Path Loss Model Optimization for Urban Outdoor Coverage Using Code Division Multiple Access (CDMA) System at 822MHZ

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Abstract

The study of this work is to develop an optimized path loss model for urban coverage in Code Division Multiple Access (CDMA) system based on the existing models and empirical measurements. The Okumura's model is chosen as a reference for optimized path loss model development based on the smallest mean relative error compared to the measured path loss. A new empirical model is developed from Okumura's model and empirical measurements by regression fitting method. Okumura's model will be optimized by using this new empirical model to achieve the smallest mean relative error. The optimized Okumura's model is implemented in the path loss calculation during the validation process. It is found to be more accurate with up to 6.67% smaller mean relative error obtained. Thus, this optimized Okumura's model is successfully improved and would be more reliable to be applied in the Malaysia CDMA system for urban path loss calculation.

Keywords: Path loss, Mean relative error, CDMA, Urban outdoor coverage

1. Introduction

In wireless communication system, there is found that a radio propagation model, also known as the Radio Wave Propagation Model or the Radio Frequency Propagation Model, is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other conditions. A single model is usually developed to predict the behavior of the propagation for all similar links under similar constraints (Iskander, M. F., et al., 2002), (Longley, A. G., et al., 1968). Created with the goal of formalizing the way radio waves are propagated from one place to another, such models typically predict the path loss along a link or around an effective coverage area of a transmitter (Awad, M., et al., 2008), (Walfsch, J., e al., 1988).

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 a few other parameters. Examples of this model category will be the Okumura model and the Hata model. Semi-deterministic models are based on empirical models and deterministic aspects, examples being the Cost-231 and Walfsh-Ikegami. Deterministic models on the other hand are site-specific, requiring enormous numbers of geometry information about the city, computational effort in deriving a more accurate model.

Code division multiple access (CDMA) is a channel access method that allow several transmitters to send information simultaneously over a single communication channel with different distinguishing code patterns (Rappaport, T. S., 2002). CDMA employs spread-spectrum technology and a special coding scheme to allow multiple users to be multiplexed over the same physical channel. In CDMA system, duplex channel made of two 1.25MHz-wide bands of spectrum for forward link and reverse link with 45MHz apart. The carrier frequencies for CDMA system in Malaysia are 821.3875MHz for uplink and 865.3875 for downlink. The frequency reuse factor for CDMA is one where network design and expanding become much easier.

The path loss for CDMA System can be calculated from forward link, the transmission path from a base transceiver station to the mobile station. All measurements data is collected within radius of 5km away from base station in the CDMA network and the blind spot is expected does not exist. Thus, the minimum allowable path loss is not considerable as the tested base station is near to the adjacent base stations where handover occurred as signal is weak.

1.1 Objectives

The objective of this project is to study on the existing path loss models and its suitability to be implemented for path loss prediction for urban area in Code Division Multiple Access (CDMA) in city centre Kuala Lumpur (KL). The optimization is performed to improve the accuracy and stability of the existing path loss model. An empirical method based on the measurement data is applied for the path loss model optimization. The expectation of this study is to obtain an optimized path loss model for outdoor urban area.

Radio propagation models are empirical in nature, which means, they are developed based on large collections of data collected for the specific scenario. For any model, the collection of data has to be sufficiently large to provide enough likeliness to all kind of situations that can happen in that specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a link, rather, they predict the most likely behavior the link may exhibit under the specified conditions.

Thus, to develop a new path loss model empirically is very time consuming and it involves very substantial collections of data obtained specifically for different scenarios. One of the best ways is to optimize the existing path loss models based on the measurement data collected in Malaysia city centre area.

In ensuring high accuracy and reliability of the existing path loss model it is then developed based on the measurement data collected directly from the tested system, being the CDMA network in Malaysia city centre. The optimized path loss model is very useful for predicting various coverage areas, interference analysis, frequency assignments and cell parameters in which are all fundamental elements for the network planning processes in mobile radio systems.

Most of the existing path loss models are wholly based on measured data with no analytical explanation given. It is useful to note that these path loss models have limitations as well, as displayed by the Okumura's model with regards to its non suitability for rural environment. On the other hand, Longley-Rice model and Egli's model are applicable for "point to point" communication system and are free spaced path loss model that are used to predict received signal strength when both the transmitter and the receiver have a clear and unobstructed line-of-sight (LOS) path between them. Thus, an optimized path loss model based on empirical measurements for all conditions is needed to overcome the limitations.

1.2 Problem Statement

The empirical path loss model may not be valid for the environment other than the measured one especially for a dense city such as Malaysia. Due to the differences in city structures, local terrain profiles, weather etc, the path loss prediction with reference to the existing empirical path loss models such as the Okumura's model, Hata's model etc may differ from the actual one. Furthermore, network planning and optimization become complicated and difficult as high numbers of base stations involved in a network with significant co channel interference. The network operators may face huge losses resulted from complaints from the network users due to improper link budget calculations and path loss predictions. Thus, a more precise path loss model is needed and would be developed based on the empirical method that is applied in Kuala Lumpur outdoor coverage for the CDMA System.

2. Methodology

Several existing path loss models such as the Free Space Path Loss model (Rappaport, T. S., 2002), the Okumura's model (Okumura, Y., et al., 1968), the Hata's model (Hata, M.,1980), and the Egli's model(Egli, J. J.,1957) are chosen as reference for optimized path loss model development. The best existing path loss model with the smallest mean relative error to the measured path loss will be chosen as a reference for the development of the optimized path loss model. The regression fitting method is used to develop a new empirical linear line by combining the best existing path loss model with the measurement data which is collected from the CDMA network. The new empirical linear line is used as a reference during optimization to develop an optimized path loss model. The optimized path loss model will be tested during the validation process by comparing the calculated path loss to the measured path loss in KL CDMA Network.

2.1 Okumura's Model

The Okumura's model was chosen as reference in new path loss model development based on the smallest mean relative error to the measured path loss with up to 10.46%. The Okumura's model is an empirical model based on extensive measurements made in Japan at several frequencies in the range from 150-1920 MHz. The Okumura's model is developed for macro cells with cell diameters from 1 to 100 km. The height of the BS antenna is between 30-1000 m. The Okumura's model takes into account on some of the propagation parameters such as the type of environment and the terrain irregularity.

The Okumura's model is expressed as:

$$L_{50}\,(dB) = L_F + A_{mu}\,(f,d) - G\,(h_t) - G\,(h_r) - G_{area} \qquad (1)$$

Where:

L_{50} (dB) is the 50th percentile value of propagation path loss,

L_F is the free space path loss,

A_{mu} is the free space attenuation,

G (h_t) is the base station antenna height gain factor,

G (h_r) is the mobile antenna height gain factor, and

G_{area} is the gain corresponding to specific environment.

2.2 Data Collection Method

The measurements were conducted radically from four CDMA transmitters located in KL city centre, with six different routes each transmitter, which are designated as path *a, b, c, d, e* and *f*, shown in Figure 1. The professional foreground test and analysis software, ZXPOS CNT1 and CNA7 are used in collecting and analysis CDMA network measurement data for path loss calculation. The measurement data such as received signal strength and T-R separation distance are recorded in *dBm* and *km* unit easier for path loss calculation. Every 10 points of received signal strength and T-R separation distance are recorded evenly from all the predefined routes of four base stations located in dense city KL. Total of 6 routes per base station with at least 60 received signal strength of mobile station and the T-R separation distance are recorded. Each measurement point is represented in an average of a set of samples by taken over a small area (10 m^2) in order to remove the effects of fast fading (Lee, W. C. Y., 1985), (Clarke, R. H., 1968).

