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CHARACTERISATION OF PROPAGATION LOSS FOR A 3G CELLULAR NETWORK IN A CROWDED MARKET AREA USING CCIR MODEL

Simeon Ozuomba[1+]
Enyenihi, Johnson[2]
Ngwu Chinyere Rosemary[3]

[1]*Department of Electrical/Electronic and Computer Engineering, University of Uyo, Akwa Ibom, Nigeria*
Email: simeonoz@yahoo.com
[2]*Department of Electrical/Electronic Engineering, Akwa Ibom State University Mkpat Enin, Akwa Ibom State, Nigeria*
[3]*Department of Computer Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria*


(+ Corresponding author)

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ABSTRACT

In this paper, the propagation loss for 1800 MHz cellular network in a crowded market is studied and characterized using the Comit´e International des Radio-Communication, (CCIR) propagation loss model. Empirical measurement of the received signal strength in the market was conducted using CellMapper android app installed on Samsung Galaxy S4 phone. The CCIR model was configured with three different percentages of covered areas (PB). The model was optimized using the root means square error (RMSE) method and also by tuning the PB value. The un-tuned CCIR model gave an RMSE value of 9.23 dB which is above the acceptable upper limit of 6 dB for propagation loss prediction models. On the other hand, the PB-tuned CCIR model gave the best prediction result with an RMSE value of 2.177 dB and prediction accuracy of 98.11 % which is better than the performance of all the RMSE-tuned CCIR models. The results showed that apart from using an RMSE value to tune the CCIR propagation loss model, adjustment of some other key parameters of the model can as well provide a better prediction performance. However, the choice of the parameter to be tuned depends on the specific nature of the case study area.

Contribution/Originality: The paper's primary contribution is the development of an alternative approach for optimizing the CCIR model by adjusting the percentage of covered area rather than using the root mean square error (RMSE). The paper demonstrated that the proposed method can give better propagation prediction performance than the RMSE-based optimization approach.

1. INTRODUCTION

Propagation loss is one of the key elements that is usually required in the planning and design of cellular networks [1-7]. Generally, propagation loss models are developed and used to estimate the expected propagation loss a given wireless signal at a particular frequency will experience while propagating in a given area [8-14]. Studies have shown that no single propagation loss model can fit every situation [11, 15-17]. As such different propagation loss models have been developed over the years for different situations that take into consideration the nature of the network and the site.

In this paper, the focus is to study the propagation loss in a crowded marked using the propagation loss model developed by the CCIR (Comite' Consultatif International des Radio Communication, which is now known as International Telecommunication Union (ITU) [18-21]. The CCIR propagation model combined the effect of the free space propagation loss and the terrain-induced propagation loss. The specific focus of this paper is to derive the tuned CCIR model that will effectively predict the propagation loss in the market with the minimal prediction error and higher prediction accuracy.

2. STUDY SITE AND DATA COLLECTION

The study site is Itam market in Uyo , Akwa Ibom state Nigeria at a latitude of 5.047908 and a longitude of 7.898721, as shown in Figure 1. Though the market operates on a daily basis, it is fully occupied on its market day which comes up every 8 days. The study was conducted on a market when the market is fully crowded.

Figure-1. The Google Map Location of the study site
Source: Google maps [22]

The relevant data, namely, latitude, longitude , received signal strength and the base station information were collected using CellMapper android app which was installed on Samsung Galaxy S4 phone . The Samsung Galaxy S4 was held at about 1.5 meters above the ground and the CellMapper app was enabled to run while the phone was taken around the market at an average speed of 1.2 m/s. The CellMapper app captured and stored the listed requisite data in a comma-separated values (CSV) file. After the data collection, the CSV file was copied into the laptop and then processed for the propagation loss characterization based on CCIR model.

