UNIVERSITI PUTRA MALAYSIA

INDOOR PROPAGATION CHANNEL MODELS FOR WIRELESS LAN BASED ON 802.11b STANDARDS AT 2.4 GHZ ISM BAND

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By

BAHRIN SUJAK

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

August 2007

To my wife, Suryani Hashim

and

to my children, Hadif Iman, E'jaaz Imran, Eyad Haleef

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: Professor Borhanuddin Mohd. Ali, PhD

Faculty: Engineering

The WLAN is a preferred choice of technology for internet connection in the building environment. The indoor models, reported in the literature are mostly studied in the 900 MHz band of cellular standard and quite scarce in the 2.4 GHz frequency band of WLAN 802.11 standard. The frequency band is also dedicated for the WiMAX technology in which deployment in the office environment is essential.

In this thesis, the semi-empirical indoor Multi Wall Classic Extended (MWCE) channel model is proposed. The model is compared and evaluated with the empirical OS and other semi-empirical Multi Wall models obtained from the literature; the Multi Wall Classic (MWC) and Multi Wall Linear (MWL). The models are evaluated based on the accuracy of prediction at two floors of office environment in one of the telecommunication company building. The validity of the proposed model is evaluated through comparison with different models of similar type from the literature. The optimized model coefficients for all models, particularly for the wood/glass and brick/concrete the common wall obstacles in the building, are found. The behavior and characterization of all the models studied are investigated by evaluating the variation of the prediction error at several locations of the same propagation condition.

The prediction from the MWCE model is significantly improved compared to the OS model. The MWCE model is also observed to have a high and consistent accuracy prediction, comparable with the MWC and MWL models. The accuracy of the MWCE model is also shown to compare closely with different models of similar type from the literature.

With simple formulation without invoking too many details and high consistent accuracy prediction, the proposed MWCE model is suitable for prediction of WLAN signal in the indoor environment to be incorporated in the software planning tool.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

MODEL-MODEL SALUR PERAMBANTAN DALAMAN UNTUK LAN BEBAS WAYAR BERDASARKAN PIAWAIAN 802.11b DALAM JALUR ISM 2.4 GHZ

Oleh

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Ogos 2007

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WLAN adalah teknologi pilihan bagi perhubungan internet di dalam persekitaran bangunan. Model-model persekitaran bangunan, yang dilaporkan di dalam literatur kebanyakkannya dikaji di dalam jalur frekuensi 900 MHz dalam piawaian bersel and sangat jarang kedapatan di dalam jalur frekuensi 2.4 GHz dalam piawaian WLAN 802.11. Jalur frekuensi tersebut juga diperuntukkan untuk teknologi WiMAX di mana pemasangan di dalam persekitaran pejabat sangat penting.

Di dalam tesis ini, model persekitaran bangunan separuh-empirik, MWCE dicadangkan. Model tersebut dibandingkan dan dinilaikan dengan model empirik OS dan lain-lain model separuh-empirik yang didapati daripada literatur; iaitu MWC dan MWL. Model-model dinilaikan berdasarkan kepada ketepatan ramalan di dua tingkat pejabat di dalam salah satu bangunan syarikat telekomunikasi. Validasi model yang dicadangkan dinilai melalui perbandingan dengan lain-lain model berjenis sama daripada literatur. Pekali-pekali pembaikkan untuk semua model-model terutamanya bagi kayu/gelas dan

batu/konkrit, yang merupakan dinding halangan yang biasa ditemui di dalam bangunan tersebut dicari. Kelakuan dan pencirian semua model-model kajian dikaji dengan penilaian variasi kesilapan ramalan di beberapa lokasi yang mempunyai keadaan perambatan yang sama.

Ramalan daripada model MWCE telah dipertingkatkan dengan nyata berbanding dengan model OS. Model MWCE juga diperhatikan mempunyai ramalan yang tinggi dan konsisten, bersamaan dengan model-model MWC dan MWL. Ketepatan model MWCE juga didapati mempunyai ketepatan yang hampir dengan lain-lain model bersamaan jenis daripada literatur.

Dengan formulasi yang mudah tanpa memerlukan banyak maklumat dan ketepatan ramalan yang tinggi lagi konsisten, model MWCE yang dicadangkan sesuai untuk ramalan isyarat WLAN di dalam persekitaran dalaman dan untuk dimasukkan di dalam perisian pengkaji.

