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Investigation of Path Loss Models for Mobile Communications in Malaysia

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Abstract: The design of a propagation path loss model requires knowledge of environment characteristics. Quite a number of propagation path loss models for mobile radio communication system were published in the literature. However, choosing the most suitable model for a given geographical and morphographical area is not a simple task because descriptions of terrain and land-use information can vary widely from country to country. Furthermore, Efficiency of present path loss models suffers when they are used in the environment other than for which they have been designed. The Malaysian geographical and morphographical area varies widely from areas where most models were developed. In addition, several studies in Malaysia, Indonesia and others have shown that the known path loss models perform unsatisfactory when compared with measured data. Hence, this prompts the necessity to investigate the models that suit the Malaysian environment conditions. To investigate the path loss models, measurements of path loss were carried out at an international Islamic university Malaysia. The measured path losses were compared with various path loss prediction models. The results were used to evaluate the accuracy for these models to determine the one that best fit Malaysian environment. The results show that log-normal and lee models were the closest to the measured data.

Key words: Communication sysem; path loss; propagation; empirical models.

INTRODUCTION

Propagation models have traditionally focused on predicting the received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in a close spatial proximity to a particular location. Propagation models that predict the signal strength for an arbitrary transmitter receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter. In addition, they are very helpful to mobile radio service providers for planning their networks because they allow optimization of the cell coverage while minimizing the intercell interference. Moreover, Propagation models are useful for predicting signal attenuation or path loss. This path loss information may be used as a controlling factor for system performance or coverage so as to achieve perfect reception (Abhayawardhana, 2005; Armoogum, 2007). These models can be broadly categorized into three types; empirical, deterministic and stochastic (Abhayawardhana, 2005). In this paper, only empirical models are considered. Empirical models use measurement data to model a path loss equation. To conceive these models, a correlation was found between the received signal strength and other parameters such as antenna heights, terrain profiles, etc through the use of extensive measurement and statistical analysis (Ayyappan). In a mobile communication system, radio transmission often takes place over irregular terrain. The terrain profile of a particular area needs to be taken into account for estimating the path loss. The terrain profile may vary from a simple curved earth profile to a highly curved mountainous profile. There are many of propagation models are available to predict path loss over irregular terrain. As all these models aim to predict signal strength at a particular receiving point, the methods vary widely in their approach, complexity and accuracy. The majority of these models are based on a systematic interpretation of measurement data obtained in the service area.

Path Loss Calculation:

The measured path loss (*PL*) for each location point (*d*) is given by (Faihan, 2006)

$$P_L(d) = EIRP_T + G_m - PM(d) \tag{1}$$

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and

$$EIRP_T = P_T - L_C + G_b \tag{2}$$

where $EIRP_T$, is the effective isotropic radiated power of the base station, P_T is the BS transfer output power, L_C is antenna cable loss, and G_m and G_b are BS and MS antenna gains. *PM(d)* is the measured IIUM MS signal strength at distance *d*. These values are known from the measurement process (Faihan, 2006).

Empirical Models:

Log-normal Shadowing Model:

The path loss is modeled according to a log-normal shadowing model as (Theodore, 2102).

$$P_L(d)[dB] = \bar{P}_L(d) + X_\sigma = \bar{P}_L(d_o) + 10n\log\left[\frac{d}{d_o}\right] + X_\sigma \tag{3}$$

where *n* is the path loss exponent which indicates the rate at which the path loss increases with distance. The value of *n* depends on the specific propagation environment. In free space, *n* is equal to 2, and when obstructions are present, *n* will have a larger value. The parameter d_0 is the close-in reference distance which is determined from measurements close to the transmitter. d is the T-R separation distance. X_σ is a zero-mean Gaussian distributed random variable (in dB) with Standard deviation (σ) (also in dB). $P_r(d)$ and P_t are the received power at distance d and the transmitted power respectively (in dBm).

The value of path loss exponent n is obtained from the measured data, by linear regression such that the difference between the measured and estimated path loss is minimized in a mean square sense. The sum of squared error is given by (Theodore, 2102).

$$E(n) = \sum_{1}^{N} [P_{Lm}(d) - P_L(d)]^2 \tag{4}$$

where $P_{Lm}(d)$ is the measured path loss at distance d and $P_L(d)$ is its estimate using equation (1). The value of n, which minimizes the mean square error, is obtained by equating the derivative of equation (4) to zero.

