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# Comparison Between Measured and Predicted Path Loss for Mobile Communication in Malaysia

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**Abstract:** Path loss models are crucial in the planning of wireless network as they assist in interference estimations, frequency assignments and evaluation of cell parameters. This paper reports measurement results of the propagation path loss in four locations in the suburban area of Kuala Lumpur. The measured path loss at each location is extracted from the data and compared with the corresponding results obtained from the six models: Log-normal shadowing, Lee model, Stanford University Interim model (SUI), COST231 Hata model, Egli model and the Electronic Communication Committee (ECC)-33. The measured results show that the SUI and the log-normal models give in general a better prediction and can be used to estimate path loss for prediction of mobile coverage in a microcell in Malaysia.

**Key words:** Path loss · Wave propagation · Empirical models

## INTRODUCTION

Propagation path loss models are an essential step in planning a wireless communication system. It is crucial in interference estimations, frequency assignments and evaluation of cell parameters. These models are divided into three basic classifications: theoretical, empirical and physical [1]. Actual environments are too complex to model accurately. In practice, most simulation studies use empirical models that have been developed based on measurements taken over a given distance for a specific frequency range and in a particular geographical area or topology. Many 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, the efficiency of the existing path loss models suffers when they are used in an environment other than the one for which they have been designed. Several studies conducted in Malaysia and other tropical countries have found that many common path loss models perform less efficiently when compared to measured data [2-5]. Hence, this prompts the necessity to investigate and determine the models that suit the Malaysian environmental conditions. This paper will investigate the performance of six common models with measured data in four locations in the suburban area of Kuala Lumpur the capital of Malaysia.

The structure of this paper is as follows. Section 2 presents an overview of six common path loss models. The tools used for obtaining the measured data are described in Section 3, along with the locations where the data is collected. Section 4 discusses the results and the main conclusion is summarized in Section 5.

**Empirical Models for Propagation Path Loss:** Many propagation empirical path loss models are available to predict path loss over irregular terrain. However, their approach differs in terms of its complexity and accuracy. This section discusses the most common propagation empirical path loss models used to predict attenuation between transmitter and receiver.

**Egli Model:** Egli Model is a terrain model for radio frequency propagation. It is suitable for use in mobile systems in the bands of 3MHz- 3GHz and is normally used when there is LOS between one fixed antenna and one mobile antenna [6]. The model takes into consideration the frequency, antenna height and polarization, forcing an agreement between the plain earth loss and the measured

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values by using the correction factors that consider all these elements. This model predicts the total path loss for a point-to-point link and it is suitable for cellular communication scenarios where one antenna is fixed and other is mobile. It is applicable to the scenario where the transmission has to go over an irregular terrain. Egli model is not applicable to a scenario where some vegetative obstruction is in the middle of the link. This model is selected for this study as the Egli model can be used for path loss prediction in the frequency range which is suitable for this study [7]. The formulas for the Egli's propagation loss prediction, $P_L$, are given in dB as follows [8]:

$$P_L = \begin{cases} 20\log_{10} f_c + P_0 + 76.3, & h_r \le 10 \\ 20\log_{10} f_c + P_0 + 83.9, & h_r > 10 \end{cases} \quad (1)$$

where

$$P_0 = 40\log_{10} d - 20\log_{10} h_t - 10\log_{10} h_r$$

$f_c$ : Frequency of transmission in MHz.
$h_t$ : Height of the base station antenna in meter.
$h_r$ : Height of the mobile station antenna in meter.
d : Distance from base station antenna in km.

**ECC-33 Path Loss Model:** The ECC-33 path loss model is developed by the Electronic Communication Committee (ECC). It is extrapolated from original measurements by Okumura and modified its assumptions [9]. The initial experimental of Okumura model were carried out at the suburban areas of Tokyo. In the Okumura model, it subdivides the urban areas into large city and medium city categories and gives correction factors to suburban and open areas [10]. A typical European city is quite different from the environment characteristics of Tokyo which is a highly build-up city. The ECC-33 path loss model is an empirical model composed from four terms [11] and it is defined in dB as:

$$P_L = A_{fs} + A_{bm} - G_b - G_m \quad (2)$$

where, $A_{fs}$, $A_{bm}$, $G_b$ and $G_m$ are the free space attenuation, the basic median path loss, the base station (BS) antenna height gain factor and the mobile station (MS) antenna height gain factor respectively. The detailed expressions for these terms can be found in [11].

