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Analysing Radio Wave Propagation Model for Indoor Wireless Communication

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***Abstract*— for** several wireless communication technologies, many propagation models have been presented in measuring path losses. In this paper, two propagation prediction models which relate signal strength log of distance are presented and compared with empirical results measured in a lecture building. For the empirical measurement, a TP-LINK router and a laptop are used to implement 2.4 GHz, indoor point to point ad hoc wireless network in our lecture building. Attenuation parameters of obstacles used in the prediction model are estimated from the empirical measurement by using statistical approach. Finally, the accuracy of the prediction models is proof by comparing empirical measurement results with the help of least square model fitting.

***Index Terms*—** propagation models, free space loss, path losses, empirical approach, statistical approach

I. Introduction

In 1886, the researcher, Heinrich Roudolf Hertz observed the transmission of electromagnetic waves. As the consequence of his observation, the long-debated Maxwell's predictions of wave propagation were realized. After that, Guglielmo Marconi made the first milestone on the road of wireless communication by radio wave communication which could provide continuous contact with ships sailing the English Channel [1]. And then, the wireless communication system has been being developed from two-way radio communications and broadcasting systems, the first generation of wireless mobile communication, the second generation (2G) digital cellular system and the third generation (3G) of wireless communication providing multimedia services and then until today 4G wireless systems with an all-IP network that integrates current available several services.

In the wireless communication system, there are three important stages, transmitter, media and receiver. Receiving power or gain of a radio communication is entirely depended on the size, shape and position of the transmitting antenna and receiving antenna. Furthermore, different media can cause different attenuations and line losses. Hence, unlike wire communication system, it is very difficult to determine the receiving power for a particular place in complex media because of different losses and attenuation parameters.

To achieve an optimized wireless communication for an environment, accurate propagation characteristics of the environment should be known before physical implementing and planning of the wireless communication system. Therefore, propagation prediction models are essential for these situations.

II. Related Work

Some of techniques which are published and not so very soon are presented as our respective works and references. In 2002, F. Iskander *et al.* presented a review of the state of the art propagation prediction models that range from early simple empirical formulas to modern site-specific ray-tracing-based models [2]. Next publication is the measurement of propagation losses in bricks and concretes in 2003 by Daniel et al. [3]. In this paper, the through-wall attenuation, the equivalent permittivity (ε) and conductivity (σ) are estimated for the 900 MHz cellular band by a "best fit" of through wall transmission measurements to the classical multi-ray model and its one-path approximation: the single-ray model.

Later, Reiner S. *et al.* published "*Measurement-based parametric channel modeling*" [4] in which the concept of deterministic measurement-based parametric channel modeling (MBPCM) combines real-time MIMO channel sounding and high-resolution multi dimensional parameter estimation. By this way, the channel model parameters describing the multidimensional wave propagation model can be resolved as accurately and generally as possible. Another one with respect to the propagation model is the publication of Charles Reis *et al.* [5] at 2006. They present practical, measurement-based models for the physical layer behaviors of static wireless networks, including packet reception and carrier sense with interference.

In this paper, we proposed a model for the indoor wireless propagation in 2.4 GHz by estimating and analyzing path losses based on complex environment of our lecture building. This paper is organized as follows. Theoretical background with respect to the proposed method is studied in the next section. In section 3, our proposed model is briefly described. In section 4, experimental results are presented by comparing between empirical measurement and model prediction. Finally, some conclusion and further work are drawn in section 5.

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III. Theoretical Background

The evolution of wireless communication technology has been being rapidly leaded to the use of higher frequency bands, smaller cell sizes with smart antennas, Hence the propagation prediction issues are faced more challenging. Furthermore, wireless communication channels are normally frequency dispersive, time varying, and space selective. Hence, for a prediction model of a particular frequency band, size and location of antennas, and the geometrical features and terrains of propagation environment are so important facts to achieve satisfactory accuracy. In theoretical background of the proposed method, some previous models of wireless propagation prediction are presented as follow.

A. Free Space Model

It is the ideal propagation model to measure only one clear line-of-sight path between transmitter and receiver. H. T. Friis presented the standard model to estimate the received signal power in free space at distance d from the transmitter.

$$Pr\,(d) = P_rG_tG_r\lambda^2 / (4\pi)^2d^2 \quad (1)$$

$$L(d) = 32.44 + 20 \log (f) + 20 \log (d) \quad (2)$$

Where d is the distance between antennas, expressed in kilometres and *f* is the carrier frequency, expressed in MHz. The free space path loss model is usual reference point for path losses measuring.

