RADIO PROPAGATION STUDIES AT 5.8GHZ WITHIN VEGETATED ENVIRONMENT FOR POINT-TO-MULTIPOINT APPLICATIONS

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To my family

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ABSTRACT

This thesis presents an empirical study for fixed wireless links based on IEEE802.16 standard in vegetated residential environment. Simulation and field measurements were conducted for suburban microcell channel by utilising 5.8 GHz of Unlicensed National Information Infrastructure (UNII). A set of comprehensive measurement that covered 13 point-to-multipoint links surrounding Universiti Teknologi Malaysia were selected to investigate the impact of vegetation on propagating radio waves. The aim of this study is to develop a path loss model that incorporates vegetation effect. Received Signal Strength (RSS), Signal-to-Noise Ratio (SNR) and factors influencing performance of the signal strength are highlighted here. Performance of RSS during daytime and night is also evaluated. The accuracy of proposed prediction model is analysed which quantifies that path loss is proportional to the distance of tree to the receiver, size, density and number of trees within the vicinity of transmitting and receiving antennas. Observation found that terrain and external effect, such as wind will significantly affect the signal performance too. Depending on the dynamic characteristics of trees presence between the communication links, the measurement results show that the path loss is increased from 5.69 dB to 33.67 dB. The results obtained are compared to Free Space Loss model, Weissberger model, and ITU-R model. Those established models are used to validate the applicability result obtained by means of Root Mean Square Error (RMSE). In view of this research work, a good agreement of the proposed excess loss model achieves the smallest RMSE for links obstructed by a single tree, row of trees, row of trees and road as well as row of trees, road and building.

ABSTRAK

Tesis ini menerangkan kajian penyelidikan rangkaian talian tanpa wayar tetap berdasarkan piawaian IEEE802.16 di kawasan kediaman yang dikelilingi pokok. Kajian yang melibatkan simulasi dan eksperimen telah dijalankan di kawasan luar bandar pada frekuensi 5.8GHz *'Unlicensed National Information Infrastructure.'* Kajian menyeluruh telah dilakukan di 13 point-ke-multipoint *link* sekitar Universiti Teknologi Malaysia bagi mengkaji kesan pokok ke atas gelombang radio. Objektif kajian adalah untuk menghasilkan model empirik yang mengambil kira kesan pokok kepada isyarat radio. Kekuatan isyarat radio, nisbah *signal-to-noise* dan faktor yang mempengaruhi perubahan kekuatan isyarat radio turut dianalisa. Perbandingan kekuatan isyarat radio pada waktu siang dan malam turut dibentangkan. Dari analisis yang dijalankan, kekuatan isyarat radio bergantung kepada jarak antara pokok dan antena, saiz, kerimbunan pokok dan jumlah pokok di antara pemancar dan penerima. Cerun dan faktor luar seperti angin turut mempengaruhi kualiti gelombang radio. Analisa menunjukkan kehilangan isyarat meningkat dari 5.69dB kepada 33.67dB bergantung kepada ciri dinamik pokok di antara pemancar dan penerima. Model empirik ini dibandingkan dengan *Free Space* model, Weissberger model dan ITU-R model untuk tujuan pengesahan keputusan yang diperoleh. Berdasarkan perbandingan mengunakan *Root Mean Square Error* (RMSE), didapati model yang dihasilkan mempunyai nilai sisihan yang terkecil untuk semua *link* yang dikaji merangkumi *link* yang dihalang oleh sebatang pokok, beberapa pokok, beberapa pokok dan jalan, juga beberapa pokok, jalan dan bangunan.

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LIST OF ABBREVIATIANS

EIRP	-	Effective Isotropic radiated Power
FWA	-	Fixed Wireless Access
IEEE	-	Institute of Electrical and Electronics Engineer
LAN	-	Local Area Network
LOS	-	Line-of-Sight
MAN	-	Metropolitan Area Network
NLOS	-	Non Line-of-Sight
RSSI	-	Received Signal Strength Indicator
SNR	-	Signal-to-Noise ratio
UNII	-	Unlicensed National Information Infrastructure
WiFi	-	Wireless Fidelity
WiMAX	-	Wireless Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

