Progress In Electromagnetics Research C, Vol. 13, 91–106, 2010

OPTIMIZATION OF HATA PROPAGATION PREDICTION MODEL IN SUBURBAN AREA IN MALAYSIA

R. Mardeni and K. F. Kwan

Faculty of Engineering
Multimedia University
Jalan Multimedia, 63100 Cyberjaya, Selangor, Malaysia

Abstract—This paper describes a study on RF attenuation path loss behavior in suburban coverage within Cyberjaya and Putrajaya areas, located in Selangor State in Malaysia. The objective of this study is to develop and optimize a path loss model based on the existing Hata path loss model and outdoor measurement using frequency range from 400 MHz to 1800 MHz. The optimized model had been used and validated at places within Putrajaya area to find the relative error in order to assess its performance. The values for modified empirical parameters of Hata model were developed and presented in this paper. From the simulation result, the optimized model is found to best fit into the base station located at Putrajaya with smaller mean relative error. The smaller mean error shows that the optimization has been done successfully and thus, this optimized model can be useful to telecommunication providers in Malaysia in order to improve their service for mobile user satisfaction.

1. INTRODUCTION

We are facing degradation of the mobile phone signal due to various obstacles between base station and mobile stations in suburban area. This problem must be addressed by Malaysia telecommunication providers in order to improve their service for user satisfaction where the competition is high in Malaysia. Thus, an accurate path loss model is useful to predict the signal strength at suburban area as well as to achieve a high quality of signal.

Path loss models are important for predicting coverage area, interference analysis, frequency assignments and cell parameters which are basic elements for network planning process in mobile radio

Corresponding author: K. F. Kwan (kkfoong07@gmail.com).

systems. The propagation models can be divided into three types of models, namely the empirical models, semi-deterministic models and deterministic models. Empirical models are based on measurement data, statistical properties and few parameters. Examples of this model category will be Okumura model and Hata model. Semi-deterministic models are based on empirical models and deterministic aspects, examples being the Cost-231 and Walfish-Ikegami. Deterministic models on the other hand are site-specific, requires enormous number of geometry information about the city, computational effort and more accurate model.

The literature review shows that a lot of analytical and experimental works have been done for radio propagation in mobile environment by using measurement as in [1, 2]. There was study on propagation path loss in Malaysia environment [3] in sub-urban, jungle, open area and dense tree area and path loss exponent being compared with empirical model.

In this paper, Hata-model is selected for optimization using numerical analysis and simulation in Matlab since this model shows good performance compared to other models. The field measurement data was collected using suitable equipment for outdoor measurements and is then compared with the simulation results. Base stations (BTS) located at Cyberjaya and Purtajaya are used for this study. The base station's information such as transmit/receive frequency and antenna height are obtained from MCMC (Malaysian Communications and Multimedia Commission) for analysis purposes.

2. RADIO PROPAGATION PATH LOSS MODEL

Path loss refers to electromagnetic wave attenuation between transmitter and receiver in the communication system. Path loss might be due to effects such as diffraction, refraction, reflection, free space loss, coupling loss and absorption between Cyberjaya and Putrajaya.

2.1. Empirical Hata Model

Hata model is the most popular model that extensively used in Europe and North America. The model developed by Y. Okumura and M. Hata [4] and is based on measurements in urban and suburban areas at Japan in 1968. Validity range of the model is frequency f_c between 150 MHz and 1500 MHz, TX height h_b between 30 and 200 m, RX height h_m between 1 and 10 m and TX-RX distance r between 1 and 10 km.

Hata's Equation are classified into three models [5, 6]:

- Rural: open space, no tall trees or building in path
- Suburban area: Village Highway scattered with trees and house with some obstacles near the mobile but not very congested.
- Urban area: Built up city or large town with large building and houses.

Definition of parameters:
h_m: mobile station antenna height above local terrain height [m]
d_m: distance between the mobile and the building
h_0: typically height of a building above local terrain height [m]
h_{te}: base station antenna height above local terrain height [m]
r: great circle distance between base station and mobile [m]
$R = r * 10^{-3}$ great circle distance between base station and mobile [km]
f: carrier frequency [Hz]
$f_c = f * 10^{-6}$ carrier frequency [MHz]
λ: free space wavelength [m]
Path loss for Hata-model is defined as below:
Urban area path loss (dB)

$$L(\mathrm{db}) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} + (44.9 - 6.55 \log h_{te}) \log R - E \tag{1}$$