**Log-Normal Shadowing Model:** The majority of radio propagation models are derived employing a combination of empirical and analytical methods. The empirical approach is based on appropriate curves or analytical expressions that recreate a set of measured data. Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels [12]. Such models have been used extensively in the literature. The average large-scale path loss for an arbitrary transmitter receiver (T-R) separation $d$, is expressed as a function of the path loss at a reference distance $d_0$ by using a path loss exponent, $n$.

$$\overline{P}_L(d) = \overline{P}_L(d_0) + 10n \log_{10}(d/d_0) \quad (3)$$

where $n$ 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 [12].

Measurements have shown that at any value of $d$, the path loss $P_L(d)$ (in dB) at a particular location is random and distributed log-normally about the mean distance-dependent value [12]. That is

$$\overline{P}_L(d) = \overline{P}_L(d_0) + 10n \log_{10}(d/d_0) + X_\sigma \quad (4)$$

where $X_\sigma$ is a zero-mean Gaussian distributed random variable in dB with Standard deviation σ also in dB.

The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but have different levels of clutter on the propagation path [12]. This phenomenon is referred to as lognormal shadowing. The close-in reference distance $d_0$, the path loss exponent $n$ and the standard deviation σ, statistically describe the path loss model for an arbitrary location having a specific T-R separation and this model may be used in computer simulation to provide received power levels for random locations in communication system design and analysis. In practice, the values of n and σ are computed from measured data, using linear regression such that the difference between the measured and estimated path losses is minimized in a mean square error sense over a wide range of measurement locations and T-R separations [12].

**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 [13]. In addition, its prediction aptitude can be significantly improved by the incorporation of measurement data. The Lee model was initially developed for use at 900 MHz and has two modes: area-to-area and point-to-point [14]. A frequency adjustment factor is an important feature characterizes this model. This factor 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 [15].

For Lee area-to-area mode which will be used in this study, Lee uses a reference median path loss $L_o$ at a range of 1 km, 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:

$$P_L(d) = L_0 + \gamma \log_{10} d - 10\log_{10} F_0 \qquad (5)$$

A number of empirical values for the reference median path loss $L_o$ and the slope of the path loss curve _γ are given in [14]. The adjustment factor $F_0$ is comprised of several parameters and can be expressed as,

$$F_0 = F_1 F_2 F_3 F_4 F_5 \qquad (6)$$

where $F_1$, $F_2$, $F_3$, $F_4$ and $F_5$ represents the respective correction factors for the base station antenna height, the base station antenna gain, the mobile antenna height, the frequency and the mobile antenna gain. The expressions of these factors can be found in [15].

**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. This model is adopted by the IEEE 802.16 group as the recommended model for fixed broadband applications [16]. This model is an extension of the Hata model with correction parameters for frequencies above 1900MHz. SUI model is proposed as a solution for planning the WiMAX network on a 3.5GHz band. SUI model can be used for the height of base station antenna from 10m to 80m, the receiving antenna height between 2m and 10 m and the cell radius between 0.1km and 8km [17].

The SUI model is used for path loss prediction in rural, suburban and urban environments. 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 [18]. However, due to the availability of correction factors for the operating frequency, this model is selected for this study. The basic expression for path loss calculation according to the SUI model is given by [19]:

Table 1: Model parameter and terrain types [17]

| 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 |

$$P_L(d) = A + 10n \log_{10}(d/d_0) + X_f + X_h + S \qquad (7)$$

where $d$ is the distance in meters between the base station and the receiving antenna, $d_o$ is smaller than $d$, $X_f$ is a correction for frequency above 2 GHz, $X_h$ is a correction factor for the receiver antenna height and $S$ is a correction for shadowing because of trees and other clutters on a propagation path. The novelty of this model lies in the introduction of the path loss exponent $n$ 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 [18]. The parameter $A$ is defined as follows:

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \qquad (8)$$

where λ is the wavelength in meters. Path loss exponent $n$ is given by:

$$n = a - b h_t + \frac{c}{h_t} \qquad (9)$$

where $h_t$ 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.