2.3 Path Loss Calculation

The link budget is accounting of all gains and losses from the transmitter, through the medium such as free space, cable, and waveguide to the receiver is calculated and compare to the classical path loss model based on the minimum mean relative error. Path loss can be calculated via forward link, of which the transmission path is from a base transceiver station to the mobile station. Thus, the path loss is derived as:

$$PL\,(dB) = P_{TX} + G_{TX} - L_{TX} - P_{RX} + G_{RX} - L_{RX} - L_M \qquad (2)$$

Where:

P_{RX} = received power (dBm)

P_{TX} = transmitter output power (dBm)

G_{TX} = transmitter antenna gain (dBi)

L_{TX} = transmitter losses (dB)

L_{FS} = free space loss or path loss (dB)

L_M = miscellaneous losses (dB)

G_{RX} = receiver antenna gain (dBi)

L_{RX} = receiver losses (dB)

2.4 Mean Relative Error

In order to find out the best suitable path loss model for optimization, the relative error (3) of the measured path loss to the existing path loss models is determined. Figure 3 shows the relative errors of measured path loss to the existing path loss model that are plotted versus T-R separation distance. The relative error is big as the T-R separation distance is small where LOS condition exists. This may be due to the shadowing effect as the antenna of the base station is high. As result, the Okumura's model has smaller relative error to the measured path loss.

$$\delta = \frac{|V - V_{approx}|}{|V|} \times 100\% \tag{3}$$

Where:

V is the exact value,

V_{approx} is the approximation.

2.5 New Empirical Model

A new empirical model is developed by using the regression fitting method. The Okumura's model and measurements collected in Kuala Lumpur urban area is plotted based on the T-R separation distance. A new linear line is developed from the Okumura's model and the measurements were obtained by using the regression fitting method. This liner line is used as a reference during the path loss model optimization process later.

2.6 Optimization

The optimization is performed using the best suitable path loss model, being the Okumura's model with reference to the new empirical linear line that was developed from the measurement data accumulated from the four base stations. Six variables namely A, B, C, D, E and F were added into the linear form equation of the Okumura's model as shown in equation (5). This linear line will be optimized to approach the new empirical linear line based on the smallest mean relative error. Overall, the mean relative error has improved from 3.50629% to 0.00009%, where the value of A, B, C, D, E and F are determined.

$$\textit{Okumura's Model (dB)} = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - G_{AREA} \tag{4}$$

$$\textit{Optimized Path Loss Model (dB)} = AL_{FSL} + BA_{MU} - CH_{MG} - DH_{BG} - EG_{AREA} + F \tag{5}$$

2.7 Optimized Model Development

The optimized model is developed with new determined variables of A, B, C, D, E and F based on the smallest mean relative error during the optimization process. The Microsoft Excel analysis tool 'Solver' is used to determine the variable of A, B, C, D, E and F. Firstly, the best suited path loss model, the Okumura's model is plotted in dB against distance (km). The Okumura's linear line is plotted by using the regression fitting method and compared to the new empirical linear line. The mean relative error of Okumura's linear line to the new empirical linear line is recorded, which is up to 3.50629%. For optimization process, the variable A, B, C, D, E and F are multiplied with the linear form of Okumura's model with default value of 1. By using Microsoft Excel analysis tool 'Solver'; these variables are solved in order to obtain the smallest mean relative error equal to zero. The smallest mean relative error up to 0.00009% is achieved, where the value of A, B, C, D, E and F are determined.

$$\begin{aligned} \textit{Optimized Path Loss Model (dB)} &= AL_{FSL} + BA_{MU} - CH_{MG} - DH_{BG} - EG_{AREA} + F \\ &= 1.164103L_{FSL} + 0.10566A_{MU} - 1.246594H_{MG} - 1.473893H_{BG} - 0.503879G_{AREA} + 0.1 \end{aligned} \tag{6}$$

2.8 Validation

In the validation process, the optimized Okumura's model is applied for path loss calculation in other city to verify the accuracy and the suitability of this optimized Okumura's model. The city centre of Petaling Jaya, with similar building structure of KL city centre, has been chosen for the optimized Okumura's model validation test. Drive test has been performed for the measurement data collection at base station 5, which located in the city centre of Petaling Jaya. As result, it had proven to be more accurate with smaller mean relative error up to 6.67%. Thus, it can be concluded that the optimized path loss model is reliable and more suitable to be used in the Malaysia CDMA system for link budget prediction.

3. Conclusion

The optimized path loss model is developed to predict accurately the receive signal strength of the mobile phone, tested on different base station in urban areas throughout Malaysia. This path loss model is very useful for predicting various coverage areas, interference analysis, frequency assignments and cell parameters in which are all fundamental elements for the network planning processes in mobile radio systems. This would pose benefits for telecommunication providers to further improve their services in serving high signaled quality coverage for mobile users whilst increasing the capacity in urban areas throughout Malaysia.

Most of the existing path loss model has limitations. By optimizing the best suited path loss model with the empirical measurement data collected from the CDMA network in the urban area, the limitations would be overcome and thus applicable for all condition in path loss prediction with high accuracy. This model is useful for telecommunication providers to enhance the satisfaction of the mobile users.

4. Recommendation for Future Work

Based on the obtained results, the path loss is proportional to the T-R separation distance. This is due to the weak signal strength obtained when the mobile station is situated far away from the base station. There are more losses on the receive signal and this could have caused a high value of path loss. Thus, more sample points with average value will assist in higher accuracy for path loss calculation. However, there are some limitations in the collection of data. The targeted distance to be tested during test drive is only around 5km due to intensive high rise buildings in the city, constraints such as fly-over bridges, and the restricted private area etc. Furthermore, the optimized path loss model may not predict accurately the path loss if it is implemented in other urban areas with different city structures and terrain profiles.

This project is studied in the CDMA network. It is recommended to have further intensive study in other communication network such as GSM900, GSM1900, WIMAX, and LTE in the future. There are more typical environments and cities like Malaysia that are not covered in this project. The measurement data should be collected from the urban city in different locations such as Penang, Johor and Malacca.

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Table 1. The collected measurements from Base Station 1