B. Two Ray Dual Slope Model

An average signal level is estimated by the dual slope breakpoint. This model is implemented with two rays, directed rays and reflected rays [8]. The model can be illustrated as follow.

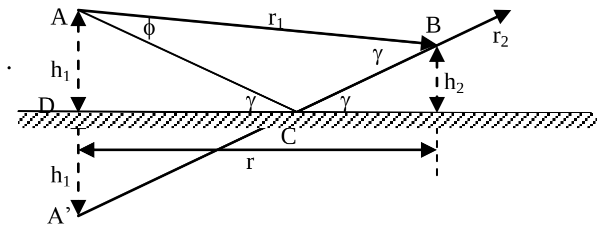

Fig. 1 Two Ray Dual Slope Model

Mathematical frame work of the model is as followed.

$$L(d) = 32.44 + 20 \log (f) + 20 \log (d) + (N_B -2)*10 \log (1 + (d\lambda/4h_th_r)) – 10 \log (p) \quad (3)$$

Where λ is wave length of carrier, receiver power (P_r), transmitted power (P_t), G_t is reader antenna gain, Gr is tag antenna gain, polarization mismatch (p) and N_B is the increased signal loss beyond the breakpoint.

C. Log-Distance Model

A simple log-distance model [9] is used to determine attenuation of transmitted signal at transmission frequency (f_T), when transmitter and receiver are in LOS situation.

$$PL(d)\,(dB) = PL(d_0)[dB] + 10*n*\log (d/d_0) \quad (4)$$

Where the reference distance d_0, taken for 1 meter is utilized to normalize to that which occurs at a distance d_0 from the transmitter and only the propagation effects are include. *n* is path loss exponent and *d* is distance between transmitter and receiver in meters.

Depending on the different theoretical background, there are a lot of different and effective propagation models in today. However, based on the above three propagation models, our proposed model will be presented in next section.

IV. Proposed Model

Our proposed model is a path loss prediction model, based on Log-Distance model. The path loss models are basically empirical mathematical formulations for the characterization of radio wave propagation.

A. Path loss

When radio wave is propagated over a particular environment, a lot of losses called path losses caused by environment effects and line attenuation usually appear along the communication path between transmitter and receiver. The path losses are measured and analysed by developing models to predict the behaviour of how the signal is propagated in the environments and places. The path losses can be defined as follow.

$$PL = P_t – P_r \quad (5)$$

Where, PL is path loss, P_t is assumed as transmitting power and P_r is receiving power. Hence, on the other word, total transmitting power is the addition of path loss (PL) and receiving power (P_r). In the saying the path loss, in the open environment and LOS communication, the path loss is only the free space loss and others can be neglected. However, for an indoor propagation, there are a lot of obstacles. Among the obstacles, some can absorb the RF, some cause the RF to scatter or reflect and next possible is the refraction. Depending on the receiver location, some reflected and scatter waves can reach to the receiver and cause to be fading and attenuation. Hence, the path loss can be divided into free space, absorbed and unabsorbed as below.

$$PL = L_{free\ space} + L_{absorbed} + L_{unabsorbed} \quad (6)$$

Where, $L_{absorbed}$ is the losses absorbed by obstacles of the communication medium and $L_{unabsorbed}$ is caused by reflection, refraction and scattering.

B. Proposed Model

By Friis path loss model, free space path loss for 2400 MHz (2.4 GHz) carrier frequency using close-reference distance 1m is as below.

By equation 2,

$PL(d) = 32.44 + 20 \log (f) + 20 \log (d)$

By calculating with f = 2400MHz

$$PL(d) = 100.0442 + 20 \log (d) \tag{7}$$

As the attenuations caused by obstacles are depended on the number and type of the obstacles. Hence, the following equation can be derived by substituting equation 7 in equation 6 and adding type and number of obstacles.

$$PL(d) = 100.04 + 20 \log (d) + \sum_{i=1}^{P}\sum_{j=1}^{Q}(L_{abs})_{ij} + \sum_{i=1}^{P}\sum_{j=1}^{Q}(L_{uabs})_{ij} \tag{8}$$

Here, L_{abs} is attenuation caused by obstacle absorption and L_{uabs} is loss caused by reflection, refraction and scattering. P and Q are the numbers and types of obstacles. The L_{abs} and L_{uabs} are estimated from empirical measurements by statistical approach.

