



Comparative Study of Least Square Methods for Tuning Erceg Pathloss Model

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Abstract: In this paper, a study of two least square error approaches for optimizing Erceg pathloss model is presented. The first approach is implemented by the addition of the root mean square error (RMSE) if the sum of prediction errors is positive otherwise, the RMSE is subtracted from the pathloss predicted by the original Erceg model. In the second method, the composition function of the residue is used to generate the model correction factor that is added to the original Erceg model pathloss prediction. The study is based on field measurement carried out in a suburban area for a GSM network in the 800 MHz frequency band. The results show that the untuned Erceg model has RMSE of 59.27384 dB and prediction accuracy of 59.57243%. On the other hand, the pathloss predicted by the RMSE tuned Erceg model has RMSE of 4.495422dB and prediction accuracy of 97.28188% and the pathloss predicted by the composition function tuned Erceg model has RME of 2.177523 dB and prediction accuracy of 98.7253%. In any case, the two methods are effective in minimizing the error to within the acceptable value of less than 7 dB. However, the composition function approach has better pathloss prediction performance with smaller RMSE and higher prediction accuracy than the RMSE-based approach.

Keywords: Pathloss, Erceg Model, Least Square Method, Propagation Model, Model Tuning, Composition Function Of Residue

1. Introduction

In wireless network planning, pathloss are usually used in link budgeting and in the estimation of network coverage area [1-5]. Mostly, network planners find it easier to use pathloss models to estimate the pathloss that can be experienced by the signal in any given area [6-10]. In this wise, empirical pathloss models are usually the first option in view of their simplicity and quite acceptable pathloss prediction capability [11-16].

However, for more accurate estimation of pathloss in any given terrain, empirical pathloss models are usually subjected to empirical prediction performance evaluation and further or optimization with respect to field measured pathloss values. In most published literatures, the least square error optimization approach is mostly used [17-21]. There are different approaches to implement the least square optimization of

pathloss model. The simplest approach is to generate the root mean square error (RMSE) from the measured and the models predicted pathloss and then add or subtract the RMSE from the pathloss predicted at each there is measurement pathloss. Other method is the adjustment of some coefficients in the original pathloss model so as to minimize the error. yet, another approach if to use function of function approach to estimate the prediction error as a function of the predicted pathloss.

In this paper, the RMSE –based optimization approach and the composite function-based approach are studied with respect to a field measurement carried out in a suburban area for a GSM network in the 1800MHz frequency band. Also, particularly, the empirical are useto evaluate and optimise Erceg pathloss model.

2. Theoretical Background

2.1. Erceg Path Loss Model

The Erceg model has been chosen by IEEE 802.16 as

$$PL_{ERCEG (dB)} = A + 10\gamma \left(\log_{10} \left(\frac{d}{d_0} \right) \right) + X_f + X_h + S \text{ for } d > d_0 \quad (1)$$

Where,

f = The frequency in MHz

d = The distance between AP and CPE antennas in meters

$d_0=100\text{m}$

X_h = The correction for receiving the antenna height in meters

γ = The path loss exponent

X_f = The correction for frequency in MHz

S = The correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of trees and other clutters on the propagation path

The parameter A is defined as:

$$A = 20 \left(\log_{10} \left(\frac{4\pi d_0}{\lambda} \right) \right) \quad (2)$$

and the path loss exponent γ is given by:

$$\gamma = a + b(h_b) + \frac{c}{h_b} \quad (3)$$

Where, the parameter h_b is the base station antenna height in meters. This is between 10 m and 80 m. The constants a, b and c depend upon the types of terrain, that are given in Table 1. The value of parameter γ is 2 for free space propagation in an urban area, $3 < \gamma < 5$ for urban none line of sight (NLOS) environment, and $\gamma > 5$ for indoor propagation.

Table 1. The Erceg Parameters.

