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Adjustment of Lee Path Loss Model for Suburban Area in Kuala Lumpur-Malaysia

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Abstract. Path loss models are essential for appropriate wireless network planning as they assist in interference estimations, frequency assignments, and the evaluation of cell parameters. One of the commonly used propagation models is the Lee model which is characterized by its simplicity and good prediction accuracy. This study will estimate the best values for the two parameters of Lee model (γ and L_0) which are suitable for suburban environment in Malaysia. The performance of the adjusted Lee model is then compared to the three widely used empirical path loss models which are: Sanford University Interim, COST231 Hata and Egli models. The Root Mean Square Error (RMSE) and the Chi square test (χ^2) are used to compare the performance of the four empirical path loss models. The study found that the adjusted Lee model outperforms the other empirical models.

Keywords: path loss, wave propagation, empirical models.

1. 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 [1]. 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. In addition, propagation models are useful for predicting path loss or attenuation of signal. Many propagation models are available to predict path loss over irregular terrain. As all these models aim to predict signal strength at a specific receiving point, their approach is different in terms of its complexity and accuracy. The majority of these models are based on a systematic interpretation of measurement data obtained in the service area. They may be suitable for specific areas, and particular terrain and climate. That's why it is so difficult to generalize these models to any environment. In order to overcome this problem, the parameters of certain empirical model can be adjusted with reference to the targeted environment in order to achieve minimal error between predicted and measured signal strength. As result, the model will be more accurate for received wireless signal predictions. Least square algorithm has been used to fit a linear model to data [2]. This process can be achieved by minimizing the summed square of residuals between measured data and prediction model data. The coefficients are determined by differentiating summed square of residuals with respect to each parameter and setting the result equal to zero [3]. In this paper, two parameters of the Lee path loss model were modified using least square algorithm to fit to measured data for suburban areas in Kuala Lumpur. The performance of the adjusted Lee model is compared with three empirical path loss models: Sanford University Interim (SUI), COST231 Hata and Egli path loss models.

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The structure of this paper is as follows. Section 2 presents an overview of Lee path loss model, followed by a brief description of the SUI, COST231 Hata, and Egli 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.

2. Empirical path loss models

2.1. Lee Model

Lee model is relatively simple and intuitive to use and it is characterized by its aptitude to achieve good prediction accuracy. In addition, its prediction can be significantly improved by the incorporation of measurement data [4]. In the beginning, the Lee model was developed for use at 900 MHz and has two modes: area-to-area and point-to-point [5]. The Lee model is a modified power law model with correction factors for antenna heights and frequency and has the ability to be easily customized to the local environment. 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 [4][6].

For the area-to-area mode, Lee uses a reference median path loss at a range of 1 km, called L_0, the slope of the path loss curve, γ in dB/decade, and an adjustment factor F_0. The median loss at distance, d, is given by

$$\boldsymbol{P_L(d)(dB) = L_o + \gamma log_{10}\, d - 10\, log_{10}(F_o)} \qquad (1)$$

The adjustment factor F_0 is comprised of several parameters and can be expressed as,

$$F_o = F_1 F_2 F_3 F_4 F_5 \qquad (2)$$

where F_1, F_2, F_3, F_4, and F_5 represents the respective correction factors for the base station antenna height (h_b), the base station antenna gain (G_b), the mobile antenna height (h_m), the frequency (f), and the mobile antenna gain (G_m). The values of these various factors can be computed as follows [2] [4]:

$$F_1 = \left(\frac{h_b(m)}{30.48}\right)^2 = \left(h_b\left(\frac{ft}{100}\right)\right)^2 \qquad (3a)$$

$$F_2 = \frac{G_b}{4} \qquad (3b)$$

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

$$F_4 = \left(\frac{f}{900}\right)^{-n} \quad \text{, for } 2 < n < 3 \; and \; f \text{ in MHz} \qquad (3d)$$

$$F_5 = \frac{1}{G_m} \qquad (3e)$$

where G_m is the gain of the mobile antenna relative to a half-wave dipole.

2.2. Other Empirical models

The COST 231 model, sometimes called the Hata model PCS extension, is an improved version of the Hata model [2]. 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, and its expression is defined in [2][7]. Although the Cost 231 model is limited to base station (BS) 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 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 [8].