Suburban areas path loss,

$$\begin{aligned} L(\mathrm{db}) &= 69.55 + 26.16 \log f_c - 13.82 \log h_{te} + (44.9 - 6.55 \log h_{te}) \log R \\ &\quad -2\left[\left(\log\left(\frac{f_c}{28}\right)\right)^2 + 5.4\right] \end{aligned} \tag{2}$$

Rural path loss,

$$\begin{aligned} L\,(\mathrm{dB}) &= 69.55 + 26.16 \log f_c - 13.82 \log h_{te} + (44.9 - 6.55 \log h_{te}) \log R \\ &\quad -4.78\,(\log f_c)^2 + 18.33 \log f_c + 40.94 \end{aligned} \tag{3}$$

For urban area divided into:

- For large cities:

$$\begin{aligned} E &= 3.2\,[\log(11.7554 h_m)]^2 - 4.97 \quad f_c \geq 400\,\mathrm{MHz} \\ E &= 8.29\,[\log(1.54 h_m)]^2 - 1.1, \quad f_c \leq 200\,\mathrm{MHz} \end{aligned}$$

- For small and medium-sized cities:

$$E = [1.1 \log(f_c) - 0.7]\, h_m - [1.56 \log(f_c) - 0.8]$$

Cyberjaya is considered as a sub-urban area. Thus, the Hata Equation being used is as below:

$$L\,(\mathrm{dB}) = 69.55 + 26.16\log(f_c) - 13.82\log(h_{te}) + [44.9 - 6.55\log(h_{te})]\log(R)) - 2\left[\log\left(\frac{f_c}{28}\right)\right]^2 + 5.4 \quad (4)$$

Simplified (4),

$$L\,(\mathrm{dB}) = 69.936 + 22.16\log(f_c) - 13.82\log(h_{te}) + [44.9 - 6.55\log(h_{te})]\log(R) \quad (5)$$

As like any other empirical propagation models, Hata model contains three basic elements [7, 8]:

- initial offset parameter,
- initial system design parameter,
- establish slope of the model curve.

From Eq. (5), the initial offset parameter is fixed at:

$$E_0 = 69.936 \quad (6)$$

From Eq. (5), the initial system design parameter may be expressed as:

$$E_{sys} = 22.16\log(f_c) - 13.82\log(h_{te}) \quad (7)$$

The slope of model curve is a constant as expressed from Eq. (5) as follow:

$$\beta_{sys} = \beta\,[44.9 - 6.55\log((h_{te})] \quad (8)$$

2.2. Egli Model

The Egli Model is a terrain model for radio frequency propagation. Egli model was first introduced by John Egli in 1957 [9]. This prediction model is applicable at frequency from 40 MHz to 900 MHz and linking range is less than 60 km. It was derived from real-world data on UHF and VHF television transmissions in several large cities. It predicts the total path loss for a point-to-point link. Egli observed that there was a tendency for the median signal strength in a small area to follow an inverse fourth-power law with range from the transmitter, so the model is based on plane earth propagation. The formulas for the Egli's propagation loss prediction model are as below [10]:

For $h_m \leq 10$,

$$L_t\,(\mathrm{dB}) = 20\log_{10} f_c + 40\log_{10} R - 20\log_{10} h_b + 76.3 - 10\log_{10} h_m \quad (9)$$

For $h_m \geq 10$,

$$L_t\,(\mathrm{dB}) = 20\log_{10} f_c + 40\log_{10} R - 20\log_{10} h_b + 85.9 - 10\log_{10} h_m \quad (10)$$

where

h_b = Height of the base station antenna. Unit: meter (m)

h_m = Height of the mobile station antenna. Unit: meter (m)

R = Distance from base station antenna. Unit: meter (m)

f_c = Frequency of transmission. Unit: megahertz (MHz)

From the formulas, it is noted that this model predicts that the average signal strength will decrease with the distance at a rate of 40 dB/decade. The decrement rate is not depending on the effective height of the radio base station antenna or other factors if all theses factors remain the same throughout the whole distance of measurement.

2.3. Cost 231 (Walfisch and Ikegami) Model

This empirical model is a combination of the models from J. Walfisch and F. Ikegami. It was further developed by the COST 231 project. It is now called Empirical COST-Walfisch-Ikegami Model. The frequency ranges from 800 MHz to 2000 MHz. This model is used primarily in Europe for the GSM1900 system [11, 12].