BTS	Line	T-R (KM)	Rx (dBm)	Tx Power	Antenna Gain	Cable Loss	Tx EIRP	Penetration Loss	Body Loss	Cable Loss	Mes PL
BTS01	1	0.420	-65.91	40	17.5	5	52.5	12	3	2	101.410
		0.561	-69.91	40	17.5	5	52.5	12	3	2	105.410
		0.756	-73.91	40	17.5	5	52.5	12	3	2	109.410
		1.383	-74.58	40	17.5	5	52.5	12	3	2	110.080
		1.559	-77.91	40	17.5	5	52.5	12	3	2	113.410
		1.682	-75.91	40	17.5	5	52.5	12	3	2	111.410
		2.207	-80.58	40	17.5	5	52.5	12	3	2	116.080
		2.707	-78.25	40	17.5	5	52.5	12	3	2	113.750
		3.406	-84.25	40	17.5	5	52.5	12	3	2	119.750
		4.168	-82.25	40	17.5	5	52.5	12	3	2	117.750
	2	0.285	-68.58	40	17	5	52	12	3	2	103.580
		0.403	-64.58	40	17	5	52	12	3	2	99.580
		0.500	-74.58	40	17	5	52	12	3	2	109.580
		0.836	-75.25	40	17	5	52	12	3	2	110.250
		1.065	-79.91	40	17	5	52	12	3	2	114.910
		1.938	-83.25	40	17	5	52	12	3	2	118.250
		2.011	-87.25	40	17	5	52	12	3	2	122.250
		2.313	-80.58	40	17	5	52	12	3	2	115.580
		2.680	-67.25	40	17	5	52	12	3	2	102.250
		3.576	-82.58	40	17	5	52	12	3	2	117.580
	3	0.100	-52.91	40	17	5	52	12	3	2	87.910
		0.126	-51.58	40	17	5	52	12	3	2	86.580
		0.226	-58.25	40	17	5	52	12	3	2	93.250
		0.541	-58.58	40	17	5	52	12	3	2	93.580
		1.314	-70.58	40	17	5	52	12	3	2	105.580
		1.696	-71.25	40	17	5	52	12	3	2	106.250
		2.282	-67.91	40	17	5	52	12	3	2	102.910
		2.467	-61.58	40	17	5	52	12	3	2	96.580
		2.850	-52.91	40	17	5	52	12	3	2	87.910
		3.180	-50.91	40	17	5	52	12	3	2	85.910
	4	0.363	-62.91	40	17	5	52	12	3	2	97.910
		0.530	-64.91	40	17	5	52	12	3	2	99.910
		0.724	-67.58	40	17	5	52	12	3	2	102.580
		0.946	-62.91	40	17	5	52	12	3	2	97.910
		1.261	-74.25	40	17	5	52	12	3	2	109.250
		1.563	-76.58	40	17	5	52	12	3	2	111.580
		1.841	-77.25	40	17	5	52	12	3	2	112.250
		2.235	-76.58	40	17	5	52	12	3	2	111.580
		2.405	-75.91	40	17	5	52	12	3	2	110.910
		2.864	-69.91	40	17	5	52	12	3	2	104.910
	5	0.146	-53.91	40	17	5	52	12	3	2	88.910
		0.466	-60.91	40	17	5	52	12	3	2	95.910
		0.802	-53.25	40	17	5	52	12	3	2	88.250
		0.817	-53.58	40	17	5	52	12	3	2	88.580
		1.283	-58.58	40	17	5	52	12	3	2	93.580
		1.428	-69.58	40	17	5	52	12	3	2	104.580
		2.052	-69.91	40	17	5	52	12	3	2	104.910
		2.644	-77.58	40	17	5	52	12	3	2	112.580
		3.272	-81.91	40	17	5	52	12	3	2	116.910
		3.989	-84.91	40	17	5	52	12	3	2	119.910
	6	0.163	-60.58	40	17.5	5	52.5	12	3	2	96.080
		0.515	-61.25	40	17.5	5	52.5	12	3	2	96.750
		0.730	-57.25	40	17.5	5	52.5	12	3	2	92.750
		0.803	-60.91	40	17.5	5	52.5	12	3	2	96.410
		0.941	-70.58	40	17.5	5	52.5	12	3	2	106.080
		1.144	-64.25	40	17.5	5	52.5	12	3	2	99.750
		1.430	-73.91	40	17.5	5	52.5	12	3	2	109.410
		2.066	-77.58	40	17.5	5	52.5	12	3	2	113.080
		2.486	-69.91	40	17.5	5	52.5	12	3	2	105.410
		2.747	-63.58	40	17.5	5	52.5	12	3	2	99.080

The measured path loss is calculated based on the empirical measurements collected from base station 1.

Table 2. The collected measurements from Base Station 2

BTS	Line	T-R (KM)	Rx (dBm)	Tx Power	Antenna Gain	Cable Loss	Tx EIRP	Penetration Loss	Body Loss	Cable Loss	Mes PL
BTS02	1	1.486	-63.62	40	17	5	52	12	3	2	98.620
		1.542	-75.12	40	17	5	52	12	3	2	110.120
		1.775	-76.25	40	17	5	52	12	3	2	111.250
		1.839	-82.63	40	17	5	52	12	3	2	117.630
		2.011	-83.58	40	17	5	52	12	3	2	118.580
		2.357	-76.91	40	17	5	52	12	3	2	111.910
		2.682	-79.91	40	17	5	52	12	3	2	114.910
		2.932	-80.91	40	17	5	52	12	3	2	115.910
		3.291	-69.58	40	17	5	52	12	3	2	104.580
		3.597	-70.58	40	17	5	52	12	3	2	105.580
	2	0.689	-68.25	40	17	5	52	12	3	2	103.250
		0.810	-76.58	40	17	5	52	12	3	2	111.580
		1.239	-67.91	40	17	5	52	12	3	2	102.910
		1.620	-82.25	40	17	5	52	12	3	2	117.250
		1.731	-71.91	40	17	5	52	12	3	2	106.910
		1.865	-70.25	40	17	5	52	12	3	2	105.250
		1.921	-76.91	40	17	5	52	12	3	2	111.910
		2.148	-78.25	40	17	5	52	12	3	2	113.250
		2.358	-73.25	40	17	5	52	12	3	2	108.250
		3.154	-77.91	40	17	5	52	12	3	2	112.910
	3	0.522	-58.58	40	17	5	52	12	3	2	93.580
		0.659	-53.58	40	17	5	52	12	3	2	88.580
		0.781	-52.58	40	17	5	52	12	3	2	87.580
		1.053	-50.25	40	17	5	52	12	3	2	85.250
		1.118	-57.91	40	17	5	52	12	3	2	92.910
		1.962	-66.58	40	17	5	52	12	3	2	101.580
		2.553	-74.25	40	17	5	52	12	3	2	109.250
		2.671	-76.91	40	17	5	52	12	3	2	111.910
		2.968	-79.91	40	17	5	52	12	3	2	114.910
		3.363	-80.91	40	17	5	52	12	3	2	115.910
	4	0.126	-60.91	40	17	5	52	12	3	2	95.910
		0.349	-64.58	40	17	5	52	12	3	2	99.580
		0.551	-56.58	40	17	5	52	12	3	2	91.580
		0.817	-49.25	40	17	5	52	12	3	2	84.250
		1.100	-67.91	40	17	5	52	12	3	2	102.910
		1.331	-79.25	40	17	5	52	12	3	2	114.250
		1.553	-81.25	40	17	5	52	12	3	2	116.250
		1.749	-76.25	40	17	5	52	12	3	2	111.250
		2.143	-71.91	40	17	5	52	12	3	2	106.910
		2.933	-74.25	40	17	5	52	12	3	2	109.250
	5	0.186	-68.58	40	17	5	52	12	3	2	103.580
		0.589	-60.25	40	17	5	52	12	3	2	95.250
		0.981	-57.91	40	17	5	52	12	3	2	92.910
		1.206	-67.91	40	17	5	52	12	3	2	102.910
		1.384	-66.91	40	17	5	52	12	3	2	101.910
		1.767	-63.91	40	17	5	52	12	3	2	98.910
		1.997	-66.25	40	17	5	52	12	3	2	101.250
		2.331	-71.58	40	17	5	52	12	3	2	106.580
		2.519	-64.91	40	17	5	52	12	3	2	99.910
		2.774	-52.91	40	17	5	52	12	3	2	87.910
	6	0.178	-63.58	40	17	5	52	12	3	2	98.580
		0.289	-62.91	40	17	5	52	12	3	2	97.910
		0.555	-67.25	40	17	5	52	12	3	2	102.250
		0.727	-69.25	40	17	5	52	12	3	2	104.250
		0.958	-71.58	40	17	5	52	12	3	2	106.580
		1.101	-66.91	40	17	5	52	12	3	2	101.910
		2.062	-84.25	40	17	5	52	12	3	2	119.250
		2.907	-74.25	40	17	5	52	12	3	2	109.250
		3.280	-79.91	40	17	5	52	12	3	2	114.910
		3.844	-73.91	40	17	5	52	12	3	2	108.910

The measured path loss is calculated based on the empirical measurements collected from base station 2.