The SUI Model is another path loss model. It is adopted by the IEEE 802.16 group as the recommended model for fixed broadband applications [9]. This model is an extension of the Hata model with correction parameters for frequencies above 1900 MHz. The basic expression for the SUI model is given in [10].

Egli Model is suitable for cellular communication scenarios where one antenna is fixed and the other is mobile [11]. It is applicable to the case 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. The formulas for the Egli's propagation loss prediction are provided in [11].

3. Data Collection

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). 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 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.

4. Results and Discussion

The parameters of the Lee path loss model were adjusted using least square algorithm to fit to measured data using the following process. First, the residual between measured path loss, P_{Lm}, and the predicted value, P_L, by the Lee model is calculated for each location point which is a distance *d* from the base station by [6]

$$e(d) = P_{Lm}(d) - P_L(d) = P_{Lm}(d) - [L_o + \gamma \log_{10} d - 10\log_{10}(F_o)] \quad (4)$$

where P_{Lm} and P_L are in dB and d is in km.
Second, the RMSE function computation of this residual is calculated based on [3]

$$RMSE = \sqrt{\sum_{i=1}^{N}(e(d_i))^2 / N} \quad (5)$$

where *N* is the number of the measured data points. Then, the least squared algorithm is used to determine the values of L_0, and γ that minimizes the residual RMSE [3]. The estimated values of the parameters L_0 and γ for the four base stations are calculated and presented in Table 1. It seems from Table 1 that there is variation in values of L_o and γ. This is due to wide different streets and different building heights in coverage areas as well as the difference in the undulation of area.

Table1: Tuned Lee model parameters

	T1	T2	T3	T4
γ	31.769	28.501	20.370	18.295
L_o	62.968	73.114	100.402	105.967

The performance of the adjusted Lee model is then compared to the COST231 Hata model, SUI model and Egli model. The performance is measured by comparing the predicted path loss values with the measured one using the RMSE and the Chi square test. The RMSE can be computed from Eq(5), whereas the Chi square statistic, χ^2, can be determined from the following expression [12]

$$\chi^2 = \sum_{i=1}^{N} \frac{(P_{Lm} - P_L)^2}{P_L} \quad (6)$$

where *N* is the number of samples. This means that the number of degree of freedom, *df*, is equal to *N*-1. According to [12], if the $\chi^2 < df$, the observed and the expected values are in agreement, and the model reflects the measured data. On the other hand if $\chi^2 \geq df$, the observed and expected values differ significantly. The values of the two performance measures, *RMSE* and χ^2, are tabulated in Table 2.

Table 2: *RMSE* and χ^2 comparison between adjusted Lee model with known models for T1, T2, T3 and T4

EMPIRICAL MODELS	T1		T2		T3		T4	
	RMSE	χ^2	*RMSE*	χ^2	RMSE	χ^2	RMSE	χ^2
LEE MODEL	8.73	27.06	9.87	32.02	9.74	30.39	7.28	17.79
COST231 MODEL	26.46	295.96	29.44	591.31	30.74	397.40	29.18	352.44
SUI MODEL	8.45	28.34	9.49	32.25	15.19	87.29	10.238	39.728
EGLI MODEL	55.86	$1.77\ 10^3$	56.39	$1.84\ 10^3$	59.42	$1.98\ 10^3$	58.049	$1.87\ 10^3$

From the results in Table 2, few points can be noted. It is found that performance of the proposed adjusted Lee model is the best since the values of the *RMSE* and χ^2 are the lowest compared to the other three models. COST231 Hata model and Egli model, on the other hand, seem to overestimate the path loss for the four coverage areas. The SUI model performance is reasonable close to the adjusted Lee model. Figure 1 consolidates the result that adjusted Lee model is the closest to the measured path loss.

The two parameters L_o and γ were calculated based on measured data. However, in most cases the measured data at most areas are not available. In order to use the adjusted Lee model, most suburban areas of Kuala Lumpur can be classified as plain or hilly areas. For example the coverage areas of T1 and T2 have similar topology and can be considered hilly areas. On the other hand, the coverage areas of T3 and T4 can be considered plain areas. Values is assigned to the two parameters for each category by averaging the results obtained for T1 and T2 for the hilly area and by averaging that of T3 and T4 for the plain area as shown in Table 3.