Path Loss,

$$L_{50}\,(\mathrm{dB}) = L_f + L_{rts} + L_{ms.} \tag{11}$$

where

L_f = free-space loss

L_{rts} = rooftop-to-street diffraction and scatter loss

L_{ms} = multiscreen loss

Free space loss is given as

$$L_f = 32.4 + 20\log d + 20\log f_c\,\mathrm{dB} \tag{12}$$

The rooftop-to-street diffraction and scatter loss is given as

$$L_{rts} = -16.9 - 10\log W + 10\log f_c + 20\log(h_r - h_m) + L_{ori}\,\mathrm{dB}. \tag{13}$$

With w = width of the roads

Orientation Loss

$$L_{ori} = \begin{cases} -9.646\,\mathrm{dB} & \text{for } 0 \leq \varphi \leq 35^\circ \\ 2.5 + 0.075(\varphi - 35)\,\mathrm{dB} & \text{for } 35^\circ \leq \varphi \leq 55^\circ \\ 4 - 0.114(\varphi - 55)\,\mathrm{dB} & \text{for } 55^\circ \leq \varphi \leq 90^\circ \end{cases}$$

Φ = incident angle relative to the street

The multiscreen loss is given as

$$L_{ms} = L_{bsh\text{-}} + k_{a\text{-}} + k_d \log R + \underline{k_f} \log f_c - 9\log R \tag{14}$$

With

$$L_{bsh} = \begin{Bmatrix} -18-18(h_{tx}-h_{roof}) & h_{tx} > h_{roof} \\ 0 & h_{tx} < h_{roof} \end{Bmatrix}$$

$$\bar{k}_a = \begin{Bmatrix} 54 & h_{tx} > h_{roof} \\ 54-0.8(h_{tx}-h_{roof}) & R \geq 500\,\mathrm{m};\ h_{tx} \leq h_{roof} \\ 54-1.6R(h_{tx}-h_{roof}) & R < 500\,\mathrm{m};\ h_{tx} \leq h_{roof} \end{Bmatrix}$$

$$k_d = \begin{Bmatrix} 18 & h_{tx} > h_{roof} \\ 18-15\left(\frac{h_{tx}-hroof}{hroof-hrx}\right) & h_{tx} < h_{roof} \end{Bmatrix}$$

$$\underline{k_f} = \begin{Bmatrix} 4+0.7\left(\frac{fc}{925}-1\right) & \text{for medium sized city and suburban area} \\ 4+1.5\left(\frac{fc}{925}-1\right) & \text{for metropolitan areas} \end{Bmatrix}$$

h_{tx} = transmitter height (m),
$h_r x$ = receiver height (m),
h_{roof} = roottop height (m)

3. BASE STATION DATA

Base station information is provided by MCMC [13] as shown in Table 1 with base station location in longitude, latitude, antenna height, transmit frequency, receive frequency, equivalent isotropically radiated power (EIRP), bearing and base station name. Table 1 depicted the spectrum allocation for mobile services in Malaysia. The base stations chosen for this study ranges from frequency 460 MHz, 800 MHz, 900 MHz and 1800 MHz.

Table 1. Spectrum allocation in Malaysia [13].

MHz	800	886	888	890	905
GSM900	MAXIS	DIGI	CELCOM	CELCOM	MAXIS
MHz	915	931	933	935	950
GSM900	MAXIS	DIGI	CELCOM	CELCOM	MAXIS
MHz	1710	1735	1760		
GSM1800	MAXIS	CELCOM	DIGI		
MHz	1805	1830	1855		
GSM1800	MAXIS	CELCOM	DIGI		

Table 2. Selected base station information [13].

BS No	Location	Base Station name	TX frequency Rx frequency MHz	Latitude Longitude	Antenna Height (m)
1	Cyberjaya	Multimedia University (MMUC)	925.2	2:55:30:N	20
			880.2	101:38:19:E	20
2		Cyberjaya	462.975	2:55:23:N	80
			452.975	101:39:0:E	80
3		KOMPLEKTSTMCBJ G0760	939.2	2:55:49:N	35
			894.2	101:39:23:E	35
4		NTT MSC Sdn Bhd	1855.4	2:55:40:N	31
			1760.4	101:39:35:E	31
5		MDEC	1852.2	2:55:25:N	25
			1757.2	101:39:32:E	25
6	Putrajaya	PUTRAJAYA	482.88	2:55:42:N	78
			462.87	101:41:23:E	78
7		PUTRAJAYAR5 G1566	936.6	2:56:16:N	42
			891.6	101:43:16:E	42
8		R2 PUTRAJAYA	877.23	2:57:14:N	41
			832.23	101:40:51:E	41
9		TM R5 PUTRAJAYA	878.49	2:56:53:N	60
			833.49	101:43:49:E	60
10		PRECINT 8. PUTRAJAYA	1806.2	2:68:28:N	60
			1710.2	101:40:6:E	60

Table 2 depicts the base station information at Putrajaya and Cyberjaya. The frequency ranges used are from 400 MHz to 1800 MHz; covering CDMA, GSM900 and GSM1900 technologies.