Table 3. The collected measurements from Base Station 3

BTS	Line	T-R (KM)	Rx (dBm)	Tx Power	Antenna Gain	Cable Loss	Tx EIRP	Penetration Loss	Body Loss	Cable Loss	Mes PL
BTS03	1	0.559	-57.91	40	17.5	5	52.5	12	3	2	93.410
		0.822	-60.25	40	17.5	5	52.5	12	3	2	95.750
		0.936	-67.91	40	17.5	5	52.5	12	3	2	103.410
		1.931	-66.91	40	17.5	5	52.5	12	3	2	102.410
		2.229	-69.91	40	17.5	5	52.5	12	3	2	105.410
		2.420	-69.91	40	17.5	5	52.5	12	3	2	105.410
		2.638	-64.25	40	17.5	5	52.5	12	3	2	99.750
		2.931	-61.91	40	17.5	5	52.5	12	3	2	97.410
		3.144	-56.25	40	17.5	5	52.5	12	3	2	91.750
		3.335	-67.25	40	17.5	5	52.5	12	3	2	102.750
	2	0.480	-64.58	40	17.5	5	52.5	12	3	2	100.080
		0.789	-70.91	40	17.5	5	52.5	12	3	2	106.410
		0.958	-71.91	40	17.5	5	52.5	12	3	2	107.410
		1.249	-70.91	40	17.5	5	52.5	12	3	2	106.410
		1.644	-69.25	40	17.5	5	52.5	12	3	2	104.750
		2.025	-61.58	40	17.5	5	52.5	12	3	2	97.080
		2.293	-66.25	40	17.5	5	52.5	12	3	2	101.750
		2.726	-49.25	40	17.5	5	52.5	12	3	2	84.750
		3.230	-45.91	40	17.5	5	52.5	12	3	2	81.410
		3.471	-54.58	40	17.5	5	52.5	12	3	2	90.080
	3	0.258	-61.25	40	17.5	5	52.5	12	3	2	96.750
		0.508	-68.58	40	17.5	5	52.5	12	3	2	104.080
		0.681	-67.58	40	17.5	5	52.5	12	3	2	103.080
		0.971	-73.91	40	17.5	5	52.5	12	3	2	109.410
		1.725	-66.25	40	17.5	5	52.5	12	3	2	101.750
		1.772	-65.25	40	17.5	5	52.5	12	3	2	100.750
		2.431	-73.25	40	17.5	5	52.5	12	3	2	108.750
		3.172	-75.91	40	17.5	5	52.5	12	3	2	111.410
		3.685	-76.25	40	17.5	5	52.5	12	3	2	111.750
		4.344	-76.58	40	17.5	5	52.5	12	3	2	112.080
	4	0.640	-67.58	40	17.5	5	52.5	12	3	2	103.080
		0.752	-65.91	40	17.5	5	52.5	12	3	2	101.410
		0.916	-66.91	40	17.5	5	52.5	12	3	2	102.410
		1.551	-71.58	40	17.5	5	52.5	12	3	2	107.080
		1.816	-74.91	40	17.5	5	52.5	12	3	2	110.410
		1.992	-82.25	40	17.5	5	52.5	12	3	2	117.750
		2.397	-75.91	40	17.5	5	52.5	12	3	2	111.410
		2.876	-80.25	40	17.5	5	52.5	12	3	2	115.750
		3.165	-79.58	40	17.5	5	52.5	12	3	2	115.080
		3.712	-73.91	40	17.5	5	52.5	12	3	2	109.410
	5	0.654	-63.25	40	17.5	5	52.5	12	3	2	98.750
		0.997	-67.25	40	17.5	5	52.5	12	3	2	102.750
		1.142	-64.58	40	17.5	5	52.5	12	3	2	100.080
		1.301	-75.25	40	17.5	5	52.5	12	3	2	110.750
		1.614	-74.58	40	17.5	5	52.5	12	3	2	110.080
		1.880	-75.91	40	17.5	5	52.5	12	3	2	111.410
		2.510	-79.25	40	17.5	5	52.5	12	3	2	114.750
		2.802	-85.25	40	17.5	5	52.5	12	3	2	120.750
		3.186	-86.58	40	17.5	5	52.5	12	3	2	122.080
		3.319	-88.25	40	17.5	5	52.5	12	3	2	123.750
	6	0.829	-72.58	40	17.5	5	52.5	12	3	2	108.080
		1.196	-70.25	40	17.5	5	52.5	12	3	2	105.750
		1.364	-72.58	40	17.5	5	52.5	12	3	2	108.080
		1.529	-72.25	40	17.5	5	52.5	12	3	2	107.750
		1.683	-75.25	40	17.5	5	52.5	12	3	2	110.750
		1.865	-73.91	40	17.5	5	52.5	12	3	2	109.410
		2.054	-71.91	40	17.5	5	52.5	12	3	2	107.410
		2.488	-80.91	40	17.5	5	52.5	12	3	2	116.410
		2.907	-76.58	40	17.5	5	52.5	12	3	2	112.080
		3.086	-69.91	40	17.5	5	52.5	12	3	2	105.410

The measured path loss is calculated based on the empirical measurements collected from base station 3.

Table 4. The collected measurements from Base Station 4

BTS	Line	T-R (KM)	Rx (dBm)	Tx Power	Antenna Gain	Cable Loss	Tx EIRP	Penetration Loss	Body Loss	Cable Loss	Mes PL
BTS04	1	0.191	-62.25	40	17	5	52	12	3	2	97.250
		0.396	-61.25	40	17	5	52	12	3	2	96.250
		0.799	-71.25	40	17	5	52	12	3	2	106.250
		1.122	-67.25	40	17	5	52	12	3	2	102.250
		1.492	-69.58	40	17	5	52	12	3	2	104.580
		1.816	-54.91	40	17	5	52	12	3	2	89.910
		2.187	-75.91	40	17	5	52	12	3	2	110.910
		2.210	-76.91	40	17	5	52	12	3	2	111.910
		2.449	-74.25	40	17	5	52	12	3	2	109.250
		2.815	-78.91	40	17	5	52	12	3	2	113.910
	2	0.754	-44.91	40	17	5	52	12	3	2	79.910
		1.014	-58.58	40	17	5	52	12	3	2	93.580
		1.253	-67.58	40	17	5	52	12	3	2	102.580
		1.616	-76.58	40	17	5	52	12	3	2	111.580
		1.738	-71.91	40	17	5	52	12	3	2	106.910
		1.972	-76.91	40	17	5	52	12	3	2	111.910
		2.153	-69.58	40	17	5	52	12	3	2	104.580
		2.399	-77.91	40	17	5	52	12	3	2	112.910
		2.800	-75.58	40	17	5	52	12	3	2	110.580
		3.227	-77.25	40	17	5	52	12	3	2	112.250
	3	1.316	-84.91	40	17	5	52	12	3	2	119.910
		1.554	-82.91	40	17	5	52	12	3	2	117.910
		2.053	-76.91	40	17	5	52	12	3	2	111.910
		2.718	-86.25	40	17	5	52	12	3	2	121.250
		2.879	-86.25	40	17	5	52	12	3	2	121.250
		3.035	-76.58	40	17	5	52	12	3	2	111.580
		3.286	-69.58	40	17	5	52	12	3	2	104.580
		3.796	-88.58	40	17	5	52	12	3	2	123.580
		4.865	-85.58	40	17	5	52	12	3	2	120.580
		5.106	-89.91	40	17	5	52	12	3	2	124.910
	4	0.339	-54.91	40	17	5	52	12	3	2	89.910
		0.961	-62.91	40	17	5	52	12	3	2	97.910
		1.130	-54.25	40	17	5	52	12	3	2	89.250
		1.339	-75.58	40	17	5	52	12	3	2	110.580
		1.723	-73.91	40	17	5	52	12	3	2	108.910
		2.193	-71.91	40	17	5	52	12	3	2	106.910
		2.638	-73.91	40	17	5	52	12	3	2	108.910
		2.964	-82.91	40	17	5	52	12	3	2	117.910
		3.248	-79.58	40	17	5	52	12	3	2	114.580
		3.338	-69.25	40	17	5	52	12	3	2	104.250
	5	0.240	-56.91	40	17	5	52	12	3	2	91.910
		0.862	-58.91	40	17	5	52	12	3	2	93.910
		1.249	-70.91	40	17	5	52	12	3	2	105.910
		1.681	-68.58	40	17	5	52	12	3	2	103.580
		2.042	-75.58	40	17	5	52	12	3	2	110.580
		2.148	-72.58	40	17	5	52	12	3	2	107.580
		2.237	-71.91	40	17	5	52	12	3	2	106.910
		2.618	-78.58	40	17	5	52	12	3	2	113.580
		3.069	-81.58	40	17	5	52	12	3	2	116.580
		3.211	-89.91	40	17	5	52	12	3	2	124.910
	6	0.358	-46.91	40	17	5	52	12	3	2	81.910
		0.552	-54.91	40	17	5	52	12	3	2	89.910
		0.744	-57.91	40	17	5	52	12	3	2	92.910
		1.160	-64.58	40	17	5	52	12	3	2	99.580
		1.518	-57.91	40	17	5	52	12	3	2	92.910
		1.865	-74.25	40	17	5	52	12	3	2	109.250
		2.050	-74.58	40	17	5	52	12	3	2	109.580
		2.215	-76.91	40	17	5	52	12	3	2	111.910
		2.517	-78.91	40	17	5	52	12	3	2	113.910
		3.280	-74.91	40	17	5	52	12	3	2	109.910

