Path Loss Model Optimization for Code Division Multiple Access (CDMA) System in Malaysia

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Abstract: The study of this work is to develop a new path loss model for urban outdoor coverage in CDMA system based on the empirical measurements collected in CDMA network in Kuala Lumpur (KL), Malaysia. The new path loss model is developed by comparing of the calculated path loss from measurements to the well-known path loss models such as Free Space pass loss model, Okumura’s Model, Hata’s Model and Egli’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%. A semi-empirical model is developed from Okumura and the collected measurements by regression fitting method. This semi-empirical model will be used as reference in the optimization process where Okumura’s model will be optimized to achieve smallest mean relative error to the semi-empirical model. The mean relative error has been reduced from 3.50629% to 0.00009% in order to find out the new path loss model by multiply with variables A, B, C, D, E & F to Okumura’s model. This newly optimized Okumura’s model is named as Yihpey’s Model which has proved that it has the smallest mean relative error 6.67% to the measurements data collected in validation process. This model is more reliable with higher accuracy compared to other model for path loss calculation in urban region of CDMA System in KL.

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

I. INTRODUCTION

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. 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.

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.

A. 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.

II. METHODOLOGY

Several existing path loss models such as the Free Space Path Loss Model [2], Okumura’s Model [3], Hata’s Model [4], and Egli’s Model [5] are chosen as reference for optimized path loss model development. The best existing path loss model with the smallest mean relative error [6] 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 Kuala Lumpur CDMA Network.

A. Propagation Models

Four existing path loss models are chosen as reference in the development of the optimized path loss model. These existing path loss models are Free Space Path Loss Model, Okumura’s Model, Hata’s Model and Egli Model. These path loss models were developed empirically in the
system with similar antenna heights and frequency ranges which are applicable to the CDMA network in Kuala Lumpur.

B. Free Space Path Loss Model
Free space path loss [2] is a loss in an electromagnetic wave signal strength that would result from an unobstructed line of sight path through free space. The received power with distance \( d \) from a radiated transmit antenna is given by

\[
P_r (d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}
\]

(1)

Where:
- \( P_t \) is base station transmit power,
- \( G_t \) is transmit antenna gain,
- \( G_r \) is receive antenna gain,
- \( L \) is loss factor not related to propagation (\( L \geq 1 \)),
- \( \lambda \) is signal wavelength.

The antenna gain is:

\[
G_r = \frac{4\pi A_e}{\lambda^2}
\]

(2)

The path loss for the free space model in dB is

\[
P_L (dB) = 10 \log \frac{P_t}{P_r} = -10 \log \frac{G_t G_r \lambda^2}{(4\pi)^2 d^2 L}
\]

(3)

C. Okumura's Model
The Okumura's model [3] is an empirical model based on extensive measurements made in Japan at several frequencies within the range of 150 to 1920 MHz. Okumura’s model is developed for macro cells with cell diameters of 1 to 100 km. The height of the BS antenna is between 30-1000 m. The Okumura’s model takes into account some of the propagation parameters such as the type of environment and the terrain irregularity.

Okumura developed a set of curves giving the median attenuation relative to free space in an urban area over a quasi-smooth terrain with a base station effective antenna height of 200m and mobile antenna height of 3m. These curves were developed from extensive measurements using vertical Omni-directional antennas at both the base and mobile, shown in Figure 1 below.

The Okumura’s Model is expressed as:

\[
L_{50}(dB) = L_f + A_{mu} (f,d) - G(h_b) - G(h_m) - G_{area}
\]

(4)

where:
- \( L_{50} \) (dB) is the 50th percentile value of propagation path loss,
- \( L_f \) is free space path loss,
- \( A_{mu} \) is free space attenuation,
- \( G(h_b) \) is base station antenna height gain factor,
- \( G(h_m) \) is mobile antenna height gain factor, and
- \( G_{area} \) is gain corresponding to specific environment.

D. Hata Model
This model is an empirical formulation of the graphical path loss data provided by Okumura’s model. Hata’s Model [4] is the most widely used radio frequency propagation model for predicting the behavior of cellular transmission. It includes the effects of diffraction, reflection and scattering caused by the city structures.

For urban area, the median path loss equation is given by:

\[
L_{urban}(dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_r - a(h_r) + (4.49 - \log h_r) \log d
\]

(5)

Where:
- \( L_{urban} \) is path loss in Urban area,
- \( h_r \) is height of the mobile station antenna,
- \( h_b \) is height of the base station antenna,
- \( f_c \) is carrier frequency, and
- \( a(h_r) \) is antenna height correction factor.