4. MEASUREMENT DATA

The data collection tool consists of test phone, Global Positioning System Receiver Set (GPS system) and a laptop equipped with ZXPOS CNT1 and CNA7 software. ZXPOS CNT1 is the professional foreground test software for communication networks. It can collect and display various types of network data in real time and provide users to learn the network performance and diagnose existing problems in short time.

The measured data was collected with six different routes for selected base station 2, 3 and 4 as shown in Figure 1. Field strength due to the base stations are examined as in Figure 2, Figure 3 and Figure 4.

Received power for BS 2 with frequency 462.975 MHz is better compare with BS 3 and BS 4 as in Figure 2. Due to building obstacles more than 3 km from base station, the received power is not stable and fluctuated. The received power is poor when the frequency is higher as in Figure 4 with frequency is 1855.4 MHz.

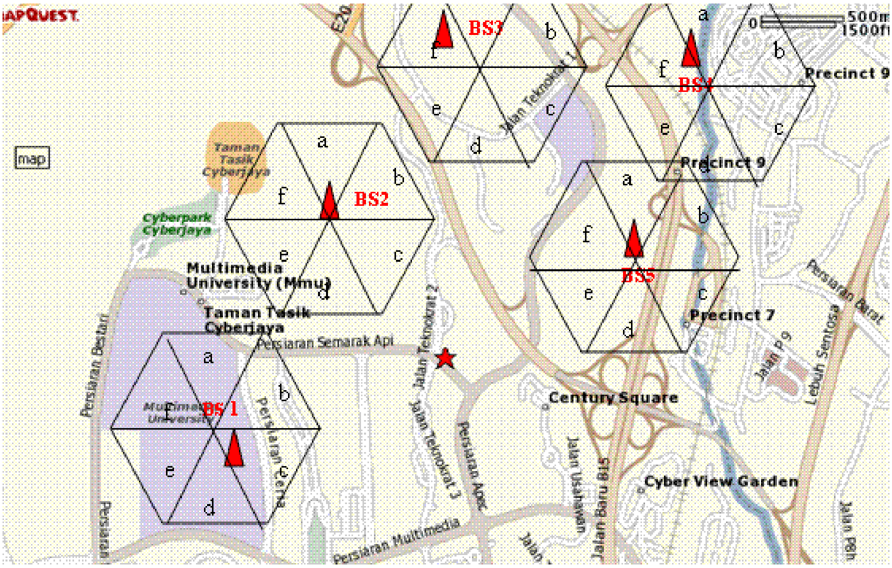

Figure 1. Detail location of base station in Cyberjaya Malaysia [14, 15].

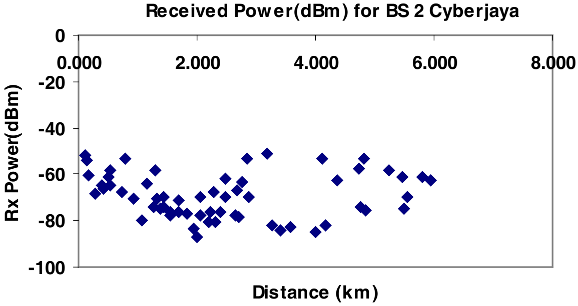

Figure 2. Base station 2 with frequency 462.975 MHz.

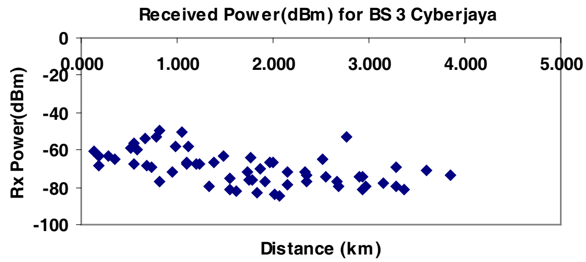

Figure 3. Base station 3 with frequency 939.2 MHz.

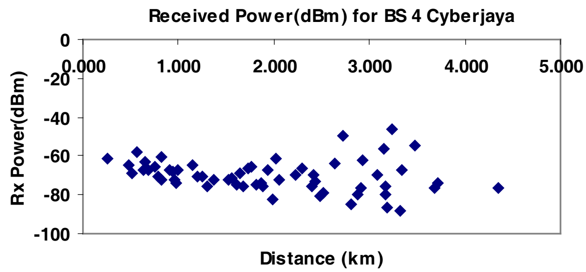

Figure 4. Base station 4 with frequency 1855.4 MHz.

