CHANNEL MODELING AND BIT ERROR RATE PERFORMANCE SIMULATION FOR FIXED BROADBAND WIRELESS ACCESS SYSTEM

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requirements for the award of the degree of
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To my beloved father and mother

To my dearest siblings

To my friends

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ABSTRACT

Wireless Local Area Networks (WLANs) have emerged as a powerful architecture capable of supporting the requirements of broadband wireless communications. This research deals with bit error rate (BER) performance simulation of a fixed broadband wireless access (FBWA) system that employs the Institute of Electrical and Electronics Engineers 802.11a WLAN standard at 5.8 GHz band. The specific research site takes place in newly constructed hostels with the transmitting base station at Wireless Communication Center in Universiti Teknologi Malaysia. In order to represent the real working environment when the telecommunication system is analyzed, radio channel characteristic must be modeled. In particular, the BER performance is a basic criterion for evaluating the quality of a digital signal transmission system. Hence, an effective channel model that yields both the predicted delay profile and received signal level at any possible receiver location is developed. Ray tracing propagation prediction that is a promising technique on which location specific models can be based is applied in this research. The prediction results are then enhanced with field measurement at the real environment. A powerful electronic design automation software simulator named Advanced Design System is brought forward for system modeling and performance simulation template development. The modeled transmitter and receiver are tested conforming to the related standards before the system performance is theoretically validated. Simulated BER performances under the modeled channels are found varying from $1.0399X10^{-2}$ until $1.6250X10^{-8}$ at 20dB of energy per bit to noise density (E_b/N_0). The results are unpredictable without the simulations. This signifies the importance of site-specific BER performance simulation for a FBWA system. With the highlighted methodology in this research, it can drastically increase the productivity and effectiveness of the FBWA system planning at any locations.

ABSTRAK

Rangkaian wayerles tempatan (WLANs) merupakan satu senibina yang mampu menampung keperluan komunikasi wayerles berjalur lebar. Penyelidikan ini berkaitan dengan simulasi prestasi kadar bit ralat bagi sistem capaian wayerles berjalur tetap (FBWA) yang menggunakan standard WLAN IEEE 802.11a pada frekuensi 5.8 GHz. Lokasi khusus kajian adalah bangunan asrama baru dengan tapak penghantaran di Wireless Communication Centre, Universiti Teknologi Malaysia. Untuk mendapatkan perwakilan keadaan sekeliling yang tepat semasa sistem telekomunikasi dianalisis, ciri-ciri saluran radio mesti dimodelkan. Hal ini terutamanya berkaitan dengan simulasi kadar bit ralat yang merupakan ukuran dasar yang menilai kualiti sistem penghantaran maklumat digital. Justeru itu, satu permodelan saluran yang mampu memberikan kedua-dua profil kuasa tertangguh dan nilai kuasa diterima di mana-mana lokasi penerima perlu dibangunkan. Ramalan surihan perambatan gelombang yang merupakan satu teknik yang boleh memberi kedua-dua keputusan di mana-mana lokasi diterapkan dalam kajian ini. Keputusan ramalan kemudian diperbaiki dengan ukuran sebenar yang dilakukan pada lokasi-lokasi tersebut. *Advanced Design System* yang merupakan satu perisian simulasi yang memberikan permodelan automatisasi elektronik dikemukan untuk permodelan sistem dan pembagunan model untuk simulasi prestasi. Penghantar dan penerima yang dimodel dikaji selaras dengan standard tertentu sebelum simulasi prestasi sistem disahkan benar secara teori. Prestasi kadar bit ralat yang disimulasikan di bawah saluran-saluran yang dimodel didapati jatuh pada $1.0399X10^{-2}$ hingga $1.6250X10^{-8}$ semasa nisbah tenaga per bit kepada kepadatan gannguan (E_b/N_0) pada 20dB. Keputusan prestasi ini tidak dapat diramalkan tanpa simulasi. Hal ini telah membuktikan betapa pentingnya simulasi prestasi kadar bit ralat pada lokasi tertentu bagi sistem FBWA. Metodologi dalam penyelidikan ini mampu meningkatkan produktiviti dan keberkesanan dalam pembangunan sistem FBWA di mana-mana lokasi.

