Hata-Okumura Model-Based Characterisation Of Propagation Loss For A Market In Urban Area

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***Abstract*— In this paper, Hata-Okumura model-based characterisation of propagation loss for a market in urban area is studied. The case study area is a market in the city of Uyo in Akwa Ibom State, Nigeria. The field measurement of Received Signal Strength Intensity (RSSI) was conducted for cellular network in the 1800 MHz frequency. Samsung Galaxy S4 phone with Android app, G-NetTrack Lite 8.0 installed was used to capture the RSSI of the cellular network. In this paper, in order to accurately characterize the propagation loss of the study area, the Hata-Okumura propagation loss model, also known as the Hata propagation loss model is tuned based on field measured data in the case study area. Three different approaches are employed in the tuning of the Hata-Okumura propagation loss model. The first tuning approach (method I) is the Root Mean Square Error (RMSE)-based tuning approach. The second approach (method II) is a function of residue method. The third approach (method III) is parameter tuning method in which the distance, d was remodelled as a logarithm function. The measurement campaign was conducted three times and the three datasets were merged and then divided into two parts of 75% of the dataset which was used for the model training and the remaining 25 % of the dataset which was used for the cross validation of the model. According to the results, the tuning method III has the best results with the lowest root mean square error (RMSE) of 2.3856 dB, the lowest range of error value of 8.8903 dB, and the lowest maximum absolute error value of 4.6528 dB. The tuning approach I has the worst results compared to the other two methods. The first approach has the highest RMSE of 2.9850 dB, the highest range of error value of 11.6966 dB and the highest maximum absolute error value of 6.2742dB. The results showed that the tuned Hata-Okumura model using the second and third tuning methods predicted the cross validation data better than the training data. In essence, the tuned model effectively characterized the propagation loss in the case study market.**

***Keywords*— Propagation Loss, Hata-Okumura Model, Model Tuning, Characterisation Of Propagation Loss , Wireless Network**

1. Introduction

In the wireless communication industry, accurate estimation of the propagation loss in any given area of interest is essential for effective deployment of wireless service in that area [1,2, 3, 4, 5,]. This is because of the inherent factors in the vicinity of the signal propagation path which can cause different forms of wireless signal degradations [6,7,8,9,10,11,12]. These factors and the resulting signal degradation can affect the communication range and other quality of service of the wireless communication system [13,14, 15,16, 17,18, 19,20, 21,22, 23,24 ,25]. Notably, the signal degradation is suffered in both terrestrial and satellite wireless communication links [26,27,28,29,30,31,32,33,34]. However, the specific factors that affect the satellite signals may differ in some ways from those that apply to terrestrial wireless communication links.

In any case, over the years, some wireless signal propagation loss models have been developed to enable prediction of propagation loss in a given area [35,36,37,38,39,40, 41,42,43,44,45,46,47,48,49,50]. While some of the propagation loss models are empirically developed based on field measurements, some are analytically developed by modelling different aspects of environmental factors that can cause signal strength degradation [51,52,53,54,55,56,57].

Among the empirical propagation loss models, Hata-Okumura is a leading model which can be used to estimate the propagation loss for rural, suburban and urban areas [58, 59, 60, 61, 62,63]. In this paper, the propagation loss in a market located in Uyo, the main city in Akwa Ibom State, Nigeria is studied. The study focus is on accurate characterization of the propagation loss in the market area by using the Hata-Okumura model for urban area.

Importantly, experts have noted that some form of model tuning may be required to enhance the prediction performance of most of the empirically developed models, especially when applied to an area other than the place where the model was originally developed. In addition, there are different was the model tuning can be performed, each method gives different result and prediction performance. Hence, in this paper, three different model tuning approaches are applied to the Hata-Okumura model for urban area and their prediction performances are compared.

2. Methodology

2.1 The Hata-Okumura Propagation Loss Model

The Hata-Okumura propagation loss model, also known as the Hata propagation loss model utilized the information from Okumura model to develop the propagation loss model for urban areas which is further adapted for other areas such as the suburban area and the open area [58,59, 60, 61,62,63,64]. The Hata-Okumura propagation loss model is expressed analytically as follows[58,59, 60];

$$LP_{HATA} = A + B * \log_{10}(d) - K \quad (5)$$

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (6)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (7)$$

$$K = \begin{cases} 0 & city\ or\ urban \\ 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 & suburban \\ 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) & rural \end{cases} \quad (8)$$

Where the antenna height correction factor , $a(h_m)$ is expressed as;

$$a(h_m) = \begin{cases} [1.1 * \log_{10} f - 0.7] * h_m - [1.56 * \log_{10} f - 0.8] & rural/suburban \\ 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 & for\ large\ city\ \text{f} \leq 200\text{MHz} \\ 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 & for\ large\ city\ \text{f} \geq 400\text{MHz} \end{cases} \quad (9)$$

- ✓ f is frequency in MHz ; d is the link distance in km
- ✓ 150 MHz≤ f≤ 1000MHz; 30m ≤h_b ≤ 200m ;1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km

2.2 Tuning of the Hata-Okumura Propagation Loss Model

Normally, the classical Hata-Okumura propagation loss model may not accurately predict the pathloss for a given case study site. In such case, the usual practice is to tune or adjust some parameters of the classical Hata-Okumura propagation loss model so that it can predict better and hence be more effective in characterizing the propagation loss in the case study area. In this paper, three different approaches are employed in the tuning of the Hata-Okumura propagation loss model. Also, the study was conducted for urban area (city).