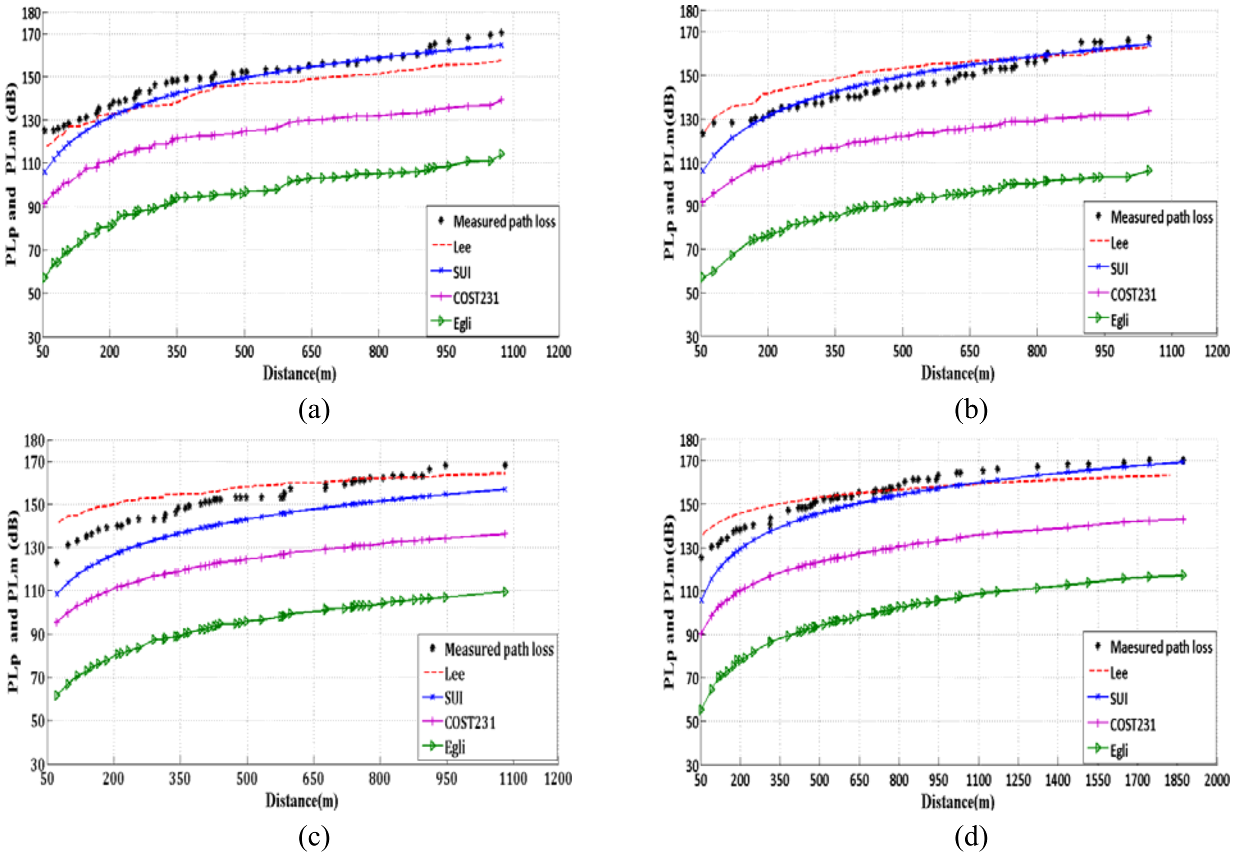

Fig. 1 Comparison between adjusted Lee model and empirical models with reference measured data for a) T1, b) T2, c) T3 and d) T4.

Table 3: Adjusted Lee model parameters

Parameters	***Hilly area***	***Plain area***
γ	30.14	19.33
L_o	68	103.14

The adjusted Lee model is used to calculate the path loss and the result is compared with the measured path loss and the estimated SUI model. The COST231 Hata and the Egli models are not considered here since their performance were shown earlier to be poorer. Table 4 shows the root mean squared error and Chi square test for these two models. Once again, the adjusted Lee model showed more agreement with the measured path loss values than the SUI model. Figure 2 shows the comparison between measured path loss and Lee model and Stanford University Interim. It is clearly evident that the adjusted Lee model shows the closest agreement with the measurement result. Therefore, the Lee model with the suggested parameters outperforms the other three models for hilly and plain areas.