SUI offers the correction factors $X_f$ and $X_h$ for the operating frequency and for the antenna height of the receiver respectively [17, ERC 99]. They are defined as follows:

$$X_f = 6\log_{10}\left(\frac{f}{2000}\right) \qquad (10)$$

$$X_h = \begin{cases} -10\log_{10}\left(\dfrac{h_r}{2000}\right), & \text{for } A \text{ and } B \\ -20\log_{10}\left(\dfrac{h_r}{2000}\right), & \text{for } C \end{cases} \qquad (11)$$

where, $f$ is the frequency in MHz, $h_r$ is the receiver antenna height in meters, A, B and C are terrain types.

**COST 231-Hata Models:** The COST 231 model 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 [20-21]. The basic equation for path loss in dB is [12, 22]:

$$P_L(d) = A + B\ \log_{10} d + C \tag{12}$$

where

$$A = 46.3 + 33.9\log_{10} f_c - 13.82\ \log_{10} h_t - a(h_r)$$

and

$$B = 44.9 - 6.55\ \log_{10} h_t$$

The correction parameter, $C$ is equal to 3dB for urban or equal to 0 dB for suburban [13]. The frequency $f_c$ is in *MHz* and it ranges from 1500 MHz to 2000 MHz. The effective base station transmitter antenna height $h_t$ is in meters ranging from 30 m to 200 m, while the effective mobile receiver antenna height $h_r$ is in meters ranging from 1 m to 10 m. The T-R separation distance $d$ is in km and $a(h_r)$ is the correction factor for effective mobile antenna height which is a function of the size of the coverage area. The expression for the correction parameter $a(h_r)$ is defined for suburban as follows [18]:

$$a(h_r) = \left(1.1\ \log_{10} f_c - 0.7\right)h_r - \left(1.56\ \log_{10} f_c - 0.8\right)$$

But for urban environments, the expression becomes

$$a(h_r) = \begin{cases} 8.29\left[\log_{10}\left(1.54h_r\right)\right]^2 - 1.1, & f_c \le 300MHz \\ 3.2\left[\log_{10}\left(11.75h_r\right)\right]^2 - 4.97, & f_c > 300MHz \end{cases}$$

Although the COST 231 model is limited to BS antenna height greater than 30m, it can be used for lower BS antenna heights provided that surrounding buildings are well below the BS antennas. It can predict path loss at lower distances, but it should not be used to estimate path loss in urban canyons or for short distances where the path loss becomes highly dependent upon the surrounding structures and topology [22].

**Experimental Setup and Data Collection:** The measurement system consists of laptop with Test Equipment for Mobile Systems (TEMS) investigation software installed. In addition, the system uses a mobile handset T610 with TEMS Pocket software installed and global positioning system (GPS) receiver. The received power 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. The numbers of readings were 50 reading for each coverage area. The International Islamic University Malaysia (IIUM) and University Putra Malaysia (UPM) campuses were selected to obtain the measurements. In each campus two sites were chosen. The measurements were conducted during the daytime. IIUM is geographically located at latitude (3.253 degrees) north of the Equator and longitude (101.7375 degrees) east of the prime meridian on the map of Kuala Lumpur. UPM is geographically located at latitude (2.989 degrees) north of the equator and longitude (101.7063 degrees) east of the prime meridian on the map of Kuala Lumpur. For the IIUM two base stations were selected within its campus, which are engineering's base station (T1) and Nusseibeh hostel's base station (T2). With regard to the UPM two base stations were selected within its campus, which are mosque's base station (T3) and hostel's base station (T4). These locations can be classified as very smooth plain or smooth plain.

## RESULTS

The path loss has been estimated using the six models described earlier. All these models were selected because they are data-dependent and can predict the mean path loss as a function of various parameters, for example distance and antenna heights. In addition, these models are suitable for frequencies ranging from 1800 MHz to 1900 MHz. The predicted and measured path losses are shown in Figure 1 to Figure 4 for the four locations: T1, T2, T3 and T4.