2.2.1 Model Tuning Approach I: the root mean square error-based propagation loss tuning approach

The first tuning method is the root mean square error-based propagation loss tuning approach. In this approach, the error (e) is computed along with sum of error (SE) and the root mean square error (RMSE), where e_i is given as;

$$e_i = PL_{meas(i)} - PL_{Hata(i)} \quad (10)$$

$$SE = \sum_{i=1}^{i=n}(e_i) = \sum_{i=1}^{i=n}\left(PL_{meas(i)} - PL_{Hata(i)}\right) \quad (11)$$

$$RMSE = \sqrt[2]{\left(\frac{1}{n}\left(\sum_{i=1}^{i=n}(e_i)^2\right)\right)} \quad (12)$$

Where , $PL_{meas(i)}$ is the measured propagation loss at the data point i and $PL_{Hata(i)}$ is the Hata-Okumura predicted propagation loss at data point i, where there is a total of n data points in the study. The tuned Hata-Okumura predicted propagation loss using this first approach is denoted as $PL_{HataTuned\_I\_(i)}$ and it is given as;

$$PL_{HataTuned\_I\_(i)} = \begin{cases} PL_{Hata(i)} + RMSE & if\ SE \geq 0 \\ PL_{Hata(i)} - RMSE & if\ SE < 0 \end{cases} \quad (13)$$

2.2.2 Model Tuning Approach II: The function of residue method

In function of residue method, the propagation loss prediction error (residue) in Eq 10 is expressed as an exponential function of distance, d and then the result of the computed residue is added to $PL_{Hata(i)}$ to obtain the tuned model as follows;

$$e_i = \text{K}_1(d^{\text{K}_2}) \quad (14)$$

In this paper, the values of K_1 and K_2 are determined using trend line and Solver tools in Microsoft Excel. The tuned Hata-Okumura predicted propagation loss using the second approach is denoted as $PL_{HataTuned\_II\_(i)}$ and it is given as;

$$PL_{HataTuned\_II\_(i)} = PL_{Hata(i)} + \text{K}_1(d^{\text{K}_2}) \quad (13)$$

2.2.3 Model Tuning Approach III: The model parameter tuning method

In model parameter tuning method, the log of distance, Log(d), in the Hata model of Eq 5 is expressed as (M_1+(M_2*LOG(d))). In this paper, the values of M_1 and M_2 are determined using trend line and solver tools in Microsoft Excel. The tuned Hata-Okumura predicted propagation loss using the third approach is denoted as $PL_{HataTuned\_III\_(i)}$ and it is given as;

$$PL_{HataTuned\_III\_(i)} = A + B * \left((\text{M}_2 * \text{LOG(d)}) + \text{LOG}(\text{M}_1)\right) - K \quad (14)$$

In essence, rather than using d, as it is in the classical Hata model, the third tuning approach used $d = \text{M}_1(d^{\text{M}_2})$ which when expressed in logarithm it gives $(\text{M}_2 * \text{LOG(d)}) + \text{LOG}(\text{M}_1)$.

2.3 The Performance Metric

The result from three tuning approaches are compared using the RMSE and the range of prediction error, as well as the absolute maximum error. The propagation loss prediction error after tuning is denoted as $e_{i\_tuned\_X}$ and also the RMSE after tuning is denoted $RMSE_{\_tuned\_X}$ where;

$$e_{i\_tuned\_X} = PL_{meas(i)} - PL_{HataTuned\_X\_(i)} \quad (15)$$

$$RMSE_{\_tuned\_X} = \sqrt[2]{\left(\frac{1}{n}\left(\sum_{i=1}^{i=n}\left(PL_{meas(i)} - PL_{HataTuned\_X\_(i)}\right)^2\right)\right)} \quad (16)$$

Where X = I for the first tuning approach, X = II for the second tuning approach and X = III for the third tuning approach. s where