F_N	-	Fresnel zone radius
λ	-	Wavelength
d_1	-	Distance from one end terminal to point where F_n is being determined
d_2	-	Distance from the other end terminal to point where F_n is being determined
c	-	Speed of electromagnetic propagation
f	-	Frequency
F_1	-	First Fresnel zone
d	-	Length of the link in kilometers
PL_{dB}	-	Path loss
P_T	-	Transmitted power
P_R	-	Receiver power
G_T	-	Transmitter antenna gain
G_R	-	Receiver antenna gain
L	-	Total loss
L_{FSL}	-	Free space loss
L_{EXCESS}	-	Excess loss due to Vegetation
$PL_{(R0)}$	-	Path loss at reference distance R_0
R_0	-	Reference distance
R	-	Distance between receiver and transmitter

n	-	Path loss exponent
μ	-	Mean of random variable r
σ	-	Standard deviation of random variable r
σ^2	-	Time-average power of the received signal before envelope detection
r	-	Received signal envelope
ϑ	-	Variance of either real or imaginary terms of random multipath component
I_0	-	Modified Bessel function
A	-	Amplitude of dominant component
m	-	Shape parameter
Ω	-	Scale parameter
Γ	-	Gamma function
Am	-	Maximum attenuation for one terminal within a specific type and depth of vegetation in dB
γ	-	Specific attenuation for every short vegetation paths in dB/m
$Erms$	-	Root mean square error

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Emergence of interactive multimedia communication tools have led to a dramatic increase of interest on wireless communication technology during the last few years. Recent study conducted by Burson-Marsteller (2011) revealed that demand for wireless communication is constantly growing to provide network access which was previously dominated by wired communications. To cater large number of user and concurrently sustaining the scarcity of spectrum utilization, an accurate prediction model for reliable radio communication infrastructure is essential. This chapter briefly describes the development and application of fixed wireless access, as well as the research background, objective, scope and thesis outline. The subsequent chapters detailed out the research work conducted.

1.2 Development of Broadband Wireless Access

Fixed Wireless Access (FWA) refers to a range of radio system, used primarily to support various applications including data, voice and video services to multiple users within a radio coverage area. Instead of cables, radio link is used to convey fast broadband services between user and core networks. Rates for internet access will likely become cheaper due to lesser need to extend the cables for each subscriber and less number of access points. In fact, FWA has become a viable solution owing to its' convenience, flexibility and cost effectiveness.

Most of the FWA systems are deployed in millimeter-wave range as it offers large availability of bandwidth and high frequency reusability (Lacan & McBride, 2009). By leveraging the advanced of antenna innovation and smaller electronics components, large number of user can afford to use the technology in microcell systems.

The convergence of WiFi and WiMAX has contributed to an explosive growth of FWA systems. Integration of IEEE802.11 and IEEE802.16 for WiFi and WiMAX provided a complete suite of broadband services in large scale area (Finneran, 2004). WiMAX provides the ability to expand broadband services by offering coverage not in WiFi hotspots (Motorola & Intel, 2007). Synergy of both technologies also improved quality of signal received.

In terms of deployment perspective, both standards were designed for completely different applications. IEEE 802.11 was intended to add mobility to local area networks (LAN) while, IEEE 802.16 is designed to provide a basis for a carrier-provided to metropolitan access networks (MAN), wireless local area networks

(WLAN) and cellular mobile networks (Kowal, Kubal, Piotrowski, & Zielinski, 2010). However, some elementary technical characteristics are common such as spectrum shared between 802.16 and 802.11a at 5.8GHz as defined by Institute of Electrical and Electronics Engineers (2003).

Unlicensed National Information Infrastructure (UNII) is part of radio frequency spectrum used for WLAN based on IEEE 802.11standards. WLAN operates in two frequency bands which are 2.4GHz and 5.8GHz. IEEE802.11b and IEEE802.11g standards govern for 2.4GHz whereas IEEE802.11a is specifically used for 5.8GHz (Dean, 2010). In Malaysia, upper UNII band which ranges from 5.75GHz to 5.875GHz is particularly used for FWA, mobile, radiolocation and amateur radio application (MCMC, 2009).

The evolution of broadband wireless specifically IEEE 802.16 standard was successfully initiated around year 2000. Several standards were revised through four phases. They are narrowband wireless local-loop systems, first generation line-of-sight (LOS) broadband systems, second generation non-line-of-sight (NLOS) broadband systems and standards-based broadband wireless systems to enable specific scenarios in both licensed and unlicensed frequencies (Andrews, Ghosh, & Muhamed, 2007).

Continued development of wireless technology based on IEEE802.16 and IEEE802.11 are likely to address connection challenges between suburban environment and wireless network. Therefore, to design a high performance FWA system, it is imperative that a detailed understanding of radio propagation mechanisms is achieved.

1.3 Application of Fixed Wireless Access

FWA is generally used for fast Internet access which provides businesses and residential user reliable and uninterrupted Internet access without the need to dial up each time a connection is required. It also offers potential for rapid development, backwards-compatibility with older laptop and desktop computer and low router operating power which are usually restricted to 1W, or 1/5000 of cellular telephone tower (Dobkin, 2005).