Table-1. The distance (d) from the base station to the mobile device and the received signal strength , (RSSI) captured within the case study site in October 2018.

d (km)	RSSI (dB)	d (km)	RSSI (dB)
0.3932	-77	0.6521	-85
0.4088	-78	0.6967	-84
0.4243	-77	0.7011	-85
0.4725	-81	0.7054	-85
0.4867	-85	0.7161	-86
0.5009	-81	0.7378	-87
0.5037	-83	0.7595	-86
0.5168	-82	0.7711	-86
0.5298	-84	0.7775	-88
0.5635	-82	0.7838	-89
0.573	-86	0.7884	-92
0.5824	-87	0.792	-90
0.6026	-88	0.7955	-92
0.6038	-87	0.8032	-88
0.6049	-86	0.8075	-89
0.6201	-87	0.8118	-90
0.6342	-87	0.8165	-96
0.6483	-88	0.8277	-97
0.6494	-87	0.8389	-97
0.6508	-86	0.8518	-98

Based on the data captured by the cell mapper, the prevailing circular network signal in the market area is the 3G network signal running at the frequency of about 18000 GHz. The key data obtained and used for the characterization of propagation loss in this paper is presented in Table 1 and Figure 2, where d is the distance from the base station to the mobile device and the RSSI is the received signal strength.

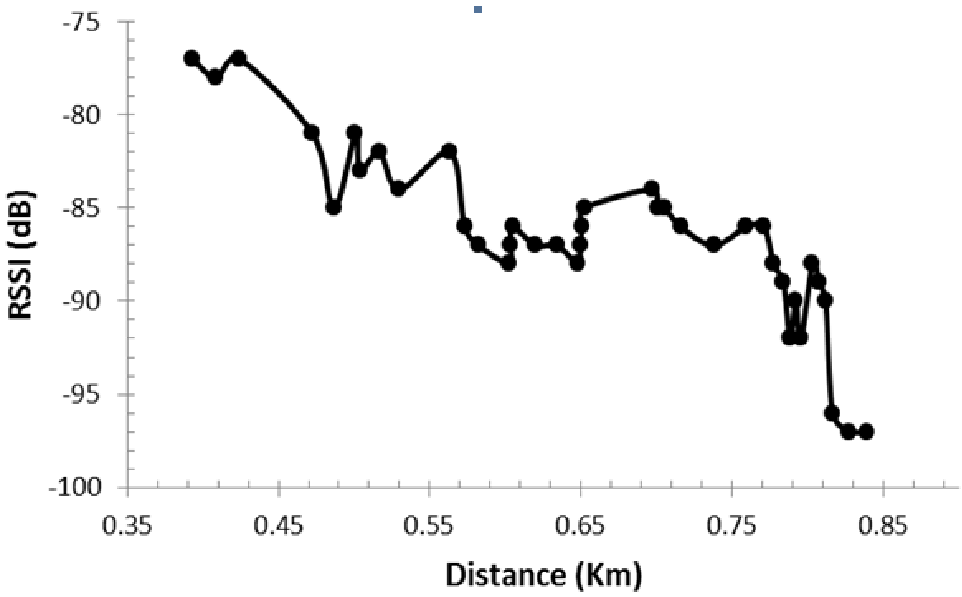

Figure-2. The graph plot of the received signal strength, (RSSI) versus distance (d) from the base station to the mobile device for the case study site in October 2018.

3. THE CCIR PROPAGATION LOSS MODEL

The Comit´e International des Radio-Communication, now ITU-R developed the CCIR propagation loss model which takes into account the varying degrees of urbanization in a given area. The model is given as Akinbolati, et al. [18]; Nnadi, et al. [20]; Oluwafemi and Femi-Jemilohun [21]:

$$LP\ (dB) = A + B * \log_{10}(d) - E \qquad (1)$$

where

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

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \qquad (3)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \qquad (4)$$

The degree of urbanization is denoted as E which is defined in terms of (PB) the percentage of the covered area which in the case of urban area is the percentage area covered by buildings , hence

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

If the area is covered by about 16% buildings then E = 0.