Table 4: *RMSE* and χ^2 comparison between adjusted Lee model with SUI model for T1, T2, T3 and T4

EMPIRICAL MODELS	**T1**		**T2**		**T3**		**T4**	
	RMSE	χ^2	***RMSE***	χ^2	**RMSE**	χ^2	**RMSE**	χ^2
LEE MODEL	8.16	23.35	8.78	25.73	8.75	24.95	8.77	24.84
SUI MODEL	8.45	28.34	9.49	32.25	15.19	87.29	10.24	39.73

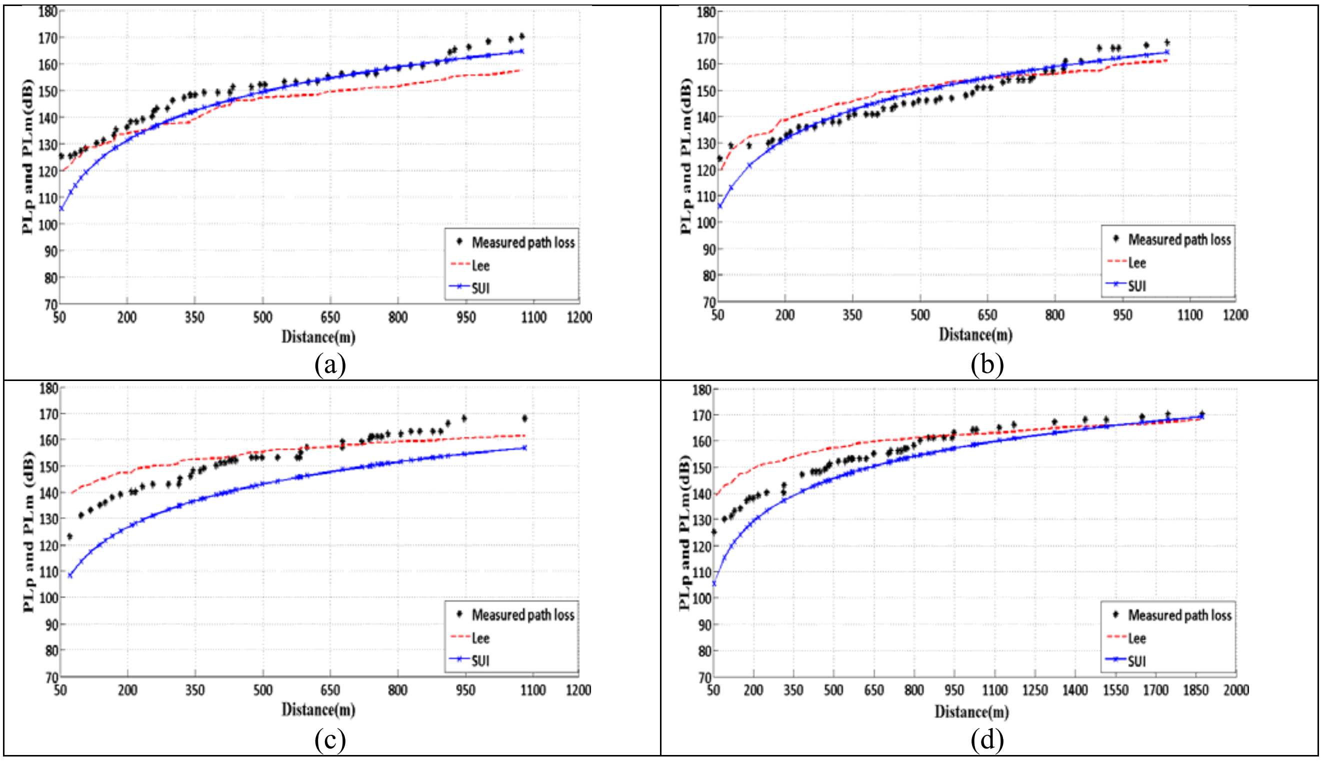

Fig. 2 Comparison between adjusted Lee model and SUI model with reference measured data for a) T1, b) T2, c) T3 and d) T4

5. Conclusion

This paper proposed new values for the two parameters γ and L_0 of the Lee model for hilly and plain areas. The new values are derived from measured data at four suburban areas in Kuala Lampur and using the least squared algorithm. The measured path losses at the four areas were compared with the predicted ones using the adjusted Lee model along with COST231 Hata, SUI and Egli models. It was found that the adjusted Lee model outperforms the other three models since it produces the lowest RMSE and χ^2 statitic. In addition, it is found that COST231 Hata, and Egli empirical models overestimates the path loss in all the measured areas.

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