Parameters	Type A	Type B	Type C
d_0	100m	100m	100m
a	4.6	4.0	3.6
b	0.0075 m^{-1}	0.0065 m^{-1}	0.0050 m^{-1}
c	12.6m	17.1m	20.0m

The frequency correction factor, X_f and the correction for receiver antenna height, X_h are expressed as:

$$X_f = 6 \left(\log_{10} \left(\frac{f}{2000} \right) \right) \quad (4)$$

$$X_h = -10.8 \left(\log_{10} \left(\frac{h_m}{2} \right) \right) \text{ for terrain type A and B} \quad (5)$$

$$X_h = -20.8 \left(\log_{10} \left(\frac{h_m}{2} \right) \right) \text{ for terrain type C} \quad (6)$$

$$d = 2r \left\{ \sqrt{\sin^2 \left(\frac{LAT_2 - LAT_1}{2} \right) + \cos(LAT_1) \cos(LAT_2) \sin^2 \left(\frac{LONG_2 - LONG_1}{2} \right)} \right\} \quad (9)$$

$$LAT \text{ in Radians} = \frac{(LAT \text{ in Degrees} * 3.142)}{180} \quad (10)$$

$$LONG \text{ in Radians} = \frac{(LONG \text{ in Degrees} * 3.142)}{180} \quad (11)$$

Where

reference propagation model for WiMAX system evaluation [22-26]. This model can be applied in three different environments, Type A, B and C. By using this model the total attenuation $PL_{ERCEG (dB)}$ for outdoor is given by [27]:

Where, f is the operating frequency in MHz, and h_m is the receiver antenna height in meter.

Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities.

Type B is characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities.

Type C is associated with minimum path loss and applies to flat terrain with light tree densities.

2.2. Data Collection and Processing

The Received Signal Strength (RSS) and spatial data (longitude and latitude) dataset are then collected along a route selected for the study. Samsung Galaxy S4 mobile phone with Cellmapper android application installed is used to capture and store the dataset (RSS and spatial datasets) as CSV file. The RSS is converted to the measured pathloss ($PL_m (dB)$) using the formula [13-15]:

$$PL_m (dB) = P_{BTS} + G_{BTS} + G_{MS} - L_{FC} - L_{AB} - L_{CF} - RSS (dBm) \quad (7)$$

where

$PL_m (dB)$ is the measured pathloss for each measurement location at a distance d (km)

RSS is the mean Received Signal Strength in dBm, that is, the measured received signal strength.

P_{BTS} is the Transmitter Power (dBm), G_{BTS} is the Transmitter Antenna Gain (dBi), G_{MS} is the receiver antenna gain (dBi), L_{FC} is the feeder cable and connector loss (dB), L_{AB} is the Antenna Body Loss (dB) and L_{CF} is the Combiner and Filter Loss (dB).

The values of these parameters are given as [13] as: $P_{BTS} = 40 \text{ W} = 46 \text{ dBm}$, $G_{BTS} = 18.15 \text{ dBi}$, $G_{MS} = 0 \text{ dBi}$, $L_{FC} = 3 \text{ dB}$, $L_{AB} = 3 \text{ dB}$, $L_{CF} = 4.7 \text{ dB}$. Hence,

$$PL_m (dB) = 53.5 (dBm) - RSS (dBm) \quad (8)$$

Again, the Haversine formula in Eq 9 is used to compute the distances (d) between each measurement point and the base station as follows;

LAT1 and LAT2 are the latitude of the coordinates of point1 and point 2 respectively

LONG1 and LONG2 are the longitude of the coordinates of point1 and point 2 respectively

R = radius of the earth = 6371 km; R varies from 6356.752km at the poles to 6378.137 km at the equator

d = the distance between the two coordinates

2.3. Performance Analysis of the Models

These statistical performance measures or goodness of fit measures for the Erceg model are defined as follows:

i) The Root Mean Square Error (RMSE) is calculated as follows:

$$MSE = \sqrt{\frac{1}{n} \left[\sum_{i=1}^{i=n} PL_{(measured)(i)} - PL_{(predicted)(i)} \right]^2} \quad (12)$$

ii) Then, the Prediction Accuracy (PA, %) based on mean absolute percentage deviation (MAPD) or Mean Absolute Percentage Error (MAPE) is calculated as follows:

$$PA = \left\{ 1 - \frac{1}{n} \left(\sum_{i=1}^{i=n} \left| \frac{PL_{(measured)(i)} - PL_{(predicted)(i)}}{PL_{(measured)(i)}} \right| \right) \right\} * 100\% \quad (13)$$