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I certify that an Examination Committee has met on **23 August 2007** to conduct the final examination of **Bahrin Sujak** on his **degree** thesis entitled "**Indoor Propagation Channel Models for Wireless LAN Based on 802.11b Standards at 2.4 GHZ ISM Band**" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

BAHRIN SUJAK

Date: 18 February 2008

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LIST OF ABBREVIATIONS

2G	2^{nd} Generation network
3G	3^{rd} Generation network
AP	Access Point
CDF	Cumulative Distribution Function
DEM	Digital Elevation Model
dB	deciBel
dBi	deciBel with reference to gain of isotropic antenna
dBm	deciBel with reference to 1 miliWatt
EIRP	Equivalent isotropic radiated power
EURO-COST	European Scientific and Technical Research
IAM	Image Approach Model
IEEE	Institute of Electrical and Electronic Engineers
IMT-2000	International Mobile Telecommunication - 2000
ITU-R	International Telecommunication Union of Radio Communication section
LAN	Local Area Network
LOS	Line of Sight
MAC	Medium Access Control
MMSE	Minimum Mean Square Error
MW	Multi Wall path loss channel model
MWC	Multi Wall Classic path loss channel model
MWCE	Multi Wall Classic Extended path loss channel model

MWL	Multi Wall Linear path loss channel model
NLOS	Non Line of Sight
OFDM	Orthogonal Frequency Digital Multiplexing
OS	One Slope path loss channel model
PCMCIA	Peripheral Component Micro Channel Interconnect
PCS	Personal Communication System
QoS	Quality of Service
RF	Radio Frequency
RLM	Ray Launching model
RSSI	Received signal strength indicator
STD	Standard deviation
UGTD	Uniform Geometrical Theory of Diffraction
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunication
Wi-Fi	Wireless LAN of 802.11b standard
WLAN	Wireless LAN

CHAPTER 1

INTRODUCTION

1.1 An overview

Wireless communication is one of the most active areas of technology development. The development is driven by the transformation of medium for voice to multimedia services. Similar with the wire line capacity in the 1990s, the demand for new wireless capacity is growing at a very rapid pace. The interaction of wireless devices is made possible with the convergence of different standards. This allows the creation of global wireless network with variety of services. Cellular phone has evolved from Second Generation (2G) to Third Generation (3G) supporting multimedia data services. There are many types of wireless networks in use around the world and most of them have access to the Internet. The Wireless LAN (WLAN), a flexible communication system has been available for some time and still, a preferred choice for wireless Internet.

WLAN has been implemented as an extension or alternative to wired LAN within buildings providing network services where it is difficult or too expensive to deploy a fixed infrastructure. WLANs can coexist with fixed infrastructure to provide mobility and flexibility to users. Using electromagnetic waves WLANs transmit and receive data over air interface, minimizing need for wired connection, thereby it enables user mobility in covered area without losing connectivity to the backbone network. The system implementation varies from simple peer-to-peer connection between two computers, to cover entire buildings by many transmitter/receiver devices, which are connected to the wired network [1]. Most of the WLANs deployments are in the indoor environments. It is very difficult to predict how radio wave travels in an indoor environment. The indoor signal propagation differs from an outdoor case particularly in distances and variability of the environment. For small network in a limited area, only manufacturer's information on the coverage range is sufficient to deploy the Access Points (APs). For larger network, a more accurate deployment procedure is required to ensure sufficient coverage and network functionality. Basically there are two approaches. The first approach is based on a site survey measurements and experimental decision. The second approach is based on prediction using propagation models, incorporated in the software planning tool. The advantages and disadvantages of using these two approaches are discussed in [2].

Designing the coverage is very much related with the Quality of Service (QoS). QoS is described through the selection of a set of QoS parameters, specification of QoS target values, the choice of QoS measurements and evaluation mechanisms. The most important network parameters for the effective data transmission are delay, throughput, jitter, bandwidth, echoes and packet loss [1]. Almost all of these parameters depend on proper signal strength i.e. coverage planning.

1.2 IEEE 802.11 standard

IEEE 802.11 is a standard of specification for WLANs developed by the Institute of Electrical and Electronics Engineers (IEEE). The 802.11 standard specifies parameters for both the physical and medium acces control (MAC) layers of a WLAN [3]. The physical layer handles the transmission of data between nodes. The MAC layer consists of protocols responsible for maintaining the use of the shared medium. There are three physical layers for WLANs: two radio frequency specifications (RF-direct sequence and frequency hopping spread spectrum) and one infrared. Most WLANs operate in the 2.4 GHz license-free band. There are various versions of the 802.11 standard. A brief description of the more popular revisions is given below.