The measured path loss is calculated based on the empirical measurements collected from base station 4.

Table 5. The collected measurements from Base Station 5 for path loss calculation and validation test

BTS	Line	T-R (KM)	Rx (dBm)	Tx Power	Antenna Gain	Cable Loss	Tx EIRP	Car Penetration Loss	Body Loss	Path Loss
BTS05	1	0.172	-57.91	40	17	5	52	12	5	92.910
		0.562	-51.91	40	17	5	52	12	5	86.910
		0.962	-58.58	40	17	5	52	12	5	93.580
		1.294	-53.58	40	17	5	52	12	5	88.580
		1.504	-74.25	40	17	5	52	12	5	109.250
		1.981	-66.58	40	17	5	52	12	5	101.580
		2.224	-74.25	40	17	5	52	12	5	109.250
		2.517	-72.58	40	17	5	52	12	5	107.580
		3.177	-70.25	40	17	5	52	12	5	105.250
		3.865	-75.25	40	17	5	52	12	5	110.250
	2	0.343	-65.91	40	17	5	52	12	5	100.910
		0.534	-64.25	40	17	5	52	12	5	99.250
		0.814	-63.58	40	17	5	52	12	5	98.580
		1.079	-68.25	40	17	5	52	12	5	103.250
		1.190	-73.91	40	17	5	52	12	5	108.910
		1.408	-70.91	40	17	5	52	12	5	105.910
		1.665	-70.25	40	17	5	52	12	5	105.250
		2.156	-85.58	40	17	5	52	12	5	120.580
		2.318	-88.91	40	17	5	52	12	5	123.910
		2.965	-84.91	40	17	5	52	12	5	119.910
	3	0.152	-62.91	40	17	5	52	12	5	97.910
		0.361	-58.91	40	17	5	52	12	5	93.910
		0.717	-52.91	40	17	5	52	12	5	87.910
		1.165	-61.91	40	17	5	52	12	5	96.910
		1.329	-70.91	40	17	5	52	12	5	105.910
		1.720	-72.91	40	17	5	52	12	5	107.910
		2.279	-76.91	40	17	5	52	12	5	111.910
		2.772	-73.91	40	17	5	52	12	5	108.910
		3.126	-77.58	40	17	5	52	12	5	112.580
		3.372	-75.25	40	17	5	52	12	5	110.250
	4	0.239	-71.25	40	17	5	52	12	5	106.250
		0.466	-71.58	40	17	5	52	12	5	106.580
		0.719	-65.25	40	17	5	52	12	5	100.250
		1.086	-67.91	40	17	5	52	12	5	102.910
		1.371	-70.58	40	17	5	52	12	5	105.580
		1.727	-74.91	40	17	5	52	12	5	109.910
		1.891	-74.91	40	17	5	52	12	5	109.910
		2.211	-67.91	40	17	5	52	12	5	102.910
		2.757	-72.25	40	17	5	52	12	5	107.250
		3.134	-69.91	40	17	5	52	12	5	104.910
	5	0.287	-68.58	40	17	5	52	12	5	103.580
		0.700	-64.25	40	17	5	52	12	5	99.250
		1.092	-60.25	40	17	5	52	12	5	95.250
		1.315	-67.25	40	17	5	52	12	5	102.250
		1.641	-73.91	40	17	5	52	12	5	108.910
		2.322	-79.91	40	17	5	52	12	5	114.910
		2.509	-72.91	40	17	5	52	12	5	107.910
		2.755	-69.91	40	17	5	52	12	5	104.910
		3.659	-80.58	40	17	5	52	12	5	115.580
		4.040	-82.91	40	17	5	52	12	5	117.910
	6	0.242	-57.25	40	17	5	52	12	5	92.250
		0.680	-60.25	40	17	5	52	12	5	95.250
		1.130	-73.91	40	17	5	52	12	5	108.910
		1.541	-80.58	40	17	5	52	12	5	115.580
		1.874	-77.91	40	17	5	52	12	5	112.910
		2.253	-73.58	40	17	5	52	12	5	108.580
		2.658	-75.91	40	17	5	52	12	5	110.910
		3.016	-68.25	40	17	5	52	12	5	103.250
		3.148	-70.91	40	17	5	52	12	5	105.910
		4.108	-81.58	40	17	5	52	12	5	116.580

The measured path loss is calculated based on the empirical measurements collected from base station 5.