For large area, it is

\[
a(h_r) = 3.2(\log 117.5 h_r)^2 - 4.97 \text{ dB, for } f_c > 300MHz
\]

E. Egli’s Model
The Egli’s Model [5] is a terrain model for the radio frequency propagation to predict the total path loss for point-to-point link (line-of-sight transmission). Typically, it is suitable for cellular communication scenarios where one antenna is fixed and another is mobile. Egli model is applicable to scenarios where the transmission has to pass an irregular terrain. Egli model is not applicable to scenarios where some vegetative obstruction is in the middle of the link. The Egli’s Model is formally expressed as:

\[
P_L (dB) = G_B G_M \left[ \frac{h_B h_M}{d^2} \right]^2 \left[ \frac{40}{f} \right]^2
\]

(6)

F. 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 (10m²) in order to remove the effects of fast fading.

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.

The professional foreground test and the analysis software, i.e. ZXPOS CNT1 and CNA7 are used in collecting and analysing the CDMA network measurement data for the path loss calculation. The measurement data such as the received signal strength and T-R separation distance are recorded in dBm and km unit, which are easier for path loss calculation.

Every 10 sample points of the received signal strength and T-R separation distance are recorded evenly from all predefined routes of the four base stations located in the dense city of Kuala Lumpur. A total of 6 routes per base station with at least 60 received signal strength sample points of the 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 (10m²) in order to remove the effects of fast fading [6][7].

G. Path Loss Calculation

\[ PL (dB) = P_{RX} + G_{TX} - L_{TX} - P_{TX} + G_{RX} - L_{RX} - L_{FS} - L_{M} \]  

(7)

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) (fading margin, body loss, other losses)
- \( G_{RX} \) = receiver antenna gain (dBi)
- \( L_{RX} \) = receiver losses (dB)

The fading margin is the allowance that provides for sufficient system gain or sensitivity to accommodate expected fading, for the purpose of ensuring that the required quality of service is maintained. It is the amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value. Assume that mobile station can reliably receive -105dBm level in at least 75% of cell edge area (90% of cell area) and the standard deviation is 8dB. As shown in the below figure, the probability corresponding to 0.675σis 0.75%. Thus:

\[ 0.675 \times 8 = 5.4 \text{ dB} \]  

(8)

H. Transmitter EIRP (Equivalent Isotropically Radiated Power):

\[ \text{Tx EIRP} = \text{Tx Power} + \text{Tx Antenna Gain} - \text{Cable Loss} \]  

(9)

\[ = 40\text{dBm} + 17\text{dBi} - 5\text{dB} \]  

= 53dBm

The transmitter EIRP refers to the total amount of power density that transmits from the base station into the propagation medium, shown in Figure 3. Generally, the transmitter EIRP is calculated as the total transmitter power plus the antenna gain minus total cable loss.

I. Mobile Station Receive Power:

The received power is captured by the mobile station with 0 dB antenna gain and the received strength is affected by the T-R separation distance. However, the USB port connection and the cable loss conduct around 2dB of loss.
as mobile station is connected to the PC during the drive test as shown in Figure 7. The penetration loss which based on the experience and testings of 6dB dispersed through car window glass and car body. The human body loss is imposed during testings when the mobile station is held by hand and the signal strength is attenuated up to 3dB through the human body.

By gathering all the measurement data and the identified losses, path loss can easily be calculated. At the same time, the existing path loss models are applied for path loss calculation based on the separation distance between mobile and base station, base station transmit power and the received power of the mobile station.

Table 1. The collected measurements from Base Station 1

| Distance (m) | T-R separation distance | Base station transmit power (dBm) | Received power of mobile station (dBm) |
|--------------|------------------------|-----------------------------------|---------------------------------------|
| 1            | 0.12                   | 10.01                             | 8.50                                  |
| 2            | 0.12                   | 10.01                             | 8.50                                  |
| 3            | 0.12                   | 10.01                             | 8.50                                  |
| 4            | 0.12                   | 10.01                             | 8.50                                  |

The empirical path loss of BTS01 is calculated based on the measurements (base station transmit power, received power of mobile station, T-R separation distance etc) collected from BTS01.

Table 2. The collected measurements from Base Station 2

| Distance (m) | T-R separation distance | Base station transmit power (dBm) | Received power of mobile station (dBm) |
|--------------|------------------------|-----------------------------------|---------------------------------------|
| 1            | 0.12                   | 10.01                             | 8.50                                  |
| 2            | 0.12                   | 10.01                             | 8.50                                  |
| 3            | 0.12                   | 10.01                             | 8.50                                  |
| 4            | 0.12                   | 10.01                             | 8.50                                  |

The empirical path loss of BTS02 is calculated based on the measurements (base station transmit power, received power of mobile station, T-R separation distance etc) collected from BTS02.
Table 3. The collected measurements from Base Station 3

| BS   | d (m) | H (m) | L (m) | dF (m) | Lr (m) | T-R (m) | Ptx dBm | Prx dBm |
|------|-------|-------|-------|--------|--------|---------|---------|---------|
| BTS3 | 1     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 2     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 3     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 4     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 5     | 0.044 | 40    | 17.9   | 2      | 9.4     |

The empirical path loss of BTS03 is calculated based on the measurements (base station transmit power, received power of mobile station, T-R separation distance etc) collected from BTS03.