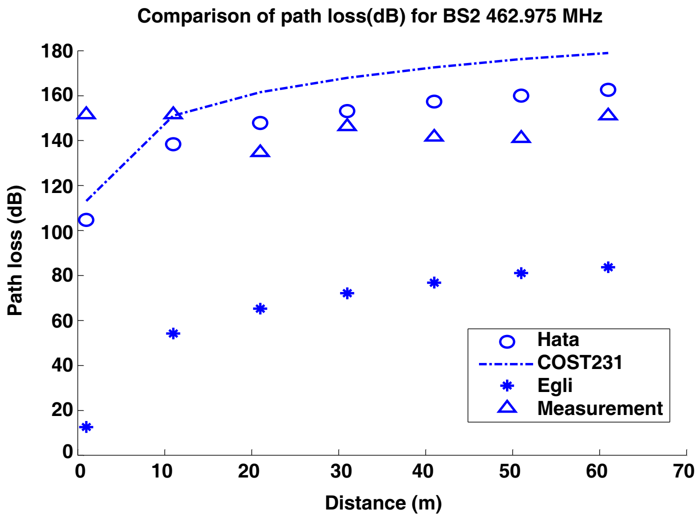

Figure 5. Comparative path loss model in BS 2.

In Figure 5 to Figure 7, the measurement data is examined with other known model such as Egli, COST-231 and Hata. The measurement data are more close to the Hata model. Other models are over estimate the path loss for suburban environment in Malaysia.

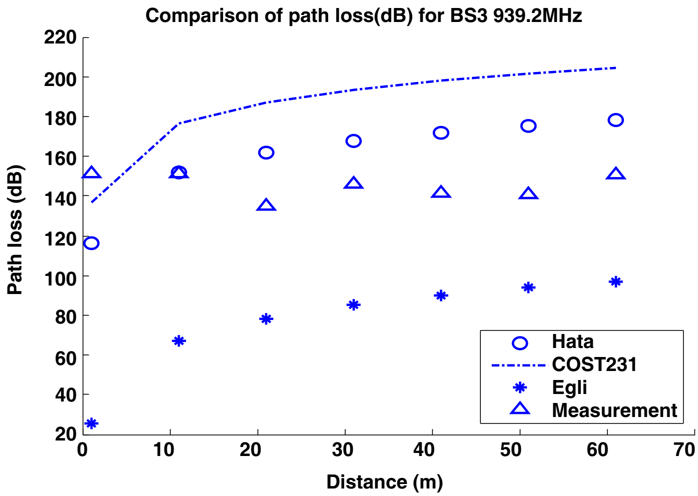

Figure 6. Comparative path loss model in BS 3.

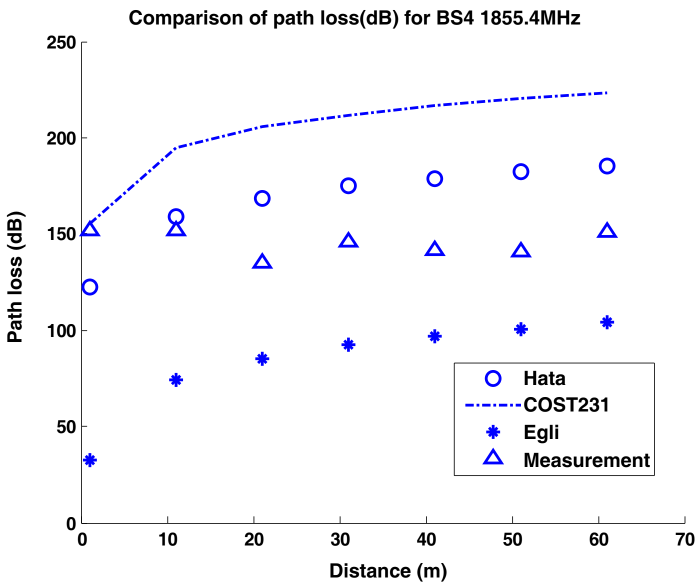

Figure 7. Comparative path loss model in BS 4.

