

Comparative Study of Least Square Methods for Tuning CCIR Pathloss Model

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Abstract: Comparative study of two least square methods for tuning CCIR pathloss model is presented. The first model tuning approach is implemented by the addition or subtraction of the root mean square error (RMSE) based on whether the sum of errors is positive or negative. The second method is implemented by addition of a composition function of the residue to the original CCIR model pathloss prediction. The study is based on field measurement carried out in a suburban area for a GSM network in the 1800 MHz frequency band. The results show that the untuned CCIR model has a root mean square error (RMSE) of 17.33 dB and prediction accuracy of 85.33%. On the other hand, the pathloss predicted by the RMSE tuned CCIR model has RMSE of 4.09dB and prediction accuracy of 96.82% while the pathloss predicted by the composition function tuned CCIR model has RME of 2.15 dB and prediction accuracy of 98.39%. In all, both 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, Propagation Model, CCIR Model, Composition Function, Empirical Model, RMSE-Based Tuning Approach, Least Square Method

1. Introduction

Pathloss models are mathematical expressions designed for predicting the expected pathloss that signal can experience in a given environment [1-6]. Pathloss prediction is particularly essential in wireless network communication systems for determining the network coverage area. Empirical pathloss models are the pathloss models that are developed based on empirical measurements conducted in a specific area [7-9]. Empirical pathloss models are limited in their ability to predict pathloss effectively in different environments other than the one where they are developed from [10-14]. As such, model tuning is normally used to modify the model parameters so as to improve on the its pathloss prediction performance [15-18].

In this paper, comparative study of two pathloss tuning approaches are presented. The two approaches are basically least square methods that use different correction factors to minimize the pathloss prediction error. In the first approach, the correction factor is the root mean square error (RMSE)

whereas in the second approach the correction factor is obtained by using a composition function that estimates the pathloss prediction error based on the current pathloss prediction. Particularly, in this paper, the CCIR pathloss model is considered for 1800MHz GSM network in a suburban area.

2. Methodology

2.1. CCIR Pathloss Model

The CCIR (Comité International des Radio-Communication, now ITU-R) developed an empirical pathloss model that takes into account the varying degrees of urbanization. The CCIR model is given as follows [19-22]:

$$LP_{CCIR} = A + B * \log_{10}(d) - E \quad (1)$$

where A and B are defined in the Okumura-Hata model with $a(h_m)$ being the medium or small city value.

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (2)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (3)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (4)$$

Eq 4 is for small city, medium city, open area, rural area and suburban area. The parameter E accounts for the degree of urbanization and is given by;

$$E = 30 - 25\log_{10}(PB) \quad (5)$$

Where PB is the % of area covered by buildings where E = 0 when the area is covered by approximately 16% buildings.

For Urban Area $PB \geq 16\%$ and hence, E is set to 0 for urban area.

For Sub-Urban Area $PB < 16\%$ (typical $PB = 8\%$).

For Rural Area $PB < 16\%$ (typical $PB = 3\%$).

Where

- f is the centre frequency f in MHz
- d is the link distance in km
- $a(h_m)$ is an antenna height-gain correction factor that depends upon the environment
- $150 \text{ MHz} \leq f \leq 1000 \text{ MHz}$
- $30 \text{ m} \leq h_b \leq 200 \text{ m}$
- $1 \text{ m} \leq h_m \leq 10 \text{ m}$
- $1 \text{ km} \leq d \leq 20 \text{ km}$

2.2. Model Optimization Process

The parameters of the CCIR pathloss model were adjusted (optimized) using least square algorithm to fit to measured data using the following process.

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

$$e_{(i)} = PL_{m(dB)(i)} - Pr_{m(dB)(i)} \quad (6)$$

- 2) Second, the RMSE is calculated based along with sum of errors, that is $\sum_{i=1}^n (e_{(i)})$.
- 3) Thirdly, if $\sum_{i=1}^n (e_{(i)}) < 0$ then the optimised model is obtained by subtracting RMSE from each $Pr_{m(dB)(i)}$ otherwise, if $\sum_{i=1}^n (e_{(i)}) \geq 0$ the optimised model is obtained by adding RMSE to each $Pr_{m(dB)(i)}$, as given in Eq 6 ; $e_{(i)} = PL_{m(dB)(i)} - Pr_{m(dB)(i)}$
- 4) For the RMSE-based tuning, the tuned pathloss model is denoted as $PL_{RMSETUNED}$ where,

$$PL_{RMSETUNED} = PL_{m(dB)(i)} + RMSE$$

- 5) For the composition function –based tuning, the tuned pathloss model is denoted as $PL_{CFRTUNED}$ and the composition function of residue is denoted as $fe_{(i)}$ where,

$$PL_{CFRTUNED} = PL_{m(dB)(i)} + fe_{(i)} \quad (7)$$

where

$$fe_{(i)} = K1 (PL_{m(dB)(i)}) + K2 \quad (8)$$

K1 and K2 are the tuning coefficients for the composition of function of residual given as $fe_{(i)}$.