PB ≥ 16% For urban area ; PB < 16% (typical PB =8%) for sub-urban area and PB < 16% (typical PB =3%) for sub-urban area.

Where f is frequency in MHz; d is distance in km; 150 MHz≤ f≤ 1000MHz; 30m ≤h_b ≤ 200m; 1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km.

The prediction performance of the propagation loss models considered in this paper are assessed using RMSE given in equation 6 and prediction accuracy (PA) given in equation 7).

$$\mathrm{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}\left|PL_{m(i)} - PL_{CCIR(i)}\right|^2\right]\right\}} \qquad (6)$$

Where $PL_{m(i)}$ propagation loss (dB) data measured is point i, $PL_{CCIR(i)}$ is the CCIR predicted propagation loss (dB) for data point i and n is the total number of measured data points considered in the computation.

$$\textbf{PA} = \left(1 - \left(\frac{1}{n}\left(\sum_{i=1}^{i=n}\left|\frac{|PL_{m(i)} - PL_{CCIR(i)}|}{PL_{m(i)}}\right|\right)\right)\right) * 100\ \% \qquad (7)$$

4. OPTIMISATION OF THE CCIR PROPAGATION LOSS MODEL

4.1. The CCIR Model is Optimised in Two Different Ways, Namely

(i) By using the root means square error

(ii) By tuning (PB) the percentage of covered area

4.2. Optimisation of the Ccir Propagation Loss Model by Using the Root Means Square Error

In this case, the root mean square error (RMSE) of equation 6 is used to tune each of the CCIR predicted propagation loss. The sum of errors (SoE) is given as;

$$\text{SoE} = \sum_{i=1}^{i=n}\left(PL_{m(i)} - PL_{CCIR(i)}\right) \qquad (8)$$

Now the tuning is done as follows;

(i) For all i > 1

(ii) IF (SoE ≥ 0) Then $\left(PL_{CCIR(i)tuned} = PL_{CCIR(i)} + RMSE\right)$

(iii) ELSEIF (SoE < 0) Then $\left(PL_{CCIR(i)tuned} = PL_{CCIR(i)} - RMSE\right)$

4.3. Optimisation of the Ccir Propagation Loss Model By Tuning the Percentage of Covered Area

The tuning of PB, the percentage of covered area is conducted by using a tuning factor K such that the degree of urbanization is given as;

$$\text{E}_{tuned} = 30 - 25\left(\log_{10}\left(K_{PB}(PB)\right)\right) \qquad (9)$$

Then from equation 1 the tuned CCIR model is given as ;

$$PL_{CCIR(i)tuned} = A + B * \log_{10}(d) - \text{E}_{tuned} \qquad \text{for all i} > 1 \qquad (10)$$

The value of K is repeatedly adjusted using Microsoft Excel Solver until the minimal value of RMSE is obtained. Then, the tuned value of E in equation 9 is used in equation 1 to determine the CCIR predicted propagation loss.

5. RESULTS AND DISCUSSION

The CCIR propagation loss model was configured with three different values of the percentage of covered area (PB%), namely; PB = 12 %, PB = 8% and PB = 3 %. The result of the CCIR model propagation loss prediction and performance measures are given in Table 2 for the case where PB = 12% . The un-tuned CCIR model gave An RMSE value of 9.23 dB which is above the acceptable upper limit of 6 dB for propagation loss prediction models. On the other hand, the RMSE–tuned CCIR model gave An RMSE value of 2.576 dB with a prediction accuracy of 98.70 %. The results of the un-tuned CCIR model propagation loss prediction for PB = 12 %, PB = 8 % and PB = 3 % are shown in Figure 4 while the prediction performance results of the un-tuned CCIR model and the RMSE-tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 % are given in Table 3. Among the un-tuned CCIR model the one with PB = 12 % gave the best prediction with An RMSE value of 9.23 dB and prediction accuracy of 92.02% while among the RMSE- tuned CCIR model the tuned model with PB = 12 % gave the best prediction with An RMSE value of 2.771 dB and prediction accuracy of 98.10 %.