COST 231 Model:

The COST 231 model, sometimes called the Hata model PCS extension, is an improved version of the Hata model. It is widely used for predicting path loss in mobile wireless system. It is designed to be used in the frequency band from 1500 MHz to 2000 MHz. It also includes corrections for urban, suburban and rural (flat) environments (Parsons, 2000; COST Action, 1999).

$$P_L\,(d)(dB) = A + B\,log_{10}(d) + C \tag{5}$$

where

$$A = 46.3 + 33.9\,log_{10}(f_c) - 13.82\,log_{10}(h_b) - a(h_m)$$

$$B = 44.9 - 6.55\,log_{10}(h_b)$$

and C=0 dB for medium sized city and suburban area with moderate tree city or *C* =3 dB for metropolitan centers. Also f_c is the frequency in MHz from 1500 MHz to 2000 MHz, h_b is the effective transmitting antenna height in meters ranging from 30 m to 200 m, h_m is the effective mobile (receiver) antenna height ranging from 1 m to 10 m, d is the T-R separation distance in km, and $a(h_m)$ is the correction factor for e mobile antenna height which is a function of the size of the coverage area. For a large city and for f_c larger than 300 MHz, the mobile antenna correction factor is given by

$$a(h_m) = 3.2[log_{10}(11.75h_m)]^2 - 4.9 \tag{6}$$

Although the Cost 231 model is limited to BS (base station) antenna height greater than 30 m, it can used for lower BS antenna heights provided that surrounding buildings are well below the BS antennas. It can guess path loss at lower distances, but it should not be used to predict path loss in urban canyons or for short distances where the path loss becomes highly dependent upon the surrounding structures and topology (Gordon, 2001).

Lee Model:

Lee model is one of the most broadly used propagation models because of its aptitude to achieve good prediction accuracy as still remaining relatively simple and intuitive. In addition, its prediction aptitude can be significantly improved by the incorporation of measurement data (Kostanic, 1998). In the beginning, the Lee model was developed for use at 900 MHz and has two modes: area-to-area and point-to-point (Lee, 1993). The simple implementation, ability to be fixed to empirical data, and the results it provides make it an attractive option. A frequency adjustment factor is important feature characterizes this model that it can be used to increase the frequency range analytically. The Lee model is a modified power law model with correction factors for antenna heights and frequency and has the ability to be customized to the local environment easier than other empirical models. A typical application involves taking measurements of the path loss in the target region and then adjusting the Lee model parameters to fit the model to the measured data (John, 2005; Adel A. Ali, 1992).

Lee Area-to-Area Mode:

In this case, Lee uses a reference median path loss at a range one of 1 km, called L_o, the slope of the path loss curve, γ in dB/decade, and an adjustment factor F_o. The median loss at distance, d, is given by

$$P_L(dB) = L_o + \gamma \log_{10} d - 10 \log_{10}(F_o) \tag{7}$$

The adjustment factor, F_o is comprised of several factors,

$$F_o = F_1 F_2 F_3 F_4 F_5 \tag{8a}$$

The values of these various factors can be computed with the following steps:

- The base station antenna height correction factor is

$$F_1 = \left(\frac{h_b(m)}{30.48}\right)^2 = \left(h_b\left(\frac{ft}{100}\right)\right)^2 \tag{8b}$$

- The base station antenna gain correction factor is

$$F_2 = \frac{G_b}{4} \tag{8c}$$

where G_b is the actual base station antenna gain relative to a half-wave dipole.

- The mobile antenna height correction factor is

$$F_3 = \begin{cases} \left(\frac{h_m(m)}{3}\right)^2 & if \quad h_m(m) > 3 \\ \left(\frac{h_m(m)}{3}\right) & if \quad h_m(m) < 3 \end{cases} \tag{8d}$$

- The frequency adjustment factor is

$$F_4 = \left(\frac{f}{900}\right)^{-n}, \tag{8e}$$

where 2 n < 3 and *f* is in MHz

- The mobile antenna gain correction factor is

$$F_m = \frac{1}{G_m} \tag{8f}$$

where G_m is the gain of the mobile antenna relative to a half-wave dipole (Parsons, 2000; John S. Seybold, 2005).