From Figure 1 to Figure 4, it can be observed that in all four cases the Lee and ECC-33 models overestimates the propagation path loss values while the Egli and Cost231 models underestimates it. However, for a distance larger than 300m, the measured path losses are closest to the SUI model for the three locations: T1, T2 and T3. For smaller distances, the log-normal model produces the best fit. For location T3, the measured path loss is best estimated by the log-normal model and followed by the SUI model. Therefore, the results show that the SUI and the log-normal models can be used to estimate path loss in mobile microcell coverage Malaysia.

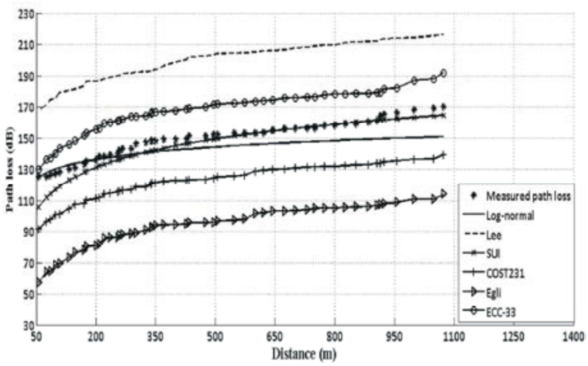


Fig. 1: Comparison between measured path loss and that predicted by using empirical models for T1

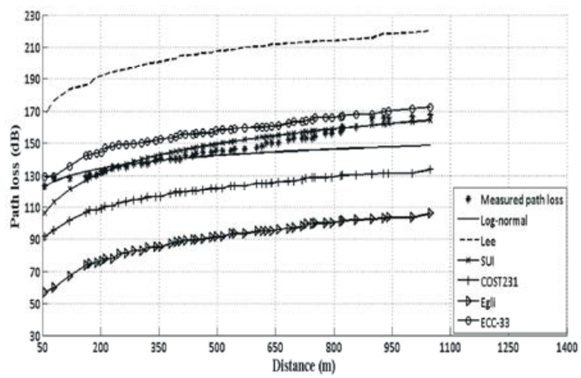


Fig. 2: Comparison between measured path loss and that predicted by using empirical models for T2

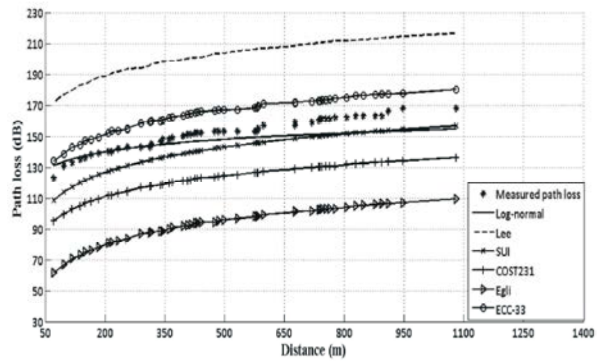


Fig. 3: Comparison between measured path loss and that predicted by using empirical models for T3

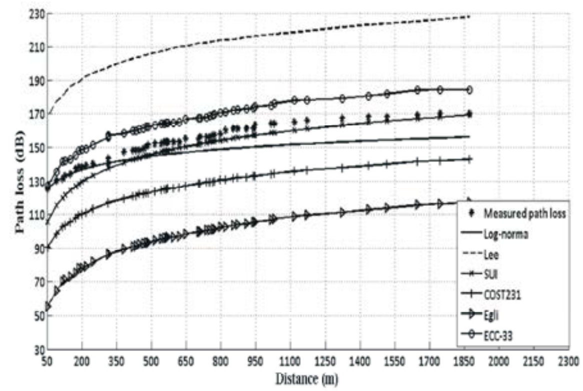


Fig. 4: Comparison between measured path loss and that predicted by using empirical models for T4

## CONCLUSION

The path loss has been estimated using six models, namely the log-normal shadowing model, Lee model Stanford University Interim, COST231Hata model, ECC-33 model and Egli model. The measured results show that the SUI model gives in general a better prediction for distances between 300m and 1100m from the base station, whereas the log-normal produces the best results for smaller distances.

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