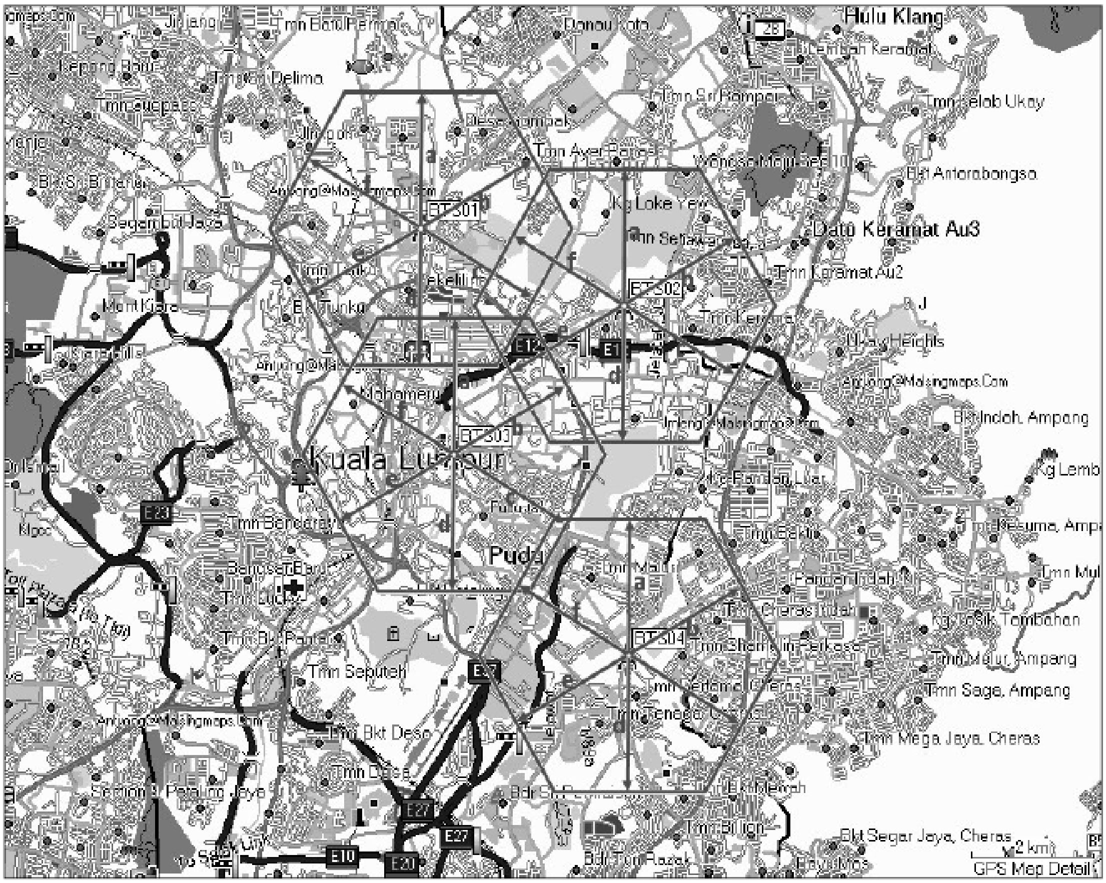

Figure 1. The location of four transmitters in KL City Centre

Figure 1 shows the site map where measurements are taken. The four transmitters are set in the center of the hexagon cell with six different routes designated as a, b, c, d, e and f.

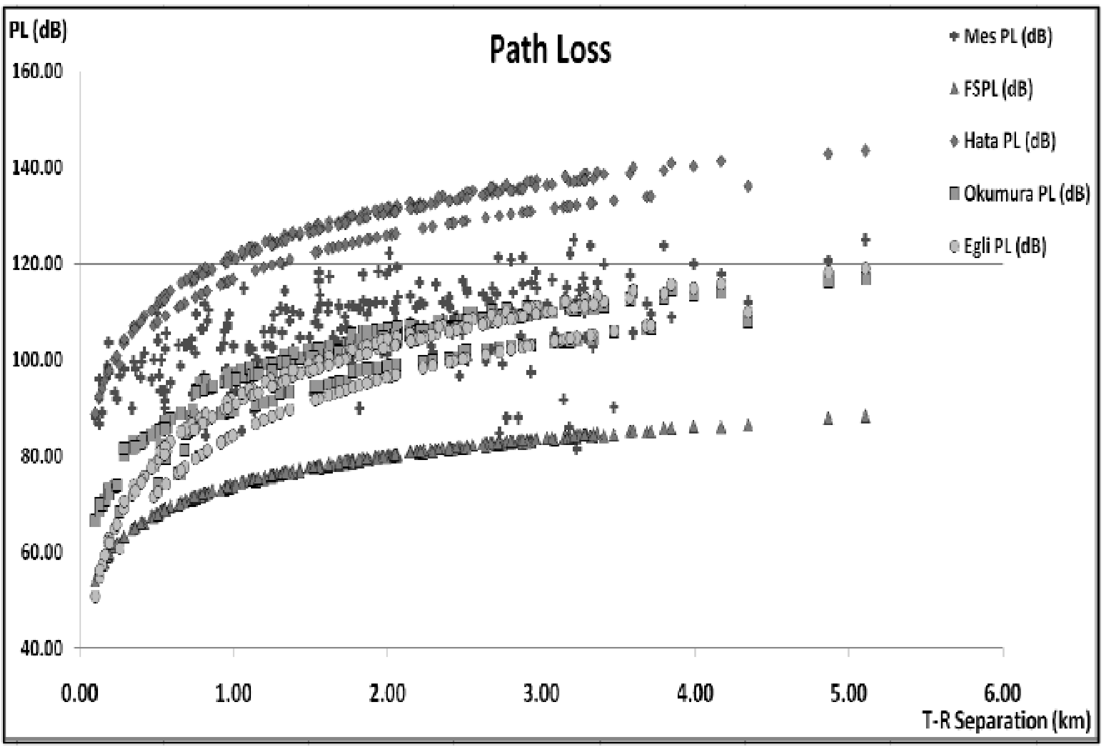

Figure 2. The measured path loss VS the prediction path loss by the existing path loss models

Figure 2 shows the measured path loss and the empirical path losses that calculated by using the existing path loss models. The path losses are plotted versus the separation distance of mobile station and base station.

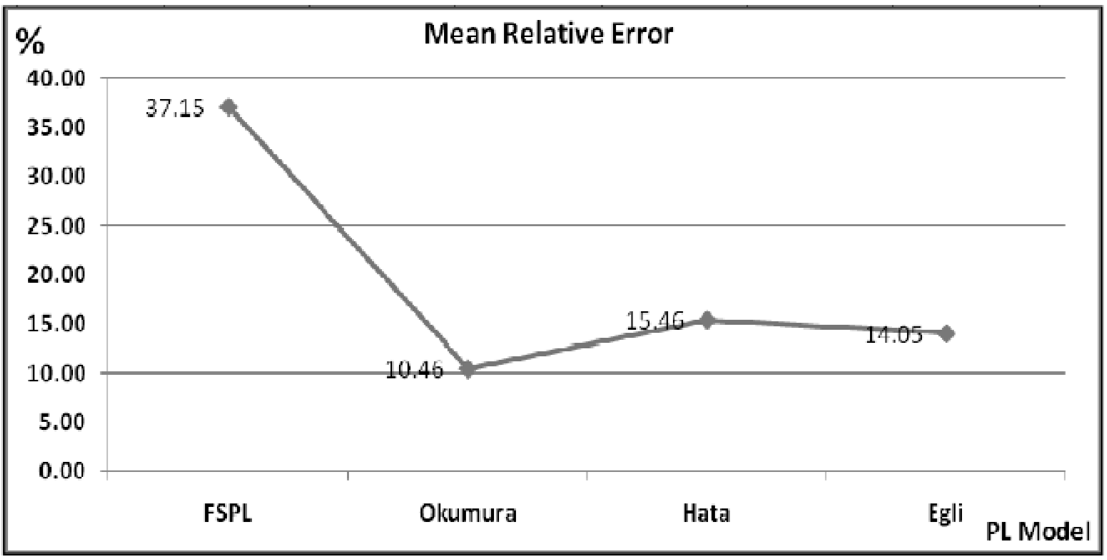

Figure 3. The mean relative error of measurement path loss to the existing path loss models

In deriving the minimum mean relative error of measured path loss to the reference path loss models, the Okumura's model has the smallest mean relative error among the path loss models of 10.46% as shown in Figure 3.