Tuning of Lee Model Parameters:

The residual between measured data and prediction model data for each location point is calculated by (Faihan).

$$e(d) = P_{Lm}(d) - [L_o + \gamma\, log_{10}\, d - 10\, log_{10}(F_o)] \tag{9}$$

The *RMSE* function of this residual will be as follows (Simic, 2001).

$$E(L_o, \gamma) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[e(d_i)]^2} \tag{10}$$

where, N is number of measured points. To minimize RMSE function, it should be differentiated partially to their coefficients that achieve this minimization. To obtain Lee model's parameters (L_0, γ) that optimize equation (10), N equations based on equation (9) corresponding to N measured points should be solved. The N equations are given by:

$$\begin{bmatrix} 1 & \log(d_1) \\ 1 & \log(d_2) \\ \cdots\cdots & \cdots\cdots\cdots\cdots \\ \cdots\cdots & \cdots\cdots\cdots\cdots \\ 1 & \log(d_N) \end{bmatrix} \times \begin{bmatrix} L_o \\ \gamma \end{bmatrix} = \begin{bmatrix} P_{Lm}(d_1) - A_1 \\ P_{Lm}(d_2) - A_2 \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ P_{Lm}(d_N) - A_N \end{bmatrix}$$

Or

$$W \times \bar{F} = Y \tag{11}$$

which can be obtained using LS algorithm as follows (Simic, 2001):

$$\bar{F}_{LS} = [W^T W]^{-1} W^T \tag{12}$$

Stanford University Interim (SUI) Model:

The SUI Model is based on extensive experimental data collected at 1.9 GHz in 95 macro cells across the United States. The model, adapted by the IEEE 802.16 group as the recommended model for fixed broadband applications (Erceg, 1999). This model is an extension of the Hata model with correction parameters for frequencies above 1900 MHz. SUI model is proposed as a solution for planning the WiMAX network on a 3.5 GHz band. SUI model can be used for the height of base station antenna from 10 m to 80 m, the receiving antenna height between 2 m and 10 m and the cell radius between 0.1 km and 8 km (Erceg, 2001). Innovation of this model is the introduction of the path loss exponent, and the weak fading standard deviation, S, as random variables obtained through a statistical procedure. The value of standard deviation of s is typically 8.2 to 10.6 dB (IEEE 802.16 Working Group, 1999). The model distinguishes three types of terrain, called A, B and C. Type A is associated with maximum path loss and is suitable for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities (Abhayawardhana, 2005). The basic expression for path loss calculation according to the SUI model is given by (Harry R. Anderson, 2003).

$$P_L(d)(dB) = A + 10\gamma\, log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + S \tag{13}$$

where $d > d_0$ (d in meters) is the distance between the base station and the receiving antenna, d_o=100 m, X_f is a correction for frequency above 2 GHz, X_h is a correction for the receiver antenna height, and S is a correction for shadowing because of trees and other clutters on a propagation path. Parameter A is defined as follows

$$A = 20\ log_{10}\left(\frac{4\pi d_o}{\lambda}\right) \tag{14}$$

where λ is the wavelength in meters. Path loss exponent γ is given by (18)

$$\gamma = a - bh_b + \frac{C}{h_b} \tag{15}$$

where h_b is the base station antenna height in meters, and *a*, *b* and *c* are constants dependent on the terrain type, as given in Table 1.

Table 1: Model Parameters for Different Terrains.

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

The correction factors for the operating frequency and for the receiver antenna height for the model are

$$X_f = 6.0\ log_{10}\left(\frac{f}{2000}\right) \tag{16}$$

And, for terrain type

$$X_h = -10\ log_{10}\left(\frac{h_r}{2000}\right) \tag{17}$$

where, *f* is the frequency in MHz, and h_r is the receiver antenna height in meters. The SUI model is used for path loss prediction in rural, suburban and urban environments.

Experimental Setup:

The measurements were conducted in the IIUM campus. Two base stations located in Ali's Mahallah (T1) and Othman's Mahallah (T2) were selected to take readings. The base station located in T1 has a longitude=101.736913, latitude=3.248690 and height=30m above the ground. For T2, the base station has a longitude=101.739548, latitude=3.249015 and height=20m. The measurement system consists of Laptop with Test Equipment for Mobile Systems (TEMS) investigation software installed, Mobile handset T610 with TEMS Pocket software installed and GPS receiver. The received power (RP Level) is measured using the Ericsson handset and transferred to the TEMS log file in the laptop, the GPS receiver provides the three coordinates: (Altitude, Longitude and Latitude) synchronously with the received power Level readings.

After operating the system, the readings were taken for many different distances in areas covered by the two base stations. The measurements include line of sight and no line of sight points.