In this situation, receiving power is $Pr = (P_t + G_t + G_r) – PL$ [10] in which P_t is transmitting power, G_t is transmitter gain and G_r is receiver gain. Hence, by substituting equation 8, the receiving power can be described as followed.

$$Pr = (P_t + G_t + G_r) – 100.04 + 20 \log (d) + \sum_{i=1}^{P}\sum_{j=1}^{Q}(L_{abs})_{ij} + \sum_{i=1}^{P}\sum_{j=1}^{Q}(L_{uabs})_{ij} \tag{9}$$

The above equation 8 and 9 are our proposed prediction model for indoor 2.4 MHz propagation and the accuracy of the model is proof in the next section comparing with empirical results.

V. Indoor Environment & Experimental Results

In this section, our proposed model results are compared with empirical results to infirm model accuracy and study radio wave propagation characteristics.

A. Experimental Setting

The site selected for the experiment is lab1 and lab2 buildings of our university, University of Technology, Yantanapon Cyber City (UTYCC). These two buildings are the same architectures and equal layouts, and composed of RC and brick structure as shown figure 2. Each building has two floors and each floor contain three lab rooms. Hence, both buildings are multi-storied and equipped with furniture like benches, wooden and steel cupboards with other laboratory instruments. They can be caused complex wireless propagation. However, the site is used to small scale phenomenon for multi-paths and reflection mechanism, not for shadowing and obstructions.

TP-LINK router TL-WR941ND is used for wireless transmitter and laptops are used for receivers. In the measurement, TP-LINK router is placed on the corridor of the first floor of each building with the height of 1m above the floor. For the propagation measurement, Netstumbler and inSSIder 2.1 are used on Microsoft Window 7 OS. Transmission frequency was 2.4 GHz with **10dBm** transmitted power. Mobile host, laptops are moved to different locations on the floor of each storey.

All measurements are carried out both Line-Of –Sight (LOS) and Non-Line-of-sight (NLOS) in the area of complex building along all corridors and lab rooms. Care has been taken that laptop was all the time oriented towards Access Point (TP-LINK router). For the purpose of this work, the measurements of radio signal strength are limited to consider and only focus on the path loss analysis and building penetration attenuation. The objectives of the measured experiments are to simply collect a number of data points and to compare them with proposed model. The following table describe measurement setup for transmitter and receiver.

C. Experimental Results

To estimate the experimental results, equation 7, 8 and measured results are used to describe the accuracy of proposed model. In the equation 8, L_{abs} and L_{uabs} are estimated from measured results by graphical and statistical approach. The following figure show the free space path loss, prediction results for the path loss and practical measured result by their comparison form.