Table-2. The measured propagation loss, the un-tuned CCIR model propagation loss prediction and the RMSE-turned CCIR model propagation loss prediction for PB = 12%

d (km)	Field Measured Propagation loss (dBm)	CCIR Predicted Propagation loss (dBm)	Predicted Propagation loss By The RMSE-Tuned CCIR Prediction	d (km)	Field Measured Propagation loss (dBm)	CCIR Predicted Propagation loss (dBm)	Predicted Propagation loss By The RMSE-Tuned CCIR Prediction
0.3932	102.3	101.9397	101.9397	0.70105	110.3	110.5804	110.5804
0.40875	103.3	102.5193	102.5193	0.7054	110.3	110.6728	110.6728
0.4243	102.3	103.0772	103.0772	0.7161	111.3	110.8978	110.8978
0.4725	106.3	104.685	104.685	0.7378	112.3	111.3439	111.3439
0.4867	110.3	105.1274	105.1274	0.7595	111.3	111.777	111.777
0.5009	106.3	105.5571	105.5571	0.7711	111.3	112.0035	112.0035
0.5037	108.3	105.6404	105.6404	0.77745	113.3	112.1261	112.1261
0.51675	107.3	106.0226	106.0226	0.7838	114.3	112.2476	112.2476
0.5298	109.3	106.3953	106.3953	0.7884	117.3	112.3351	112.3351
0.5635	107.3	107.3168	107.3168	0.79195	115.3	112.4022	112.4022
0.57295	111.3	107.5653	107.5653	0.7955	117.3	112.469	112.469
0.5824	112.3	107.8097	107.8097	0.8032	113.3	112.613	112.613
0.6026	113.3	108.3192	108.3192	0.8075	114.3	112.6927	112.6927
0.60375	112.3	108.3477	108.3477	0.8118	115.3	112.7721	112.7721
0.6049	111.3	108.3761	108.3761	0.8165	121.3	112.8584	112.8584
0.6201	112.3	108.747	108.747	0.8277	122.3	113.0619	113.0619
0.6342	112.3	109.0829	109.0829	0.8389	122.3	113.2628	113.2628
0.6483	113.3	109.4115	109.4115	0.8518	123.3	113.4908	113.4908
0.6494	112.3	109.4368	109.4368				
0.65075	111.3	109.4679	109.4679		The Model Prediction Performance Measures		
0.6521	110.3	109.4988	109.4988		RMSE	9.23	2.771
0.6967	109.3	110.4874	110.4874		PA(%)	92.02	98.10