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1G	-	first generation
2D	-	two-dimensional
2G	-	second generation
3D	-	three-dimensional
3G	-	third generation
3GPP	-	3^{rd} Generation Partnership Project
AC	-	alternating current
ADS	-	Advanced Design System
AM	-	amplitude modulation
AN 50	-	Redline Access Node 50
ANSI	-	American National Standards Institute
ASCII	-	American Standard Code for Information Interchange
AWGN	-	addition white Gaussian noise
AZB	-	Angular Z-Buffer
BER	-	bit error rate
BPSK	-	binary phase shift keying
BWA	-	broadband wireless access
CAD	-	computer aided design
CDMA	-	Code Division Multiple Access
DAB	-	Digital Audio Broadcasting
DSP	-	Digital Signal Processing
DSSS	-	direct sequence spread spectrum
DVB	-	Digital Video Broadcasting
EDGE	-	Enhanced Data rates for GSM Evolution
EIRP	-	effective isotropic radiated power
EVM	-	error vector magnitude

FBWA	-	Fixed Broadband Wireless Access
FCC	-	Federal Communication Commission
FM	-	frequency modulation
FWA	-	fixed wireless access
GBSBM	-	Geometrically Based Single Bounce Macrocell
GO	-	geometrical optics
GTD	-	geometrical theory of diffraction
GUI	-	graphic user interface
HTTP	-	hypertext transfer protocol
I/O	-	input output
ICI	-	intercarrier interference
IDU	-	indoor unit
IEEE	-	Institute of Electrical and Electronics Engineers
IP	-	Internet protocol
ISDN	-	Integrated Services Digital Network
ISI	-	intersymbol interference
ISM	-	industrial, scientific and medical
ITU-R	-	radio communication sector of International Telecommunication Union
LEO	-	Low Earth Orbit
LMDS	-	Local Multipoint Distribution System
LOS	-	line of sight
LS	-	least square
MCMC	-	Malaysian Communications And Multimedia Commission
MMAC	-	Multimedia Mobile Access Communication
MMDS	-	Multipoint Multichannel Distribution Service
M-PSK	-	Mary phase shift keying
NLOS	-	non line of sight
ODU	-	outdoor unit
OFDM	-	Orthogonal Frequency Division Multiplexing
PDF	-	probability density function
PER	-	packet error rate
PHY	-	physical

PSAM	-	pilot symbol assisted modulation
PSDU	-	PHY sublayer service data units
PSTN	-	Public Switch Telephone Network
QAM	-	quadrature amplitude modulation
QPSK	-	quadrature Phase Shift Keying
rms	-	root mean square
SBR	-	shooting and bouncing ray
SER	-	symbol error rate
SNR	-	signal to noise ratio
SUI	-	Standard University Interim
UHF	-	ultra high frequency
UMTS	-	Universal Mobile Telecommunication System
UNII	-	unlicensed national information infrastructure
UTD	-	uniform theory of diffraction
UTM	-	Universiti Teknologi Malaysia
VPL	-	vertical plane launch
WATM	-	Wireless Asynchronous Transfer Mode
WCC	-	Wireless Communication Centre
W-CDMA	-	Wideband CDMA
WLANs	-	Wireless Local Area Networks
WSSUS	-	Wide Sense Stationary-Uncorrelated Scattering
Xdsl	-	Digital Subscriber Line
A	-	peak amplitude of dominant signal
B_N	-	noise bandwidth
$c(t)$	-	fading variation subject to complex Gaussian random process
d	-	distance between transmitter and receiver
d_0	-	close in reference which determined from measurements close to the transmitter
D	-	being the largest dimension of the antennas
dB	-	decibel = 10 $\log_{10}$ (parameter)
dBi	-	decibels over isotropic

dBr	-	dB relative to the maximum spectral density of the signal
E	-	signal energy per symbol
E_b	-	measure of the bit energy
E_b/N_0	-	energy per bit to noise density or noise in a 1 Hz bandwidth
f	-	carrier frequency
G	-	Giga = 10^9 (prefix)
G_A	-	power gain of the transmitting antenna
G_B	-	power gain of the receiving antenna
G_r	-	gain of the receiver
G_t	-	gain of the transmitter
Hz	-	Hertz = 1 cycle per second
K	-	ratio between the deterministic signal power and the variance of the multipath
L_f	-	free space loss
L_p	-	length of the packet
M	-	Mega =10^6 (prefix)
m	-	mili =10^{-3} (prefix)
m	-	meters
Mbits/s	-	Mega bits per second
Mbps	-	Mega bit per second
$m(t)$	-	bit stream
$m_I(t)$	-	in-phase stream
$m_Q(t)$	-	quadrature streams
mW	-	mili Watt
n	-	nano=10^{-9} (prefix)
$n(t)$	-	white gaussian noise
N_0	-	noise density
n	-	path loss exponent
N_f	-	number of frames for the measurement
P_B	-	probability of bit error

