing of algorithm flow which incorporated into MATLAB programming software. It is hoped that with the availability of data, the design process of fade mitigation techniques will be greatly simplified. The ITU-R study Group 3 database will be use.

Therefore, the scope of this project consists of three parts, rain attenuation prediction techniques of slant path and terrestrial path, fade mitigation techniques and site diversity gain. The methodology diagram of overall project is shown in figure 1.1.

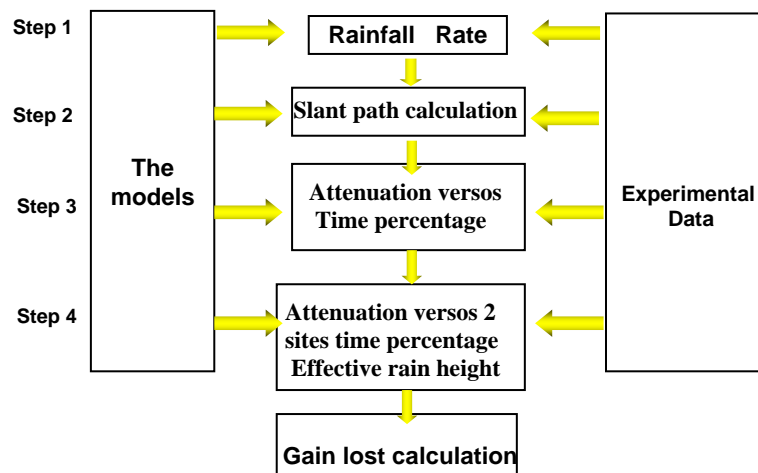


Figure (1.1) Methodology diagram of overall project

**Step 1**

- Depend on the yearly and average one year (between February 2001 and February 2002) UTM skudai data.
- Various locations in Malaysia data and concentrate on Johor.
- Tropical data from international data bank (DBSG5).

**Step 2**

- Calculate the specific attenuation, reduction factor and slant path for effective vertical and horizontal length for the collected data in Skudai.
- Calculate the vertical and horizontal slant path by using ITUR data for Skudai and Johor baharu.
- Simulate the slant paths calculated data against different time percentage for vertical and horizontal data.

**Step 3**

- Calculate and simulate the relationship between percentages of time with and without diversity for the same attenuation according to improvement factor formula.

**Step 4**

- Calculate the Fade duration statistics.
- Calculate and simulate the relationship between attenuation and percentage of time for two sites in different distance depending on the improvement factor table, fade duration statistics and site diversity formula.

**Step 5**

- Calculate the gain lost from the formula :

$$G = G_d \cdot G_f \cdot G_\theta \cdot G_\psi \quad \text{dB}$$

## 1.6 Thesis Outline

Chapter 1: Consists of introduction of the project. The objectives of the project are clearly phased with detailed. The research scope and methodology background are also presented.

Chapter 2: Included introduction to the satellite communication, begins with an overview of propagation effects. Explain brief details about Malaysia climate characteristic. Rainfall distribution and rain vertical profile structure characteristics and its type also presented.

Chapter 3: include fade Durations in tropical climates, explained about fade duration modeling, overviewed of fade mitigation technique and explained accumulative distribution functions.

Chapter 4: Present site diversity and site diversity gain equations.

Chapter 5: Methodology and resents the results, analysis and discussion for the simulation program, the calculation of the attenuation, fade duration statistics, site diversity and site diversity gain calculations.

Chapter 6: Concludes the thesis. The conclusion is given based on the analysis of results from the previous chapter. Recommendations for future works are also presented.