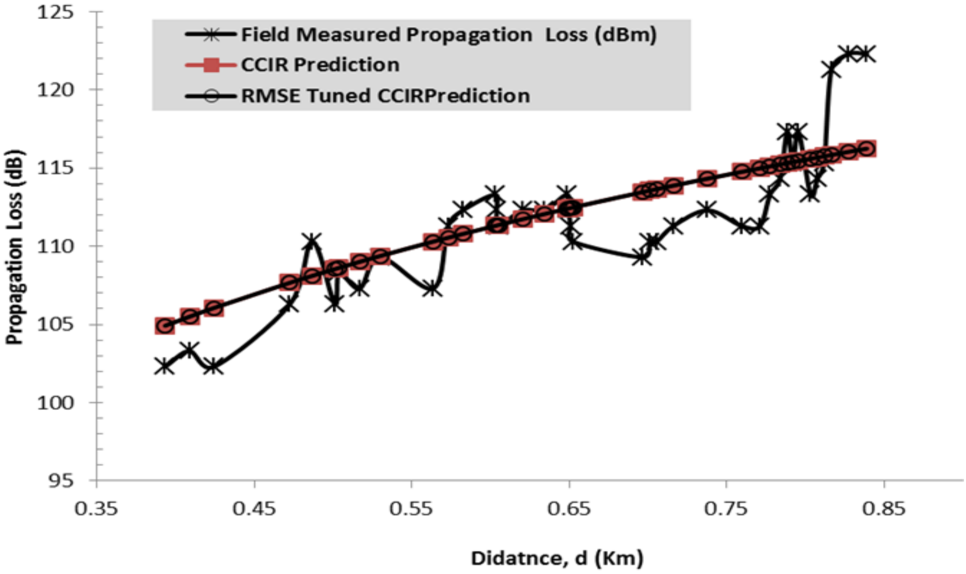

Figure-3. The measured propagation loss, the un-tuned CCIR model propagation loss prediction and the RMSE-turned CCIR model propagation loss prediction for PB = 12 %.

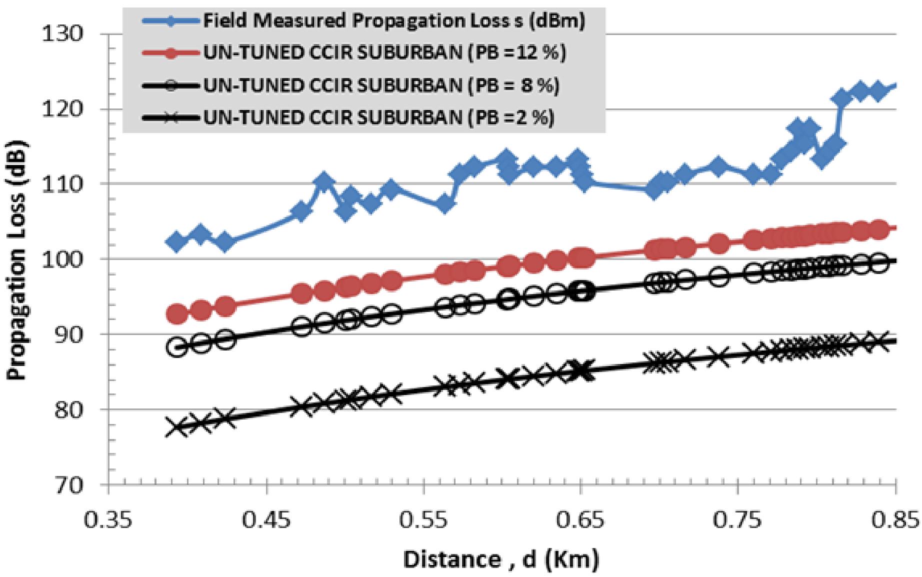

Figure-4. The measured propagation loss, the un-tuned CCIR model propagation loss prediction for PB = 12 %, PB = 8 % and PB = 3 %

The prediction performance of the un-tuned CCIR model and the PB- tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 % is given in Table 4. The graph of Figure 5 shows the measured propagation loss, the RMSE-tuned CCIR model and the PB- tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 %. The three PB-tuned CCIR model gave the same result with An RMSE value of 2.177 dB and prediction accuracy of 98.11 % which is better than the performance of all the RMSE-tuned CCIR model.

In all, the results of the PB-tuned CCIR models show that the market has a effective covered area of 35.89 % which is more than the 16 % recommended in the original CCIR model for the urban area. So, for the market, the tuned the degree of urbanization is given as;

$$E_{tuned} = 30 - 25(\log_{10} 35.89) = -8.87459825 \quad (11)$$

Then , the tuned CCIR model for the market is given as ;

$$PL_{CCIR(i)tuned} = A + B * \log_{10}(d) + 8.87459825 \quad \text{for all i} > 1 \quad (12)$$

Table-3. The prediction performance of the un-tuned CCIR model and the RMSE- tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 %