Essentially, $fe_{(i)}$ is a function that predicts the residue (that, is the prediction error) based on the pathloss predicted by the untuned CCIR model.

2.3. Received Signal Strength (RSS) and Spatial Data Collection and Processing

Samsung Galaxy S4 mobile phone with Cellmapper android and MyGPS applications installed is used to capture and store the Received Signal Strength (RSS) and spatial data (longitude, latitude and altitude) dataset. The RSS and spatial data d are captured in a suburban area for a 1800MHz GSM network. The RSS is converted to the measured pathloss (PL) using the formula [23-25]:

$$PL_{m(dB)} = P_{BTS} + G_{BTS} + G_{MS} - L_{FC} - L_{AB} - L_{CF} - RSS(\text{dBm}) \quad (9)$$

where

$PL_{m(dB)}$ is the measured pathloss for each measurement location at a distance d (km)

RSS is the mean Received Signal Strength (RSS) in dBm, P_{BTS} = Transmitter Power (dBm), G_{BTS} = Transmitter Antenna Gain (dBi), G_{MS} = receiver antenna gain (dBi), L_{FC} = feeder cable and connector loss (dB), L_{AB} = Antenna Body Loss (dB) and L_{CF} = 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,

$$PL_{m(dB)} = 53.5 (\text{dBm}) - RSS(\text{dBm}) \quad (10)$$

Again, the Haversine formula in Eq 11 is used to compute the distances (d) between each measurement point and the base station as follows;

$$d = 2r \left\{ \sin^2 \left(\frac{LAT_2 - LAT_1}{2} \right) + \cos(LAT_1) \cos(LAT_2) \sin^2 \left(\frac{LONG_2 - LONG_1}{2} \right) \right\} \quad (11)$$

$$LAT \text{ in Radians} = \frac{(LAT \text{ in Degrees} * 3.142)}{180} \quad (12)$$

$$LONG \text{ in Radians} = \frac{(LONG \text{ in Degrees} * 3.142)}{180} \quad (13)$$

Where

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

d = the distance between the two coordinates

R varies from 6356.752km at the poles to 6378.137 km at the equator

The pathloss prediction performance measures for the CCIR model are defined as follows:

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

$$MSE = \sqrt{\frac{1}{n} \left[\sum_{i=1}^n |PL_{(measured)(i)} - PL_{(predicted)(i)}|^2 \right]} \quad (14)$$

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

$$PA = \left\{ 1 - \frac{1}{n} \left(\sum_{i=1}^n \left| \frac{PL_{(measured)(i)} - PL_{(predicted)(i)}}{PL_{(measured)(i)}} \right| \right) \right\} * 100\% \quad (15)$$

3. Results and Discussions

The field measured distance, received signal strength (RSSI) and pathloss (PLm) are given in Table 1. The link budget equation, $PL_{m(dB)} = 53.5 \text{ (dBm)} - \text{RSS(dBm)}$ is used to obtain the measured pathloss (PLm) whereas 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.

Table 2 and figure 1 show the field measure pathloss and the pathloss predicted by the untuned CCIR model, the pathloss

predicted by the RMSE tuned CCIR model and the pathloss predicted by the composition function tuned CCIR model. Also, the table shows that the untuned CCIR model has RMSE of 17.33 dB and prediction accuracy of 85.33%. On the other hand, the pathloss predicted by the RMSE tuned CCIR model has RMSE of 4.09dB and prediction accuracy of 96.82% and the pathloss predicted by the composition function tuned CCIR model has RME of 2.15 dB and prediction accuracy of 98.39%. Given that RMSE = 17.33 for the then;

$$PL_{RMSETUNED} = PL_{m(dB)(i)} + RMSE = PL_{UNTUNED}(i) + 17.33 \quad (16)$$

The composition function is obtained as;

$$f_{e(i)} = K1 (PL_{m(dB)(i)}) + K2 \\ = 2.797895044 (PL_{m(dB)(i)}) + 254.35526 \quad (17)$$

Then,

$$PL_{CFRTUNED} = PL_{m(dB)(i)} + f_{e(i)} \\ = PL_{m(dB)(i)} + 2.797895044 (PL_{m(dB)(i)}) + 254.35526 \quad (18)$$

Table 1. The Field Measured Distance, Received Signal Strength (RSS) and Field Measured Path Loss (PLm).