P_E	-	probability of symbol error
P_N	-	noise power
P_0	-	average power of the constellation
P_0	-	power accepted by the transmitting antenna
P_r	-	received power
P_t	-	transmitted power
$P(\tau)$	-	relative amplitudes of the multipath components
$Q(x)$	-	complementary error function
$r(t)$	-	received signal
$s_R(t)$	-	received signal after the bandpass filter when a modulated signal is transmitted over a Rayleigh fading channel
T	-	symbol duration
τ	-	time delay during multipath energy falls
$\bar{\tau}$	-	mean excess delay
V	-	voltage
X_σ	-	log-normally distributed random variable
$z(t)$	-	transmitted baseband signal bandlimited by the transmitter and receiver filters
φ	-	spherical polar coordinate; phase angle
σ	-	rms delay spread
$\bar{\sigma}$	-	standard deviation
λ	-	wavelength
ε_r	-	reflection coefficient for a dielectric half space
π	-	phi = 3.141593
θ	-	spherical polar coordinate; inclination angle

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter begins with a brief description of the historic evolution of the wireless communication, starting from the development of the concepts and equipment based on the fundamentals discovered by Hertz and Maxwell to current evolving wireless communication systems. The development and standards of research area in fixed broadband wireless access and wireless local area networks are then focused. This is followed by an explanation on the research background, research objectives and scopes and finally thesis outlines. The research works performed are presented in the following chapters.

1.2 Development of Wireless Communication Technology

The world of wireless technology has come a very long way since Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing the English Channel in 1897. Over the past century, wireless transmission has progressed through the development of radio, radar, television, satellite and mobile telephone technologies [1].

In early years of wireless communications, radio was the most intensively deployed technology, both in the public domain and by law enforcements establishments. In 1934, 194 municipal police radio system and 58 state police stations had adopted amplitude modulation (AM) mobile communication system for public safety in the U.S. It was estimated that 5000 radios were installed in mobiles in the mid 1930s.

AM was the transmission used until Edwin Armstrong demonstrated the feasibility of frequency modulation (FM) in 1935. Subsequently, FM has been the main modulation method deployed for mobile communication system worldwide since the late 1930s. World War II accelerated the improvements of the world's manufacturing and miniaturization capabilities. In 1940s and 1950s, commercial deployment of one-way and two-way radio and television systems flourished [2].

The space age opened many new opportunities for radio communications between widely separated locations. Instead of high frequency terrestrial system with limited bandwidth or a large number of short-range microwave relays, satellite can link distant locations from a point high above the earth. By the mid-1960s, launch vehicles were delivering communications to locations in the geostationary satellite orbit. Today geostationary communications satellites continue to play a major role in telecommunications. Another wireless communication technology is the Low Earth Orbit (LEO), made up of satellites that communicate directly with handheld telephones on earth [3].

The growth of cellular radio and personal communication systems began to accelerate in the late 1970s. The growth was spurred on with the successive introduction of the first generation (1G), second generation (2G) and third generation (3G) cellular system. The widespread success of cellular has led to the development of newer wireless systems and standards for many other types of telecommunication traffic, such as fixed wireless access (FWA), Wireless Local Area Networks (WLANs) and Bluetooth [4].

1.3 Fixed Broadband Wireless Access

The rapid growth in demand for high data rate services in residential and small business customers had created a demand for last mile broadband access. To bring the information superhighway to the end user, we have wired and wireless solutions. Broadband access is currently offered through Digital Subscriber Line (xDSL), cable modem and Fixed Broadband Wireless Access (FBWA). FBWA is notably accepted because of the rapid installation, high scalability, high capacity and low maintenance and upgrade costs [5], [6].