2.4. Model Optimization Process

The parameters of the Erceg pathloss model were adjusted (optimized) using two different least square methods as follows;

1) First, the residual (or error, e) between measured pathloss, $PL_{m(dB)}$ and the Erceg model predicted pathloss $Pr_{m(dB)}$ is calculated for each location point, i.

$$e_{(i)} = PL_{m(dB)(i)} - Pr_{m(dB)(i)} \quad (14)$$

2) Second, the RMSE is calculated based along with sum of errors, that is $\sum_{i=1}^{i=n} (e_{(i)})$.

3) Thirdly, if $\sum_{i=1}^{i=n} (e_{(i)}) < 0$ then the optimised model is obtained by subtracting RMSE from each $Pr_{m(dB)(i)}$ otherwise, if $\sum_{i=1}^{i=n} (e_{(i)}) \geq 0$ the optimised model is obtained by adding RMSE to each $Pr_{m(dB)(i)}$.

4) Fourthly, if $\sum_{i=1}^{i=n} (e_{(i)}) < 0$ then the optimised model is obtained by subtracting RMSE from each $Pr_{m(dB)(i)}$ otherwise, if $\sum_{i=1}^{i=n} (e_{(i)}) \geq 0$ the optimised model is obtained by adding RMSE to each $Pr_{m(dB)(i)}$.

$$PL_{m(dB)(i)} = Pr_{m(dB)(i)} + e_{(i)} \quad (15)$$

Where $e_{(i)}$ is estimated from a composite function, $e(Pr_{m(dB)(i)})$ defined as follows;

$$e(Pr_{m(dB)(i)}) = K1 (Pr_{m(dB)(i)}) + K2$$

K1 and K2 are the tuning coefficients for the composition of function of residual given as $(Pr_{m(dB)(i)})$. Essentially, $e(Pr_{m(dB)(i)})$ is a function the predicts the residue (that is, the prediction error, $e_{(i)}$) based on the pathloss predicted by the untuned Erceg model. Furthermore, $e_{(i)} \approx e(Pr_{m(dB)(i)})$, then;

$$PL_{m(dB)(i)} = Pr_{m(dB)(i)} + K1 (Pr_{m(dB)(i)}) + K2 \quad (16)$$

The composite function tune Erceg model is therefore given as $Pr_{CFT(dB)(i)}$ where

$$Pr_{CFT(dB)(i)} = Pr_{m(dB)(i)} + K1 (Pr_{m(dB)(i)}) + K2 \quad (17)$$

3. Results and Discussions

The field measured distance, received signal strength (RSSI) and pathloss (PLm) are given in Table 2. The measured pathloss (PLm) is obtain by applying link budget equation, $PL_{m(dB)} = 53.5 \text{ (dBm)} - \text{RSS (dBm)}$ to each of the measured received signal strength. Furthermore, Haversine formula is used to obtain the distance between the GSM base station and each of the measurement point, where the longitude 1 and latitude 1 are that of the GSM base station while longitude 2 and latitude 2 are for each of the measurement points.

Figure 1 shows the radial graph of measured pathloss in dB versus distance in meters. The measure pathloss values are from 134.5 dB at a distance of 773m from the GSM base station to a pathloss value of 152.5dB at a distance of 1012 m from the GSM base station.

Table 2. The Field Measured Distance, Received Signal Strength (RSS) and Field Measured Path Loss (PLm).