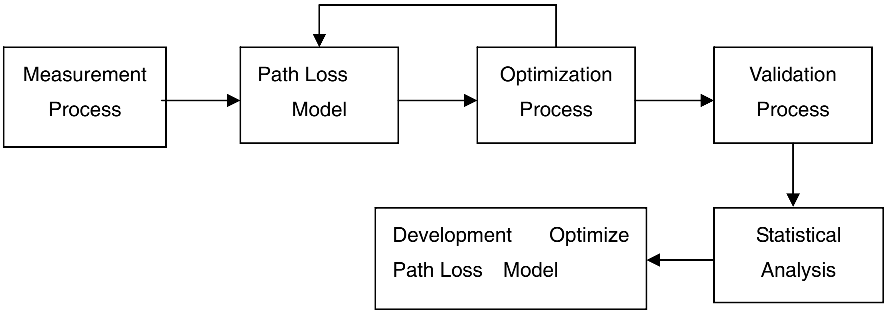

Figure 8. Flow chart of optimization process.

5. OPTIMIZATION PROCESS

Figure 8 shows the optimization process to optimize the Hata propagation model. The measurement data collected as stated in session 4. Optimization process was obtained by using least square method. The optimized model will be validated based on Putrajaya, Malaysia since the environment is similar with Cyberjaya. Statistical analysis such as relative error, standard deviation and variance were used to compare between the optimized model and other known models.

5.1. Optimization into the Model

For the optimization into the Hata model, initial system design parameter E_{sys} as in Eq. (7) and slope parameter β_{sys} in Eq. (8) are considered.

In this project, is proposed a new appropriate tool in optimizing to fit the measurement data with Hata model. The condition of a best fit of the theoretical model curve with a given set of experiment data would be met if the function of sum of deviation squares is minimum:

$$P(a, b, c, \ldots) = \sum_{i=1}^{n} [y_i - E_R(x_i, a, b, c, \ldots)]^2 = \min \tag{15}$$

where:

y_i = measurement result at the distance x_i;
$E_R(x_i, a, b, c,)$ = modeling result at the x_i *based on optimization*;
a, b, c = parameter of the modelbased on optimization;
n = Number of the experiment data set.

All partial differential of the P function should be equal zeros:

$$\begin{cases} \partial P/\partial a = 0; \\ \partial P/\partial b = 0; \\ \partial P/\partial c = 0; \\ \dots \end{cases} \tag{16}$$

Solution of Eq. (16) may simplified based on Eq. (60) to Eq. (8), parameters of the P function in Eq. (15) are expressed simplified as:

$$a = E_0 + E_{sys} \quad b = \beta_{sys}. \tag{17}$$

This would then mean that the expression of the Hata model in Eq. (5) transformed into:

$$E_R = a + b \cdot \log R \tag{18}$$

Simplified logarithm base $\log R = x$, the Eq. (18) becomes

$$E_R = a + b \cdot x \tag{19}$$

E_R is the path loss (dB).

Both factors a and b are constant for a given set of measurements. The solution of Eq. (16) may be expressed:

$$\begin{aligned} &\sum_{i=1}^{n} \left(y_i - E_R(x_i, a, b, c)) \cdot \frac{\partial E_R}{\partial a} \right) = \sum (y_i - a - bx_i) \cdot 1 = 0 \\ &\sum_{i=1}^{n} \left(y_i - E_R(x_i, a, b, c)) \cdot \frac{\partial E_R}{\partial b} \right) = \sum (y_i - a - bx_i) \cdot x_i = 0 \end{aligned} \tag{20}$$

By re-positioning of elements in Eq. (20) would provide the following expression:

$$n \cdot a + b \sum x_i = \sum y_i; \quad a \sum x_i + b \sum x_i^2 = \sum (x_i \cdot y_i) \tag{21}$$

By substituting the variable a and b into the Eq. (21), this would give the statistical estimates of parameters a and b:

$$\tilde{a} = \frac{\sum x_i^2 \cdot \sum y_i - \sum x_i \cdot \sum x_i y_i}{n \cdot \sum x_i^2 - \left(\sum x_i\right)^2}; \quad \tilde{b} = \frac{n \cdot \sum x_i y_i - \sum x_i \cdot \sum y_i}{n \cdot \sum x_i^2 - \left(\sum x_i\right)^2} \tag{22}$$

Eq. (22) allows for calculation of parameter a and b of the Hata model. The offset and slope parameters in the original Hata model can be calculated from Eq. (17) and Eq. (8):

$$\tilde{E}_o = \tilde{a} - E_{sys}; \quad \tilde{\beta} = \frac{\tilde{b}}{44.9 - 6.55 \cdot \log hte} \tag{23}$$

By substituting the measurement data using Eq. (22) and Eq. (23), number of E_0 and β values for different frequency bands can be obtained. By grouping the frequency band, the average values for the empirical model parameters were derived as presented in Table 3.

From Table 3, for higher frequencies, the initial parameter, E_o and β_{sys} will increase.