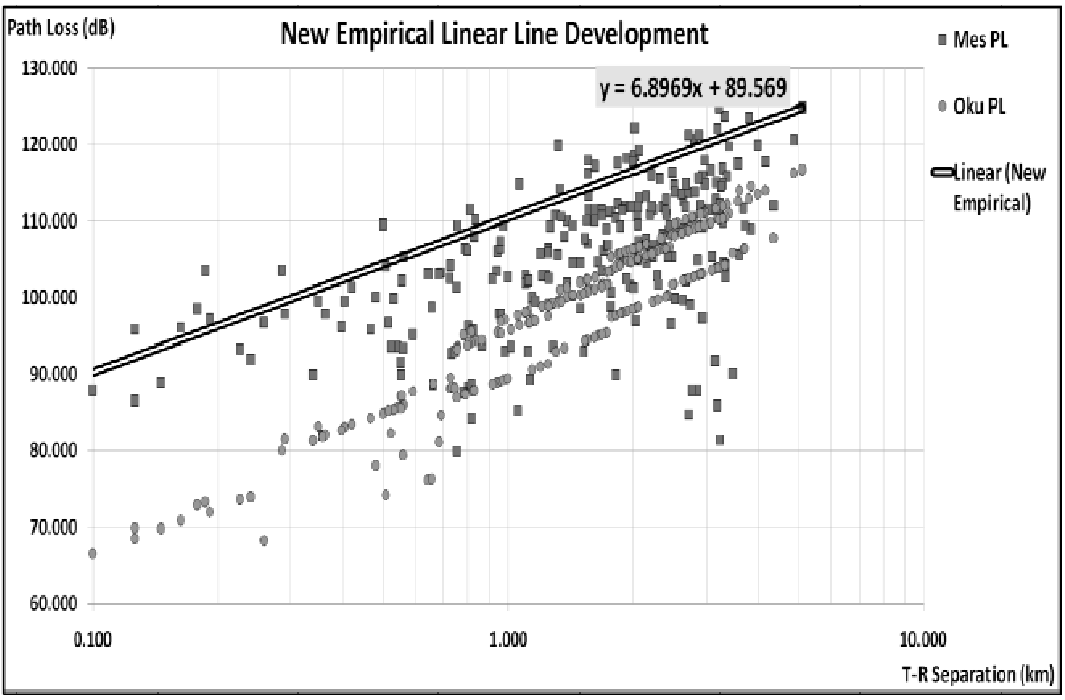

Figure 4. The new empirical linear line is developed by using regression fitting method

Figure 4 shows the new empirical linear line which is developed using the regression fitting method. The Okumura's model and measured path loss is plotted in dB versus T-R separation in log form. As a result, new empirical linear line y=6.8969x + 89.569 is obtained and this line will be used as reference for the best suited path loss model optimization.

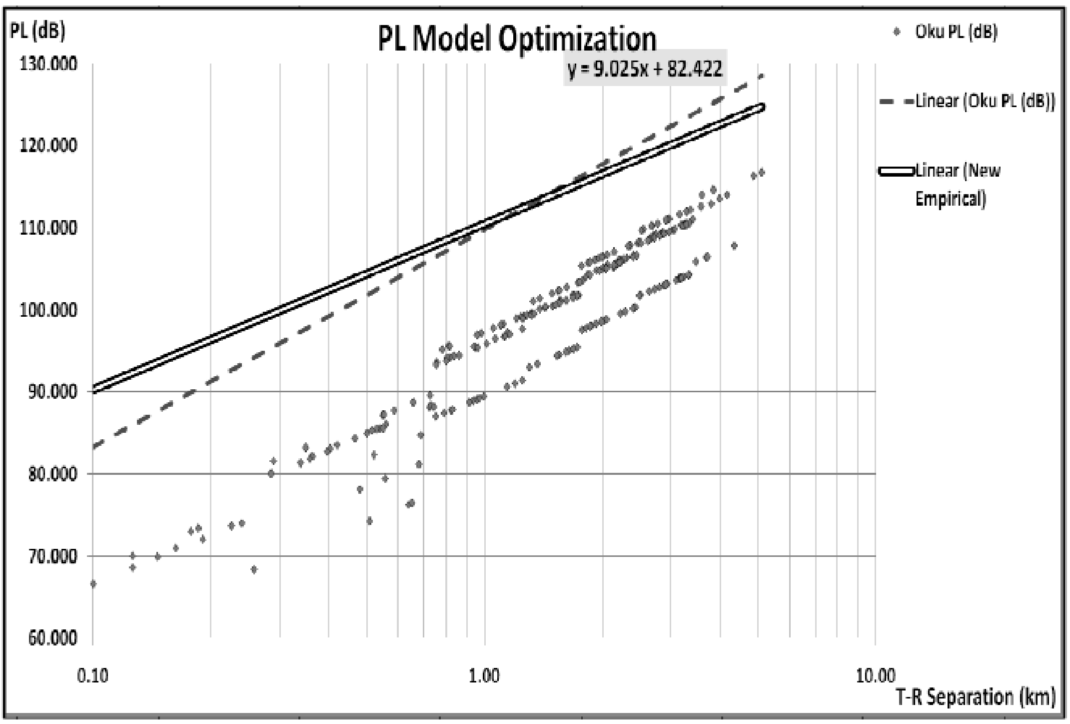

Figure 5. The Okumura's linear line is optimized to approximate to the new empirical linear line.

Figure 5 shows the best suitable path loss model, the Okumura's model of which is chosen for path loss model optimization. The linear line of Okumura's model (y=9.025x + 82.422) is plotted and optimized to approximate the new empirical linear line (y=6.8969x + 89.569).

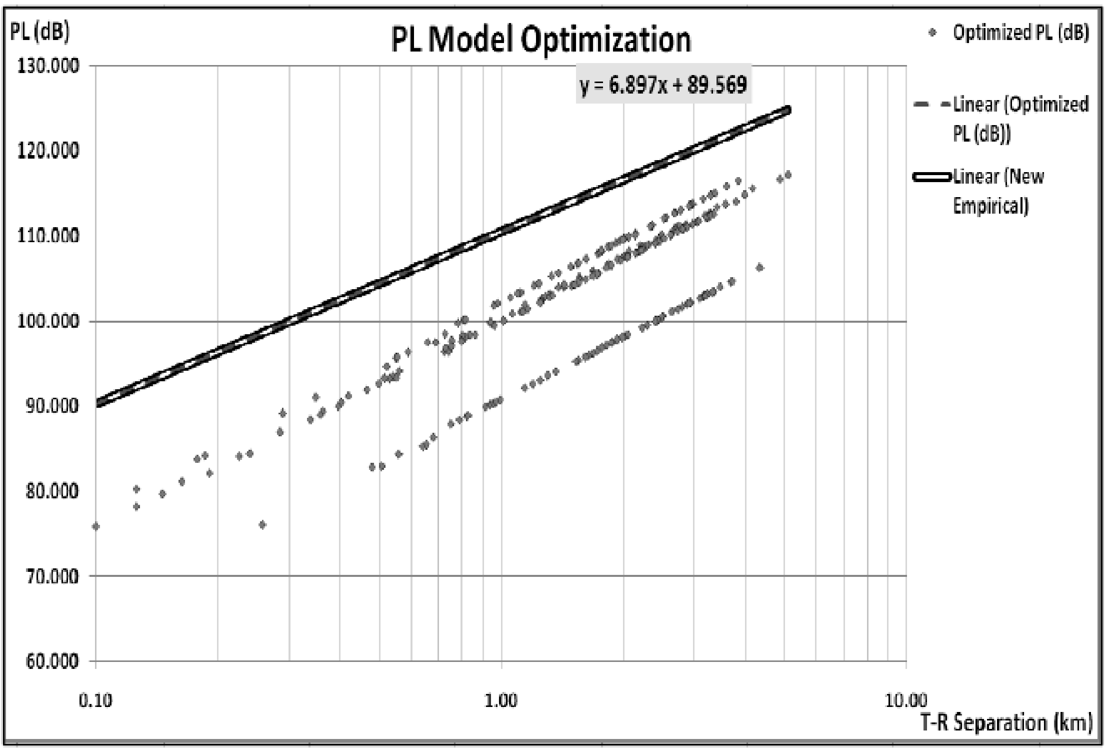

Figure 6. The Okumura's linear line has been optimized and approximated to the new empirical linear line

Figure 6 shows that Okumura linear line has been successfully optimized and it is approximated to the new empirical linear line based on the smallest mean relative error. Overall, the mean relative error has improved from 3.50629% to 0.00009%, where the value of *A, B, C, D, E* and *F* are determined.