S/N	d (km)	RSS (dB)	Field Measured Path Loss (dB)	S/N	d (km)	RSS (dB)	Field Measured Path Loss (dB)
1	0.772603	-81	134.5	15	0.9	-97	150.5
2	0.804	-85	138.5	16	0.911	-97	150.5
3	0.82	-85	138.5	17	0.912	-97	150.5
4	0.83	-85	138.5	18	0.913	-97	150.5
5	0.84	-85	138.5	19	0.92	-97	150.5
6	0.848	-85	138.5	20	0.922	-97	150.5
7	0.857	-91	144.5	21	0.93	-97	150.5
8	0.863	-91	144.5	22	0.936	-97	150.5
9	0.863	-91	144.5	23	0.951	-97	150.5
10	0.871	-91	144.5	24	0.965	-97	150.5
11	0.878	-91	144.5	25	0.984	-97	150.5
12	0.89	-91	144.5	26	1.001	-97	150.5
13	0.894	-91	144.5	27	1.012	-99	152.5
14	0.9	-91	144.5				

Table 3 and figure 1 show the field measure pathloss and the pathloss predicted by the untuned Erceg model, the pathloss predicted by the RMSE tuned Erceg model and the pathloss predicted by the composition function tuned Erceg model.

Also, the table shows that the untuned Erceg model has RMSE of 59.27384 dB and prediction accuracy of 59.57243%. On the other hand, the pathloss predicted by the RMSE tuned Erceg model has RMSE of 4.495422dB and prediction

accuracy of 97.28188%. and the pathloss predicted by the composition function tuned Erceg model has RME of 2.177523 dB and prediction accuracy of 98.7253%. Given that RMSE = 59.27384, for the untuned Erceg model then the composition function is obtained as;

$$e(Pr_{m(dB)(i)}) = 5.306988273 (Pr_{m(dB)(i)}) - 401.9577187 \quad (18)$$

So,

$$Pr_{CFT(dB)(i)} = Pr_{m(dB)(i)} + 5.306988273 (Pr_{m(dB)(i)}) - 401.9577187 \quad (19)$$

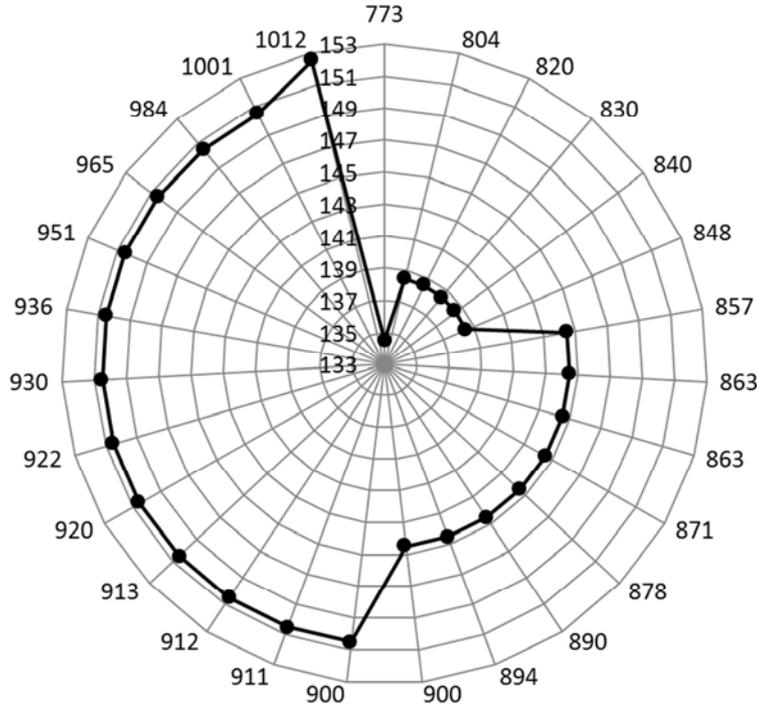


Figure 1. The radial graph of measured pathloss in dB versus distance in meters.

Table 3. The field measure pathloss and the pathloss predicted by the untuned and the tuned Erceg models.

S/N	Distance (m)	Field Measured Path Loss (dBm)	Pathloss By The Untuned Erceg Model	Pathloss By The RMSE Tuned Erceg Model	Pathloss By The Composition Function Tuned Erceg Model
1	773	134.5	85.2	144.5	135.4
2	804	138.5	85.7	144.9	138.2
3	820	138.5	85.9	145.2	139.7
4	830	138.5	86	145.3	140.6
5	840	138.5	86.2	145.4	141.5
6	848	138.5	86.3	145.5	142.1
7	857	144.5	86.4	145.7	142.9
8	863	144.5	86.5	145.7	143.4
9	863	144.5	86.5	145.7	143.4
10	871	144.5	86.6	145.9	144.1
11	878	144.5	86.7	145.9	144.7
12	890	144.5	86.8	146.1	145.7
13	894	144.5	86.9	146.1	146
14	900	144.5	87	146.2	146.5
15	900	150.5	87	146.2	146.5

Table 3. Continue.