Table 3. Calculated empirical parameters for the Hata model.

	450 MHz	900 MHz	1800 MHz
E_o	52.747	65.370	73.680
β_{sys}	0.0166	0.0170	0.0183

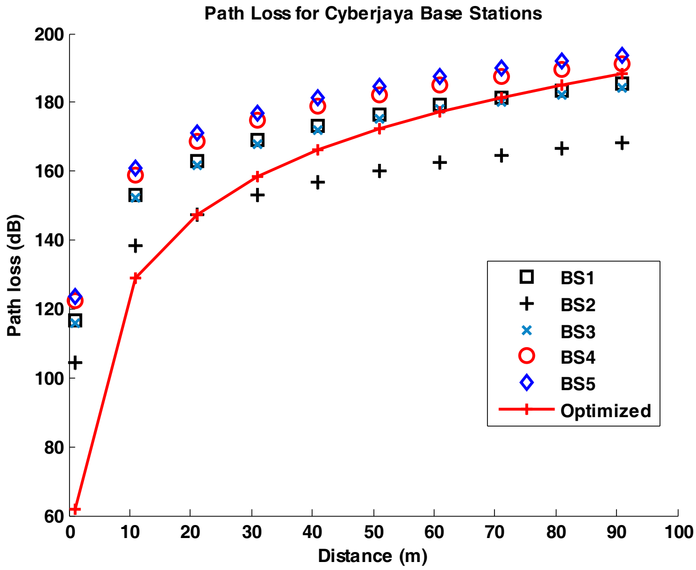

Figure 9. Comparative optimized model with other base station in Cyberjaya.

5.2. Simulation Result and Discussion

The optimized modal was validated for other base stations in Cyberjaya and Putrajaya and shown in Figure 9. It is shown that all the base stations are almost fit into the optimized model. Thus the optimized model is successfully developed with proper optimized procedure. The optimized model best fit into BS 3. BS 2 in 462.9 MHz resulting the lower path loss while BS 4 and BS 5 resulting high path loss in Hata-model.

The optimized model is also validated at different locations within Putrajaya in order to see the correctness of the optimized model as shown in Figure 10. From these results, it is shown that the optimized model does show a good agreement for all the base stations compared with Hata model. The performance of this optimized model is investigated using error analysis.

Relative errors had been calculated in order to see the performance of the model; using Eq. (24) as below [16]:

$$\delta = \frac{|V - V_{approx}|}{|V|} 100\% \tag{24}$$

where V = Empirical Path Loss (dB), V_{approx} = Optimized Hata Path Loss (dB).

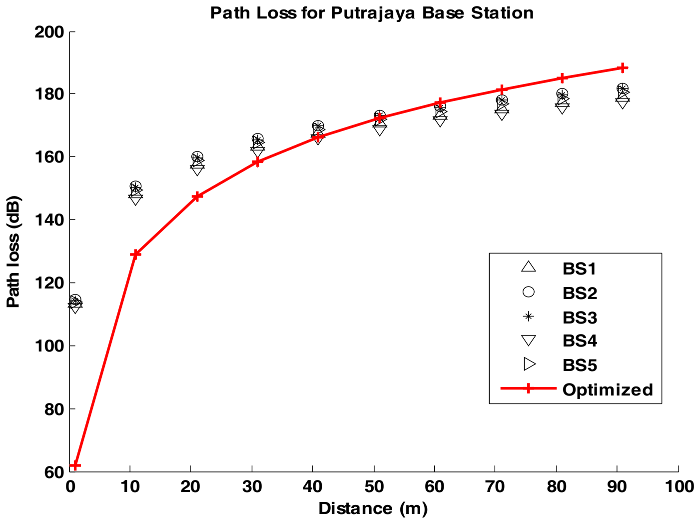

Figure 10. Path loss for selected base station in Putrajaya.

Table 4. Relative error comparison between optimized hata model with known models.

	Relative Error					Relative Error			
BS	Optimized	Hata	Egli	COST231	BS	Optimized	Hata	Egli	COST231
Cyberjaya					Putrajaya				
BS1	0.0565	0.2411	0.8354	2.6075	BS6	0.0570	0.1200	0.9642	2.6245
BS2	0.0571	0.1185	0.9726	2.6020	BS7	0.0578	0.1538	0.8422	2.9002
BS3	0.0570	0.1670	0.8397	2.8258	BS8	0.0573	0.1516	0.8521	2.8368
BS4	0.0611	0.2572	0.7412	3.2499	BS9	0.0600	0.1467	0.8567	3.0068
BS5	0.0642	0.2254	0.7422	3.3632	BS10	0.0780	0.1860	0.7479	3.7469
Average	**0.0592**	**0.2018**	**0.8262**	**2.9297**	**Average**	**0.0620**	**0.1516**	**0.8526**	**3.0230**
Standard Deviation	**0.0034**	**0.0577**	**0.0948**	**0.3579**	**Standard Deviation**	**0.0090**	**0.0235**	**0.0767**	**0.4280**
Variance	**1.13E-05**	**3.33E-03**	**9.00E-03**	**1.28E-01**	**Variance**	**8.12E-05**	**5.53E-04**	**5.89E-03**	**1.83E-01**