Application of FWA can be classified as point-to-point and point-to-multipoint. Point-to-point FWA applications enable communication from node to node comprising of a transmitter and a receiver. On the other hand, point-to-multipoint links provide multiple path of transmission from a single location to multiple locations.

A guideline for short range communications device was issued by (Malaysian Communications and Multimedia Commision, 2003) . This framework addressed the use of WLAN equipment for public wireless Internet access. The maximum Effective Isotropic Radiated Power (EIRP) should not exceed the values as specified in Table 1.1 below.

Table 1.1: Guideline for short range communication device

Frequency Band	Maximum EIRP (Watts)	Maximum EIRP (dBm)
2400 MHz to 2500 MHz	0.5	27
5250 MHz to 5350 MHz	1	30
2725 MHz to 5875 MHz	1	30

1.4 Problem Statement

Topographic features on natural elements such as vegetation and terrain has a higher effect as compared to man-made structures such as building and vehicular traffic. Trees which are varied in size, type, geometry, height and density are often planted between buildings. Some of the trees are higher than surrounding building, hence propagation is higher. Over the time, structure of trees might be changed due to growth and potentially block LOS of the communication links. Presence of trees within the first Fresnel zone will consequently degrades the signal strength to a few dB and limits the coverage area. As removing trees is not a practical solution, an accurate prediction model is required.

Numerous propagation studies in vegetated environment have been performed at UHF and VHF frequencies, which revealed that implication of vegetation cannot be neglected at frequency greater than 1GHz (Dias & Assis, 2011; Huang et al., 2006; Meng & Lee, 2010). Through extensive literature review, no satisfactory empirical model can accurately integrate the effect of vegetation in suburban areas, especially for tropical rainforest country. To date, only a few results for the NII band at 5.8GHz were presented, such as work presented by Muhammad, (2012), Pon, Rahman and Abu (2010) and (Karlsson, Schuh, Bergljung, Karlsson, & Lowendahl, 2001).

Therefore, to develop an accurate model which realistically suit Universiti Teknologi Malaysia (UTM) environment, the study is vital. Precise prediction model is imperative to determine link budget requirement, in order to achieve well-structured networks that able to cater large number of users and to optimize the scarcity of frequency in the most efficient manner.

1.5 Research Objectives

The objectives of this research are:

1) To investigate the excess loss caused by vegetation that exists in the vicinity of FWA. Factors leading to degradation of received signal strength are analyzed accordingly.
2) To develop a radio prediction model which account the existence of vegetation between the communications links for suburban areas.
3) To investigate Received Signal Strength (RSS) performance during daytime and night.