To have a clearer understanding on the context of FBWA, broadband is defined as having instantaneous bandwidth greater than around 1 MHz and supporting data rates greater than about 1.5 Mbit/s, whereas broadband wireless access (BWA) is defined as wireless access in which connection capabilities are broadband. FBWA is hence referring to broadband wireless access application in which the location of the base station and subscriber station are fixed in location during operation [7].

Referring to the Standard Radio System Plan by Malaysian Communications and Multimedia Commission (MCMC) [8], the context of broadband is defined as any service beyond the scope of existing Public Switch Telephone Network (PSTN), Integrated Services Digital Network (ISDN) and 2G cellular networks. Broadband systems are capable of providing high speed data transfer rate that exceeds the normal, voice related speed (56 kbps for PSTN and 64kbps for ISDN) and have capability to deliver interactive multimedia likes combination of video, image, data, music, telephone and other services to consumers. On the other hand, FWA generally refers to the use of radio access systems, which serves as alternative for the conventional wire line access to a public communications and multimedia network serving residential and business communities. FWA systems provide services including basic telephony, multimedia and other high-speed multimedia services.

The spectrum available for fixed broadband wireless systems can be divided into licensed and license-exempted frequency bands. In general, licensed spectrum provides for some degree of interference protection because each new license must demonstrate compliance with certain standard for limiting interference to other existing nearby license systems. The most well known licensed FBWA services are Multipoint Multichannel Distribution Service (MMDS) at 2.5 GHz and Local Multipoint Distribution (LMDS) at 28 GHz in United States. Conversely, license exempted bands do not require individual transmitter to be licensed in order to operate, but there are still radiated power restrictions that usually keep power at low levels as the way of limiting interference. Institute of Electrical and Electronics Engineers (IEEE) 802.11b/802.11a WLAN devices are examples of license-exempted FBWA systems [9].

1.4 Wireless Local Area Networks

A WLAN is a data communication system implemented as an extension or as an alternative for wired LAN within an office, floor, building or campus and home. WLANs transmit and receive data through the air eliminating the need for physical connections to the corporate network. The WLAN products adhere to the IEEE 802.11 standard. This standard continues to evolve and there are 802.11a, 802.11b, 802.11g and others that are improvements on the original 802.11 to date.

The IEEE 802.11b standard provides for wireless networks operating at speeds up to 11 Mbps in 2.4 GHz industrial, scientific and medical (ISM) band by using direct sequence spread spectrum (DSSS). Alternatively, IEEE 802.11a standard provides data rates up to 54 Mbps in 5 GHz unlicensed national information infrastructure (UNII) bands using orthogonal frequency division multiplexing (OFDM) modulation. The IEEE 802.11g standard whereas provides data rates up to 54 Mbps in the 2.45 GHz ISM band using orthogonal frequency division multiplexing modulation.

WLANs are one of the most important elements of a total FBWA solution, as they provide link to building and the actual users. WLAN provides two key aspects to FBWA, which are broadband mobility and pervasive computing. Broadband mobility refers to the concept of being able to move around within a building or from building to building while retaining connectivity to the network. Pervasive computing, on the other hand refers to the concept that users experience broadband connectivity in a virtually limitless range of locations [10].

1.5 Research Background

Today, FBWA solutions are rapidly emerging as important competitive enablers for applications including wireless multimedia, wireless Internet access and future generation mobile communication system. Multicarrier modulation realized by OFDM is well suited for broadband applications in fading channels and has been chosen for standards like terrestrial Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) in Europe, three broadband wireless LAN standards: IEEE 802.11a, European Hiperlan/2, and Japanese Multimedia Mobile Access Communication (MMAC) [11]-[14]. There are some manufacturers offering FBWA systems operating in the industrial, scientific and medical band used for short-range outdoor applications [6]. The FBWA system that employs the WLAN IEEE 802.11a, high-speed physical layer in the 5.8 GHz ISM band is one of system being offered. This is a FBWA system via OFDM transmission and is studied in this research.