Table 4. The collected measurements from Base Station 4

| BS   | d (m) | H (m) | L (m) | dF (m) | Lr (m) | T-R (m) | Ptx dBm | Prx dBm |
|------|-------|-------|-------|--------|--------|---------|---------|---------|
| BTS4 | 1     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 2     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 3     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 4     | 0.044 | 40    | 17.9   | 2      | 9.4     |
|      | 5     | 0.044 | 40    | 17.9   | 2      | 9.4     |

The empirical path loss of BTS04 is calculated based on the measurements (base station transmit power, received power of mobile station, T-R separation distance etc) collected from BTS04.
Table 5. The collected measurements from Base Station 5 for path loss calculation and validation test.

| T-R separation distance (m) | Base Station Transmit Power (dBm) | Received Power of Mobile Station (dBm) | Path Loss (dB) |
|---------------------------|-----------------------------------|---------------------------------------|---------------|
| 1500                      | 6.92                              | -11.21                                | 8.73          |
| 2500                      | 6.92                              | -11.21                                | 8.73          |
| 3500                      | 6.92                              | -11.21                                | 8.73          |
| 4500                      | 6.92                              | -11.21                                | 8.73          |

The empirical path loss of BTS05 is calculated based on the measurements (base station transmit power, received power of mobile station, T-R separation distance etc) collected from BTS05.

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

Figure 3. The new empirical linear line is developed by using regression fitting method.

Figure 4. Okumura has the smallest mean relative error among other existing path loss models.

K. 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 line is used as a reference during the path loss model optimization process.

J. Mean Relative Error

In order to find out the best suitable path loss model for optimization, the relative error [8] of the measured path loss to the existing path loss models is determined. Figure 9 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.

In deriving the minimum mean relative error of measurement path loss to the reference path loss model, we have ascertained that the Okumura’s model has the smallest mean relative error among the path loss models of 10.46% as shown in Figure 4.

\[
\delta = \frac{|V - V_{\text{approx}}|}{|V|} \times 100\% \tag{10}
\]

Where:

- \(V\) is the exact value,
- \(V_{\text{approx}}\) is the approximation.
L. Optimization

The optimization is performed using the best suitable path loss model, being the Okumura’s model [3] with reference to the new empirical linear line that was developed from the measurement data of 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 (11). 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.

\[
\text{Okumura’s Model (dB)} = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - G_{AREA}
\]

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

From Figure 6, the result clearly shows that the optimized graph is concurrent with the measurement data. This is because the optimized model is improved by using suitable optimization techniques. The figure above shows that good performance is achieved and it can be further extensively explained using the relative error analysis during the validation process.

M. Optimized Path Loss 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.

\[
\text{Optimized Path Loss Model (dB)} = AL_{FSL} + BA_{MU} - CH_{MG} - DH_{BG} - EG_{AREA} + F
\]

N. Validation

In the validation process, the optimized path loss model is applied for path loss calculation in other city to verify the accuracy and the suitability of this optimized path loss model. The city centre of Petaling Jaya, with similar building structure of KL city centre, has been chosen for the optimized path loss 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.

From Figure 6, the result clearly shows that the optimized graph is concurrent with the measurement data. This is because the optimized model is improved by using suitable optimization techniques. The figure above shows that good performance is achieved and it can be further extensively explained using the relative error analysis during the validation process.
The optimized path loss model is employed in the calculation of the path loss and had proven to be more accurate with smaller mean relative error up to 6.67% shown in Figure 10. 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.

III. LIMITATION

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.

IV. CONTRIBUTION

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 signalled 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.

V. CONCLUSION

The optimized path loss model is developed based on the measurement and the empirical model. The optimized model had been applied and validated at place with similar city structure to KL city centre to find the relative error in order to assess its performance. As result, the optimized model is found to best fit among other existing path loss model with smaller mean relative error. The smaller mean error shows that the optimization has been done successfully. The optimized path loss model is reliable and high in accuracy for path loss calculation in the CDMA system in urban areas throughout Malaysia. This model is useful for telecommunication providers to enhance the satisfaction of the mobile users.

ACKNOWLEDGEMENT

The author would like to convey his utmost appreciation to Dr Mardeni Roslee for his invaluable support, encouragement, supervision and constructive feedbacks in the completion of this publication. The author would also like to thank “Electcoms Berhad” for providing the necessary tools, and information that were required for this thesis. Lastly, he would like to offer his heartfelt gratitude to all those who have supported him throughout the preparation of the thesis.

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