Table 4 depicts the comparison of the relative error between optimized Hata model with known models. It is found that performance of the optimized Hata model is the best as relative error is the lowest compared to other models. Okumura, Cost231 and other Egli model empirical models seem to be overestimating the path loss for suburban environment in Malaysia. The average relative error for Cyberjaya's base stations is around 0.0592% while for Putrajaya is 0.0620%. The result are almost close to each other for this neighboring locations as these two locations are almost similar with terrain profile and environment structure for mobile communication system. The variance are 1.34e-05 for Cyberjaya and 8.12e05 for Putrajaya respectively. The standard deviation values are 0.0034 in Cyberjaya and 0.0090 in Putrajaya respectively. The high variance and standard deviation show that the data distribution is poor compared with lower value. This table shows the analysis for various model results obtained when tested at different locations along with the validation of the optimized mode.

6. CONCLUSION

In this paper, we have introduced optimized Hata path loss empirical model using proposed least square method. The outdoor measurement have been taken in Cyberjaya, Malaysia in order to make a path loss comparison with the existing models. We found that the performance of the optimized Hata model is the best as relative error is the lowest compared to other mentioned models. The relative error found to be in the range of 0.0592% to 0.0620% for our optimized model. Generally, Cost231 and Egli model perform better than Okumura for suburban area in Malaysia. The optimized model is found suited to the Malaysia suburban area, which can be used to predict the signal strength of mobile phone due to base station. This model is useful for Malaysia telecommunication provider to improve their service for better capacity and better mobile user satisfaction.

ACKNOWLEDGMENT

The authors wish to express their sincere thanks to Malaysian Communications and Multimedia Commission (MCMC) for providing the base stations information from different operators to be used for this study.

REFERENCES

1. Alotaibi, F. D., A. Abdennour, and A. A. Ali, "TETRA outdoor large-scale received signal prediction model in riyadh city-saudi arabia," *Wireless and Microwave Technology Conference 2006*, 1–5, IEEE Annual Digital Object Identifier:10.1109/WAMICON.2006.351966, 2006.
2. Alotaibi, F. D., A. Abdennour, and A. A. Ali, "A real-time intelligent wireless mobile station location estimator with application to TETRA network," *IEEE Transactions on Mobile Computing*, Vol. 8, 1495–1509, 2009.
3. Lim, C. Y., "Propagation path loss study in malaysia environment," Master Thesis Multi Media University, August 2004.
4. Hata, M., "Empirical formula for propagation loss in land mobile radio services," *IEEE Trans. Vehicular Technology*, Vol. 29, 317–325, 1980.
5. Micheal, D. Y., *Foundation of Mobile Radio Engineering*, CRC Press Inc., 2000.
6. Rappaport, T. S., *Wireless Communications Principles and Practice*, Prentice Hall, 2002.
7. Jacques, L. and S. Michel, *Radio Wave Propagation Principles and Techniques*, John Wiley & Sons Ltd., 2000.
8. Medeisis, A. and A. Kajackas, "Modification and tuning of the universal okumura-hata model for radio wave propagation predictions," *Asia-Pacific Microwave Conference 2007*, Vol. 11–14, 1–4, 2007.
9. Egli, J. J., "Radio propagation above 40 MC over irregular terrain," *Proceedings of the IRE*, Vol. 45, No. 10, 1383–1391, 1957.
10. http://en.wikipedia.org/wiki/Egli_Model.
11. William, C. and Y. Lee, *Mobile Communication Design Fundamentals*, John Wiley & Sons Ltd., 1993.
12. Parsons, J. D., *The Mobile Radio Propagation Channel*, 2nd Edition, John Wiley & Sons Ltd., 1992.
13. Malaysian Communications and Multimedia Commission (MCMC), http://www.skmm.gov.my.
14. http://atlas.mapquest.com/maps/latlong.adp.
15. Google Map Malaysia, http://maps.google.com.my/.
16. http://en.wikipedia.org/wiki/Relative_error.