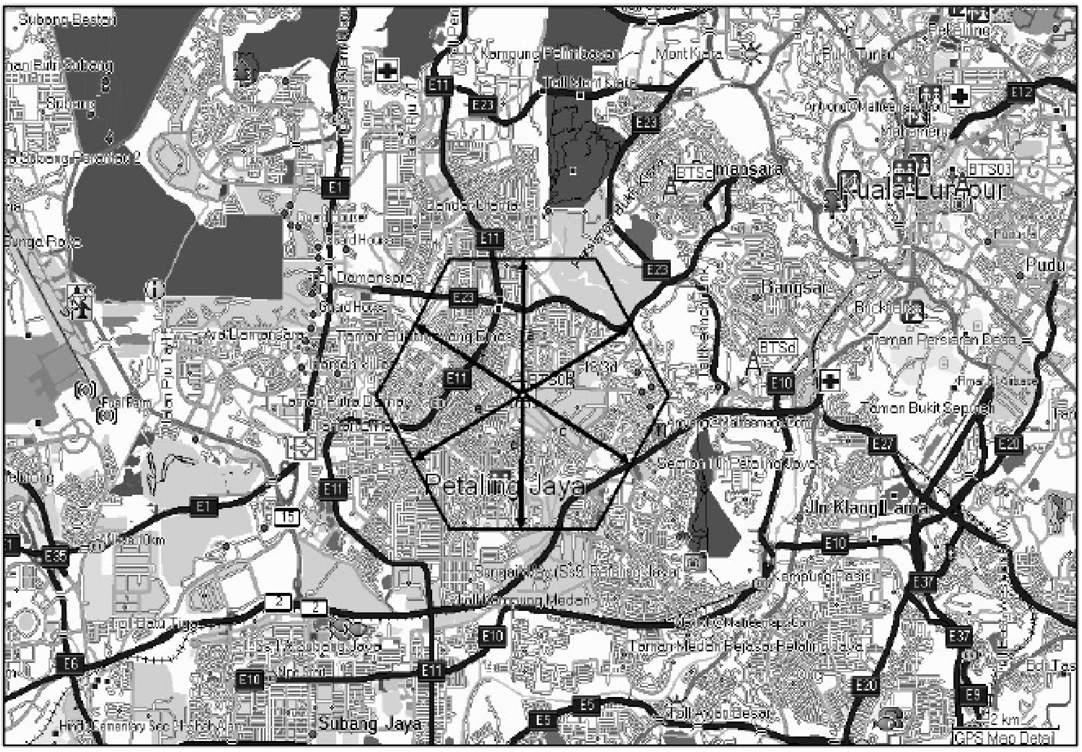

Figure 7. The base station to be tested in the validation process

Figure 7 shows the location of the base station 05 in Petaling Jaya city centre. The test drive has been performed in this area for measurement data collection. These measurement data will be used for path loss calculation and be compared to the path loss calculated by the existing path loss models and optimized path loss model.

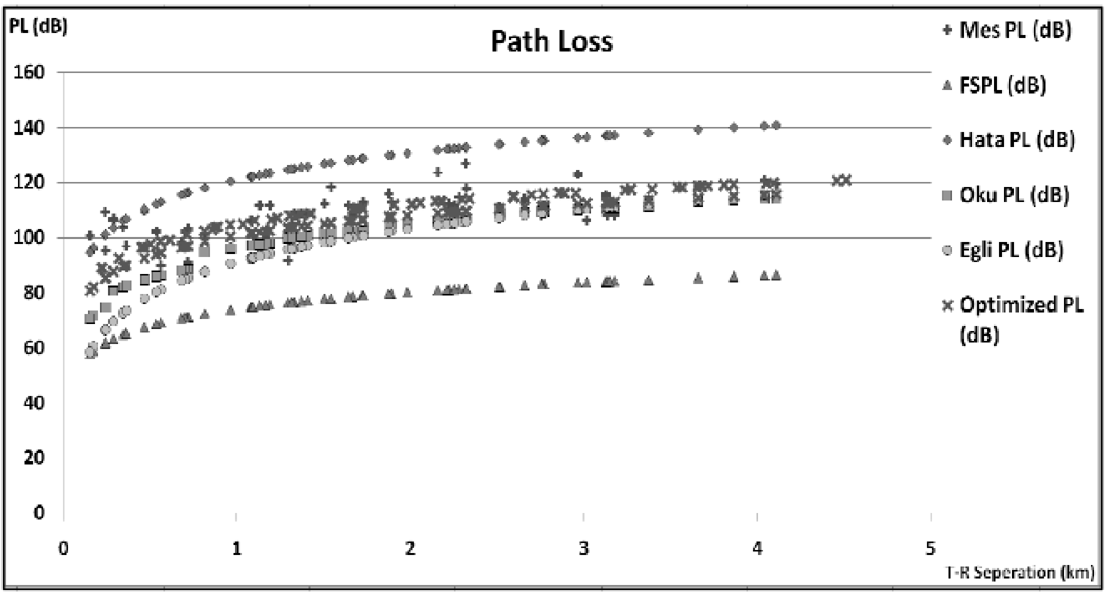

Figure 8. The measured path loss VS the prediction path loss by the existing path loss models and the optimized path loss model

Figure 8 shows the measured path loss and the empirical path losses that calculated by using the existing path loss models and the optimized Okumura's model. The path losses are plotted versus the separation distance of mobile station and base station.

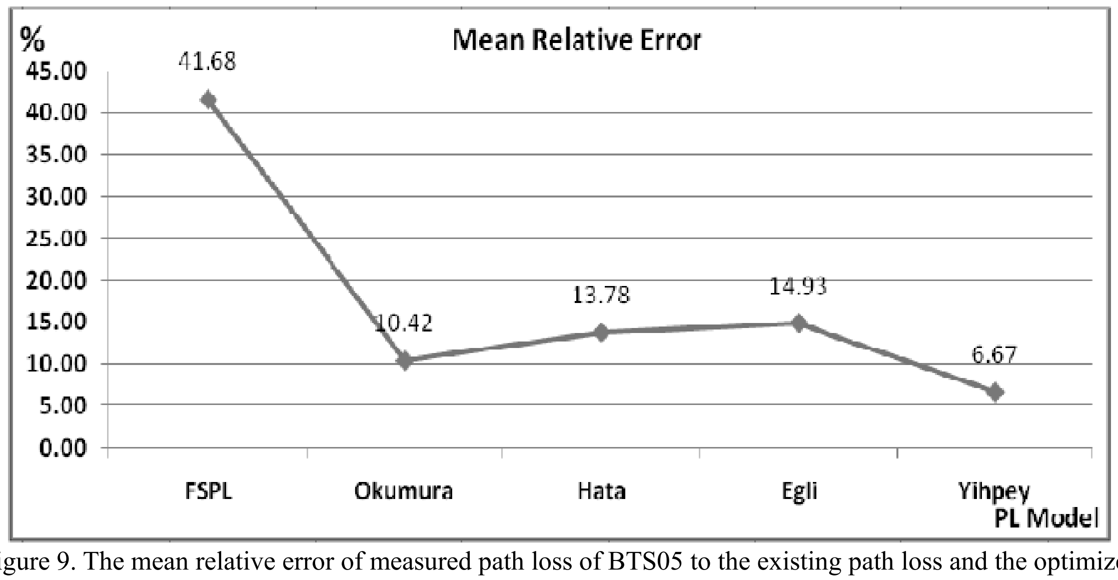

Figure 9. The mean relative error of measured path loss of BTS05 to the existing path loss and the optimized path loss model

The optimized path loss model is applied in the calculation of the path loss and had proven to be more accurate with smaller mean relative error up to 6.67% as shown in Figure 9. Thus, it can be concluded that the optimized path loss model is reliable to be used in the Malaysia CDMA system for link budget prediction.

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