- 802.11a: Operates at radio frequencies between 5 GHz and 6 GHz [4]. The modulation scheme used is orthogonal frequency-division (OFDM).
- 802.11b: The most popular of all the standards and often called Wi-Fi operates in the 2.4 GHz frequency [5]. The modulation scheme used is Direct Sequence Spread Spectrum.
- 802.11g: The newest family and uses a hybrid complementary code keying OFDM [6].

The 802.11b networks operate in the Ultra High Frequency (UHF) band, specifically between 2.4 and 2.5 GHz. There are a total of fourteen channels for use. Since the number of channels is limited they need to be reused especially when the area to be covered is huge.

Table 1-1: Frequency and channel assignments for 802.11b [5]

Channel	Frequency	Channel	Frequency
1	2.412 GHz	8	2.447 GHz
2	2.417 GHz	9	2.452 GHz
3	2.422 GHz	10	2.457 GHz
4	2.427 GHz	11	2.462 GHz
5	2.432 GHz	12	2.467 GHz
6	2.437 GHz	13	2.472 GHz
7	2.442 GHz	14	2.484 GHz

1.3 Site survey measurements

Site survey using either a standard wireless device with testing software tool or special sophisticated equipment is one way to test the WLAN networks. The issue is, the process of building up the network in term of optimal number of APs and their placement using site survey. So the main goal of a site survey is to measure enough information to determine the number and placement of APs that provides adequate coverage. Basically the procedure involves the deployment of temporary APs in preliminary location; either a single AP at a time or a whole WLAN is temporarily built up based on a designer's opinion and experiences. Afterwards the coverage is examined using the site survey measurement. Based on the results the positions and configurations of APs are changed or new AP is introduced. Then again a site survey is repeated to find an acceptable solution iteratively.

1.4 Propagation path loss model

Software planning is a much more convenient and cost-effective way to deploy a wireless network than a site survey with lots of measurements especially if the area to be covered is huge. Using simulations many different configurations of the network can be tested with no expenses to find an optimal solution. That is why efficient propagation models are required. As was stated earlier indoor propagation modeling is one of the most complicated tasks in this field. A large number of indoor propagation models can be found in literature [7]. The models can be roughly divided into two groups: deterministic and empirical, which are described in the following sub section.

1.4.1 Deterministic modeling approach

Deterministic are primarily based on electromagnetic wave propagation theory being as close to physical principles as possible. Most of the models known as ray tracing are based on geometrical optics, lead to viewing the radio wave propagation as optical rays. The outputs of deterministic models show excellent site-specific accuracy. In deterministic propagation modeling, the multi-path propagation can be fully described, other space-time properties like time delays, angles or arrival, etc can be determined. Deterministic propagation modeling requires detailed description of the scenario for which are essentially required i.e. details 3D geometry, constitutive material parameters which are not easy to obtain. Deterministic propagation modeling requires heavy processing which is why they are not very popular in common practice.

1.4.2 Empirical modeling approach

The empirical models are primarily based on statistically processed representative measurement. As the most popular example, log-distance path loss, and Attenuation Factor (AF) are types of empirical models. These models are very easy and fast to apply. The log-distance is the easiest method to compute, the average signal level within a building without having to know detailed infrastructure of the building layout. However the model only gives rough estimate and the selection of proper path loss exponent is crucial.

On the other hand the AF model provides much better accuracy than log-distance model [8], [9]. The AF path loss models can be marked site-specific since particular walls are considered during prediction, but still AF provides good estimates of the real wave propagation. Particular reflections and diffractions are not taken into account so the accuracy is limited in certain cases. As an example the wave-guiding effect of bending corridor cannot be modeled. For good prediction accuracy the proper wall attenuation factor must be used. The attenuation factors do not represent actual physical attenuations of the walls but statistical values obtained from representative measurement campaigns. It means if the receiver is hidden behind a metal wall with limited dimension, the prediction cannot result in an infinite attenuation, even though metal itself can be considered as a total reflector of the electromagnetic energy. But in the real scenario the wave can find its way around the metal obstacle due to reflection, diffraction and diffuse scattering.