1.6 Scope of Research

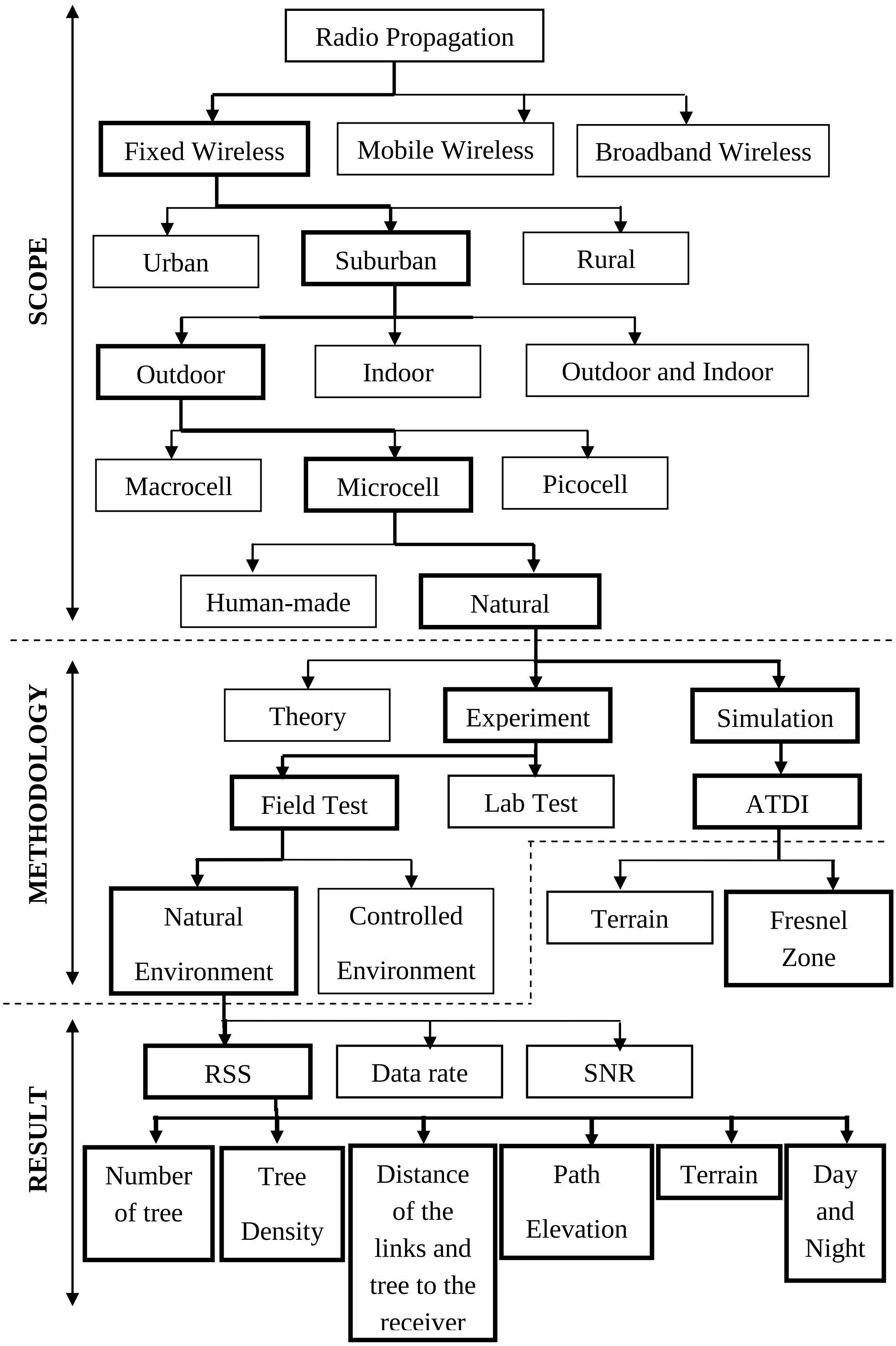
This research investigates the propagation of radio wave under the same weather condition at 5.8GHz. The links represent typical point-to-multipoint links which incorporates a diversity of obstructions due to vegetation which includes single tree, row of trees, row of trees and roads as well as row of trees, buildings and roads. However, weather effects such as rain and fog are not considered in this research as the effect is insignificant at frequency of 5.8GHz as reported in various literature such as (Meng, Lee, & Ng, 2008), (ITU-R P.530-12, 2007) and (Pelet & Wells, 2004).

ATDI simulation and a series of field measurements will be carried out to determine excess loss for 13 WLAN access points in UTM. Terrain effect and Fresnel zone clearance are visualized by means of ATDI simulation. Received signal strength (RSS) and signal-to-noise ratio (SNR) with increasing vegetation depth as well as T-R separation distance are obtained from field measurement. Signal characteristic due to dynamic environmental factor such as day versus night is considered too.

In order to validate the path loss of proposed model, comparison to the established models, which are Free Space Loss model, Weissberger model and ITU-R model are performed with the aid of Root Mean Square Error (RMSE).

Scope, methodology and expected result are graphically presented as shown in Figure 1.1.

Figure 1.1 K-chart



The scope of the research focuses on:

1) Simulation

   ATDI simulation is used to predict first Fresnel zone and RSS of the individual communication link.

2) Field measurement

   The measurement campaign is performed to investigate the average path loss of 13 links in UTM by considering LOS and NLOS links based on IEEE 802.11 WLAN standard at 5.8 GHz.

3) Collection of Data

   Measurement data obtained will be filtered and screened using Textpad. These data are classified into RSS and SNR.

4) Data Analysis

   After filtering the measurement data, RSS obtained from field measurement are illustrated with the aid of Matlab. The average path loss can be determined by using Microsoft Excel. Factors causing signal degradation are identified subsequently.

5) Model Development

   A prediction model that agrees with campus environment based on parameters above will be developed.

6) Model Validation

   The proposed model will be compared to existing vegetation model which are Weissberger model and ITU-R model.

1.7 Thesis Outline

This thesis is structured in the following manner:

Chapter 2 investigates and describes fixed wireless access which provides mechanism on radio propagation and details out the effect of vegetation.

Chapter 3 concisely describes the experimental set-up in UTM. The experiment setup includes measurement procedures and equipments setup to perform the measurement.

Chapter 4 presents the ATDI simulation and empirical results of the measurement campaign. Detailed discussion on results obtained is enclosed.

Chapter 5 contains conclusion and suggestions for future work to be done based on findings presented in Chapter 4.

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