RESULTS AND DISCUSSION

The measured path loss values are determined from equation (1), and the results are shown in Fig.1 and Fig. 2 for base station T1 and T2 respectively. Log-normal shadowing, Cost231, Lee and SUI models were applied in the area covered by each base station. The predicted path loss values are obtained by applying equations (3), (5), (7) and (13), and the results is also shown in Fig. 1 and 2 for each base station. It is clear that the SUI and Cost231 models are far away from the measured data, whereas the Lee and the log-normal shadowing are closer. A better insight can be obtained by computing the root mean square error (*RMSE*) associated with each model using the following equation (Wu, 1998).

$$RMSE = \sqrt{\sum_{i=1}^{N}(P_{Lm} - P_L)^2 / N} \tag{18}$$

where P_{Lm} is the measured path loss in dB, P_L is the predicted path loss in dB, and N is the number of measured data Points. The corresponding root mean square error is given in Tables (3) and (4).

By examining the root mean square error (RMSE) in Tables 3 and 4, as well as the graphics in Figures 1 and 2, it is clear that log -normal shadowing is closest to measured data. As for the lee model, it seems close to the measured data, but its RMSE is greater than that of the log-normal shadowing. In addition, the results clearly show that the measured path loss is smaller than the predicted path loss by the SUI model and the cost231 model. There are several reasons which may cause those significant differences. First of all, the geographical situation of countries, which were designed by are different from that in Malaysia due to geographical differences.

Table 3: Root Mean Square Error for T1.

Model	RMSE
Log-Normal Shadow	11.9
Cost231Model	36.5
Lee Model	12.7
SUI Model	63.1

Table 4: Root Mean Square Error for T2.

Model	RMSE
Log-Normal Shadow	10.40
Cost231Model	46.84
Lee Model	14.88
SUI Model	57.05

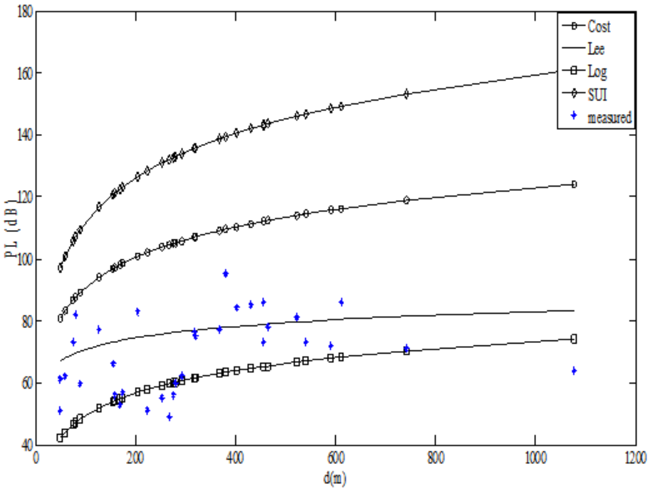

Fig. 1: Path loss as function of distance for T1.

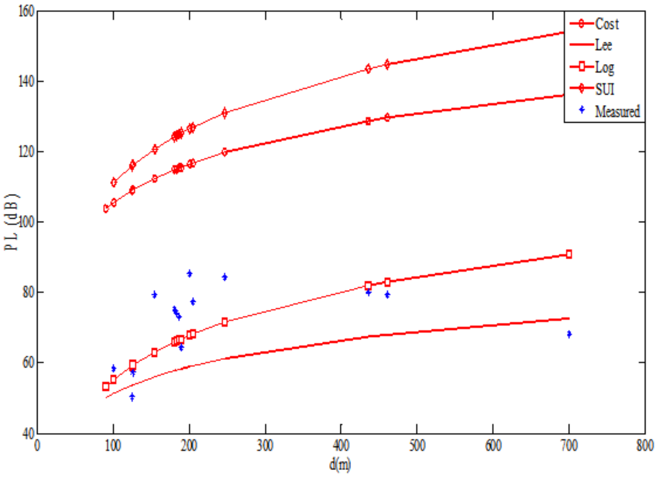

Fig. 2: Path loss as function of distance for T2.

Conclusion:

In this paper, the measured path losses in two cells are compared with four models: log-normal shadowing, lee, cost231 and SUI. The result shows that SUI and Cost231 models are very far from the measured data. The log-normal shadowing model and lee model are closer to the measurement results.

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