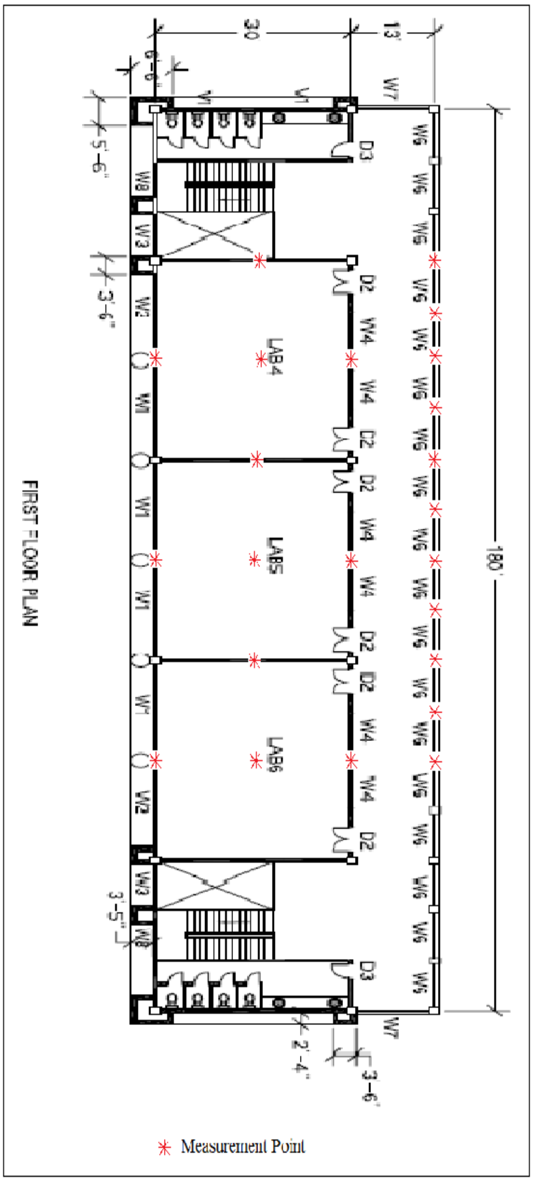

TABLE I
MEASUREMENT SET UP OF TRANSMITTER AND RECIEVER

NO.	Measurement Set Up	
	Name	**Amount**
1	Carrier Frequencey (GHz)	2.4
2	Band width (MHz)	100
3	Transmit Power (dBm)	10
4	Tx antenna height (m)	1
5	Rx antenna height (m)	1

III. Some Common Mistakes

The word "data" is plural, not singular. The subscript for the permeability of vacuum μ_0 is zero, not a lowercase letter "o." The term for residual magnetization is "remanence"; the adjective is "remanent"; do not write "remnance" or "remnant." Use the word "micrometer" instead of "micron." A graph within a graph is an "inset," not an "insert." The word "alternatively" is preferred to the word "alternately"

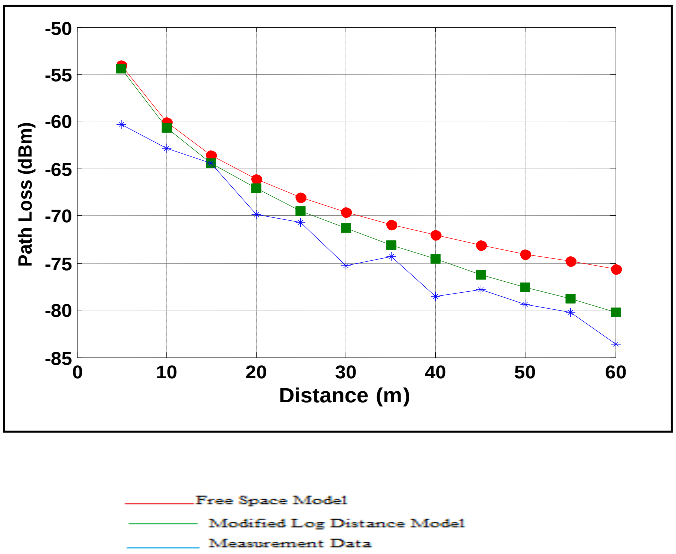

Fig.3.Path loss Comparison among Free Space and measured results

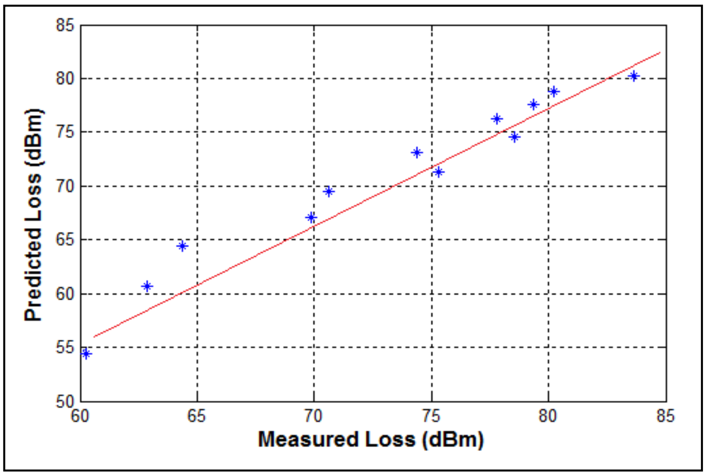

Fig.4. Scatter plot of Measure versus Prediction loss

The scatter of path loss obtained from proposed model and measured results are shown in figure 4. According to the figure, scatter points are not far away from fitting line. It means that the prediction accuracy is not too much different from measured result so the accuracy can be acceptable.

VI. CONCLUSIONS

In this paper, we have presented a propagation prediction model comparing with empirical results. The weakness of the model is the empirical dependence. The model needs so many measured results because the acceptable accuracy of the parameters, Labs and Luabs are entirely depended on the many measured points. However, by the rather enough measurements, the model can be acceptable and satisfied. The experimental results have been shown that the predictions of the proposed model are not so far from measured result.

Therefore, the proposed model can be applied to the simulated and predict in door propagation signals.

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