S/N	S/N	Distance (m)	Field Measured Path Loss (dBm)	Pathloss By The Untuned Erceg Model	Pathloss By The RMSE Tuned Erceg Model	Pathloss By The Composition Function Tuned Erceg Model
1	16	911	150.5	87.1	146.4	147.3
2	17	912	150.5	87.1	146.4	147.4
3	18	913	150.5	87.1	146.4	147.5
4	19	920	150.5	87.2	146.5	148.1
5	20	922	150.5	87.2	146.5	148.2
6	21	930	150.5	87.3	146.6	148.9
7	22	936	150.5	87.4	146.7	149.3
8	23	951	150.5	87.6	146.9	150.5

S/N	S/N	Distance (m)	Field Measured Path Loss (dBm)	Pathloss By The Untuned Erceg Model	Pathloss By The RMSE Tuned Erceg Model	Pathloss By The Composition Function Tuned Erceg Model
9	24	965	150.5	87.8	147	151.5
10	25	984	150.5	88	147.3	152.9
11	26	1001	150.5	88.2	147.5	154.2
12	27	1012	152.5	88.3	147.6	155
13						
14		RMSE (dB)		59.27384	4.495422	2.177523
15		Prediction Accuracy (%)		59.57243	97.28188	98.7253

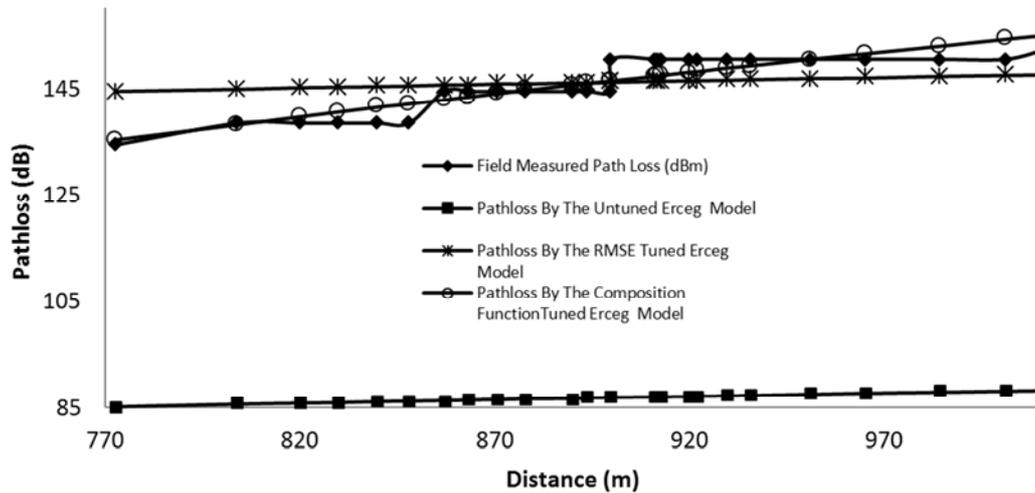


Figure 2. The field measure pathloss and the pathloss predicted by the untuned and the tuned Erceg model.

4. Conclusion

In this paper, comparative study of two least square error approaches for optimizing Erceg pathloss model is presented. Both methods are by adding or subtracting a model correction factor. In the first model tuning approach the correction factor is the root mean square error (RMSE). It is implemented is the addition or subtraction of the RMSE based on whether the sum of errors is positive or negative. In the second method the correction factor is the composition function of the residue (that is function of the prediction error of the the original Erceg model). It is implemented by adding the composition function to the pathloss predicted by the Erceg model. The study is based on field measurement carried out in a suburban area for a GSM network in the 800MHz frequency band. The results show that the composition function approach has better pathloss prediction performance with smaller RMSE and higher prediction accuracy than the RMSE-based approach.

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