S/N	Distance (km)	Received Signal Strength (dB)	Field Measured Path Loss (dBm)	S/N	Distance (km)	Received Signal Strength (dB)	Field Measured Path Loss (dBm)
1	0.5754	-77	102.3	15	0.703179	-93	118.3
2	0.6066	-81	106.3	16	0.71352	-93	118.3
3	0.6227	-81	106.3	17	0.714339	-93	118.3
4	0.6325	-81	106.3	18	0.715505	-93	118.3
5	0.6432	-81	106.3	19	0.722838	-93	118.3
6	0.6503	-81	106.3	20	0.724317	-93	118.3
7	0.6596	-87	112.3	21	0.73273	-93	118.3
8	0.6658	-87	112.3	22	0.738797	-93	118.3
9	0.6660	-87	112.3	23	0.753736	-93	118.3
10	0.6741	-87	112.3	24	0.76781	-93	118.3
11	0.6812	-87	112.3	25	0.786526	-93	118.3
12	0.6931	-87	112.3	26	0.804117	-93	118.3
13	0.6964	-87	112.3	27	0.814393	-95	120.3
14	0.7029	-87	112.3				

Table 2. The field measure pathloss and the pathloss predicted by the untuned and the tuned CCIR models.

S/N	d (km)	Field Measured Path Loss (dBm)	Untuned CCIR (dB)	RMSE Tuned CCIR (dB)	Composition Function Tuned CCIR (dB)	S/N	d (km)	Field Measured Path Loss (dBm)	Untuned CCIR (dB)	RMSE Tuned CCIR (dB)	Composition Function Tuned CCIR (dB)
1	0.575	102.3	94.1	111.4	103	15	0.703	118.3	97.1	114.4	114.3
2	0.607	106.3	94.9	112.2	106	16	0.714	118.3	97.3	114.6	115.2
3	0.623	106.3	95.3	112.6	107.5	17	0.714	118.3	97.3	114.6	115.2
4	0.632	106.3	95.5	112.8	108.3	18	0.716	118.3	97.3	114.7	115.3
5	0.643	106.3	95.7	113.1	109.3	19	0.723	118.3	97.5	114.8	115.9
6	0.650	106.3	95.9	113.2	109.9	20	0.724	118.3	97.5	114.9	116
7	0.660	112.3	96.1	113.5	110.7	21	0.733	118.3	97.7	115	116.7
8	0.666	112.3	96.3	113.6	111.2	22	0.739	118.3	97.8	115.2	117.2
9	0.666	112.3	96.3	113.6	111.3	23	0.754	118.3	98.1	115.5	118.3
10	0.674	112.3	96.4	113.8	111.9	24	0.768	118.3	98.4	115.7	119.3
11	0.681	112.3	96.6	113.9	112.5	25	0.787	118.3	98.8	116.1	120.7
12	0.693	112.3	96.9	114.2	113.5	26	0.804	118.3	99.1	116.4	122
13	0.696	112.3	96.9	114.3	113.8	27	0.814	120.3	99.3	116.6	122.7
14	0.703	112.3	97.1	114.4	114.3						
15	0.703	118.3	97.1	114.4	114.3						
<i>RMSE</i>									17.33	4.09	2.15
<i>Prediction Accuracy (%)</i>									85.33	96.82	98.39

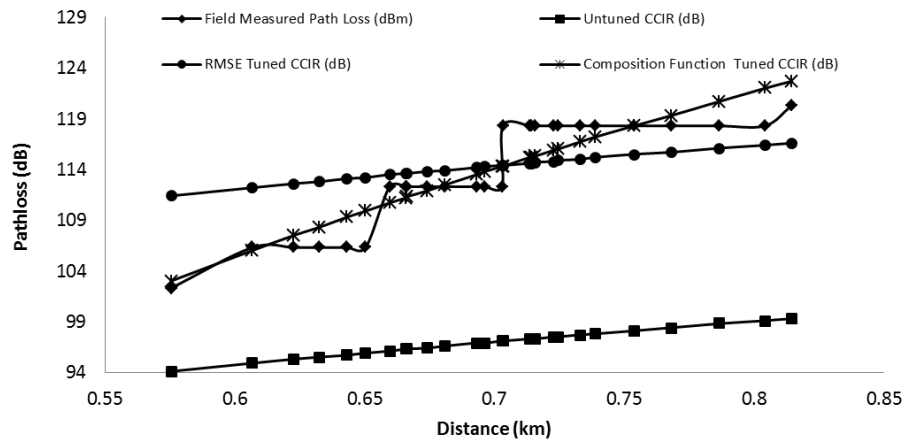


Figure 1. The field measure pathloss and the pathloss predicted by the untuned and the tuned CCIR models.

4. Conclusion

In this paper, comparative study of two CCIR pathloss model tuning approaches is presented. Both methods are least square methods. The first model tuning approach is implemented by the addition or subtraction of the root mean square error (RMSE) based on whether the sum of errors is positive or negative. The second method is implemented by adding a composition function of the residue to the original CCIR model pathloss prediction. The study is based on field measurement carried out in a suburban area for a GSM network in the 1800 MHz 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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