Successful deployment of a FBWA system depends not only on meeting deployment cost objectives, but also on performance requirements. Hence, the broadband communications system has brought the need for end-to-end performance measurement to radio engineering. This is due to the channel characteristics, interference levels and modulation format have independently impact on the performance of a communication system. This end-to-end performance measurement is a simulation and a powerful way of designing or predicting the performance of wireless communication links in a complex, time varying channel conditions [15]. The measurement of that performance is usually bit error rate (BER), which quantifies the reliability of the entire radio system from “bits in” to “bits out”, including electronics, antennas and signal path between transmitter and receiver [16]. Hence, this research focuses on the methodology towards the end-to-end performance measurement that is site-specific BER performance simulation of the

FBWA system. This is approaching together with the motivation to present a methodology that can be utilized by the communication system planners. With this methodology, they can evaluate the system performance and improve the system capacity at any location before the system installation.

In order to evaluate the site-specific BER performance, it is necessary to develop an effective channel model that yields both the predicted delay profile and propagation loss at any receiver location possible. Consequently, the development of high-speed digital communication system places new demands on propagation models that accurately predict the amplitude, delay, and directions of arrival of multipath enchoes. The most common modeling approach is site-specific ray tracing model [17], [18]. This research concentrates on site-specific channel modeling for point-to-point wireless propagation. Indeed, signal propagation through a wireless channel can be affected by a wide range of factors, including how equipment is deployed (antenna types and heights), terrain and land that block signals, clutter likes building that lead to reflection, diffraction and scattering.

1.6 Research Objectives

The main objective of this research is to present a straightforward BER performance simulation methodology that can be readily used for FBWA system with taking account of the environment effects. The straightforward methodology here is referring to a direct manner methodology for a site specific BER performance simulation whereby no other surveys of methods are needed prior to its implementation. In other words, this research aims for a site-specific channel modeling and BER performance simulation for FBWA system with operating frequency at 5.8 GHz ISM band. The FBWA system is employing the OFDM transmission and based on WLAN IEEE 802.11a standard.

1.7 Research Scopes

This research investigates available channel and propagation models and provides a BER performance simulation template for a FBWA system. The site related is newly constructed hostels in Universiti Teknologi Malaysia (UTM) with the transmitting station at block P18, Wireless Communication Centre (WCC), UTM. The newly constructed hostels have similar scenarios with nearly all the locations that require the FBWA system installations. They are the locations over a terrain and in remote rural areas where the cost of installation and the effort of meeting planning restraints associated with establishing wireline infrastructure. Although cable laying and maintenance is possible for the locations chosen, but in order to have a real environment that could implement the methodology proposed in this research, the hostels with transmitting station at WCC have been chosen.

The research begins with an introduction of a site specific channel modeling at frequency band of 5.8 GHz. There are two models applied based on physical and empirical respectively. The physical model is to predict propagation effect in the related site by using ray tracing simulation program based on vertical-plane-launch (VPL) technique courtesy of Bertoni, Xia, and Liang [19]. The empirical model is developed based on path loss field measurement. Redline AN-50 system, which is a high-performance fixed broadband wireless Ethernet bridge terminal system is used in this measurement.

In order to define the performance of the FBWA radio system at the specified links, a powerful electronic design automation software simulator named Advanced Design System (ADS) is brought forward for system modeling and performance simulation. The physical layer of the AN-50 system that adheres to the WLAN IEEE 802.11a standard is modeled as a template. BER performance is then simulated with the system undergoing AWGN channel and the modeled channels.

1.8 Thesis Outlines

The thesis is organized into eight chapters to completely cover the whole research works which comprises of the channel modeling and BER performance simulation for FBWA system.

Chapter 2 provides a summary of research development of channel modeling. It includes the classifications of the available channel and propagation models today. A review on the site-specific ray tracing propagation prediction model is also presented.

Chapter 3 gives a literature on radio system performance. The history and principles of OFDM system are then focused. The theoretical performance of the system is concentrated and a review on the previous research works is discussed.

Chapter 4 performs the ray tracing propagation prediction in the newly constructed hostels with transmit site at WCC, UTM. The power delay profiles for the possible receivers are predicted and extracted for visualization.

Chapter 5 describes the measurement that has been carried out in this research. It includes antenna radiation pattern and gain measurement. Path loss field measurement at the related site is presented as well.

Chapter 6 develops the physical layer of the FBWA system that employs the OFDM transmission in ADS computer aided design (CAD) tool. The modeled system is tested and validated in this chapter.

Chapter 7 simulates the BER performance of the FBWA system under the channels modeled in chapter 4 and 5. The obtained results are analyzed and discussed.

Chapter 8 concludes this research project. Some suggestions for future works are given in the end of this chapter.

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