The Model Prediction Performance Measures			
	RMSE (dB)	Prediction Accuracy, PA %	Effective Value of PB %
Un-tuned CCIR Model , PB =12%	9.23	92.02	12 %
RMSE-Tuned CCIR Model, PB = 12%	2.771	98.10	12 %
Un-tuned CCIR Model , PB =8%	16.532	92.24	8 %
RMSE-Tuned CCIR Model , PB =8%	2.782	98.08	8 %
Un-tuned CCIR Model , PB = 3 %	27.089	78.73	3 %
RMSE-Tuned CCIR Model , PB = 3%	2.782	98.08	3 %

Table-4. The prediction performance of the un-tuned CCIR model and the PB- tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 %

The Model Prediction Performance Measures				
	RMSE (dB)	Prediction Accuracy, PA %	K_{PB}	Effective Value of PB %
Un-tuned CCIR Model , PB =12%	12.221	97.269		12 %
PB-Tuned CCIR Model, PB = 12%	2.177	98.11	2.990905	35.89 %
Un-tuned CCIR Model , PB = 8 %	16.531	92.247		8 %
PB-Tuned CCIR Model , PB = 8%	2.177	98.11	4.486358	35.89 %
Un-tuned CCIR Model , PB = 3 %	27.089	78.73		3 %
PB-Tuned CCIR Model , PB = 3%	2.177	98.11	11.96362	35.89 %

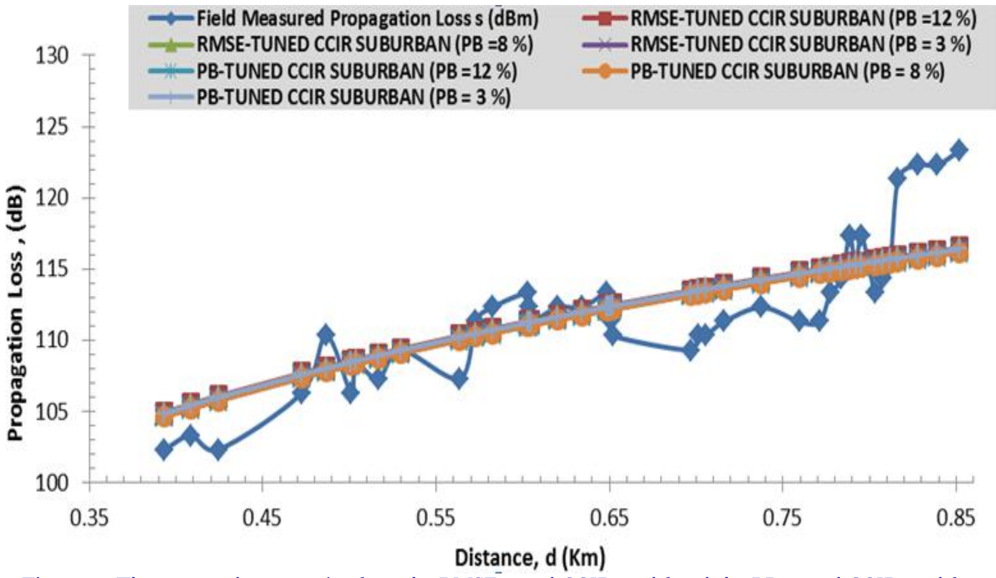

Figure-5. The measured propagation loss, the RMSE-tuned CCIR model and the PB- tuned CCIR model for PB = 12 %, PB = 8 % and PB = 3 %.

6. CONCLUSION

Propagation loss for the 1800 MHz cellular network in a crowded market is studied and characterized using the CCIR propagation loss model. The model was studied under different degree of urbanisation values and also tuned using RMSE method as well as by tuning the percentage of covered area. The results showed that the market has a higher percentage of covered area than a typical urban area whose percentage covered area is given as 16 % in the original CCIR model. Furthermore, the tuning of the CCIR model using the percentage of covered area gave the best prediction performance, hence, the mathematical expression of the optimal CCIR model for the market was derived based on the percentage of covered area tuned-CCIR model.

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