The error range consists of the maximum error, $e_{i(max)}$ and the minimum error, $e_{i(min)}$ where,

$$e_{(max)} = maximum(\, e_{i\_tuned\_X})for\ i = 1,2,3,\ldots,n \quad (17)$$

$$e_{(min)} = minimum(\, e_{i\_tuned\_X})for\ i = 1,2,3,\ldots,n \quad (18)$$

The absolute maximum error,

$$eAMAX = maximum(|e_{(max)}|, |e_{(min)}|) \quad (19)$$

2.3 The field measured data

The field measurement of received signal strength intensity (RSSI) was conducted for cellular network in the 1800 MHz frequency. The case study area is a market in the city of Uyo in Akwa Ibom State, Nigeria. Samsung Galaxy S4 phone with Android app, G-NetTrack Lite 8.0 installed was used to capture the RSSI of the cellular network. Subsequently, the link budget equation was used to convert the RSSI values to measured path propagation loss values. The measurement campaign was conducted three times and the three datasets were merged and then divided into two parts of 75% of the dataset which was used for the model training and the remaining 25 % of the dataset which was used for the cross validation of the model. The field measured propagation loss (dB) for dataset I is shown in Figure 1, while that of dataset II and dataset III are shown in Figure 2 and Figure 3 respectively. The training dataset which is 75 % of the field measured propagation loss data items is shown in Table 1.

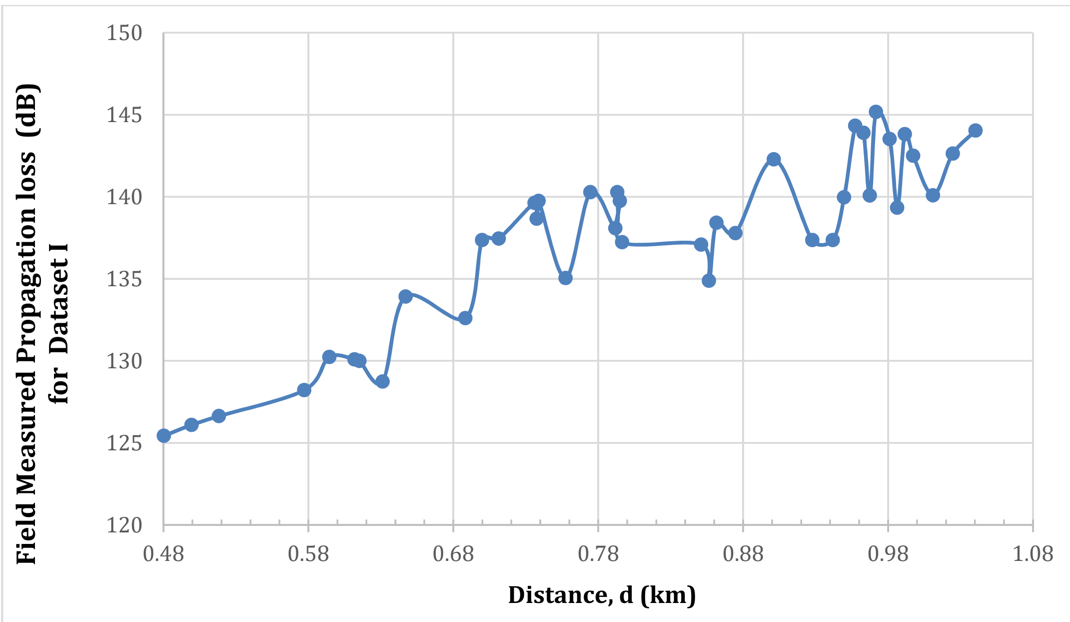


Figure 1 **Field Measured Propagation loss (dB) for Dataset I**

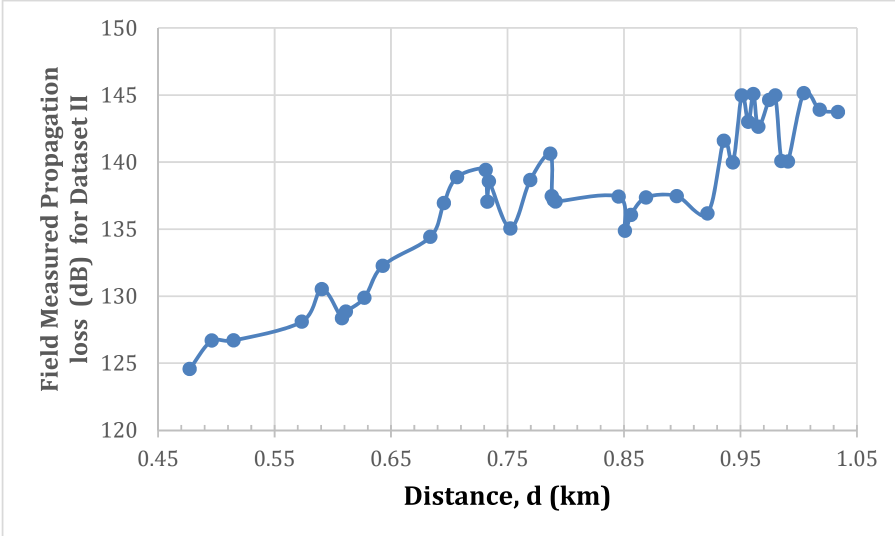


Figure 2 **Field Measured Propagation loss (dB) for Dataset II**

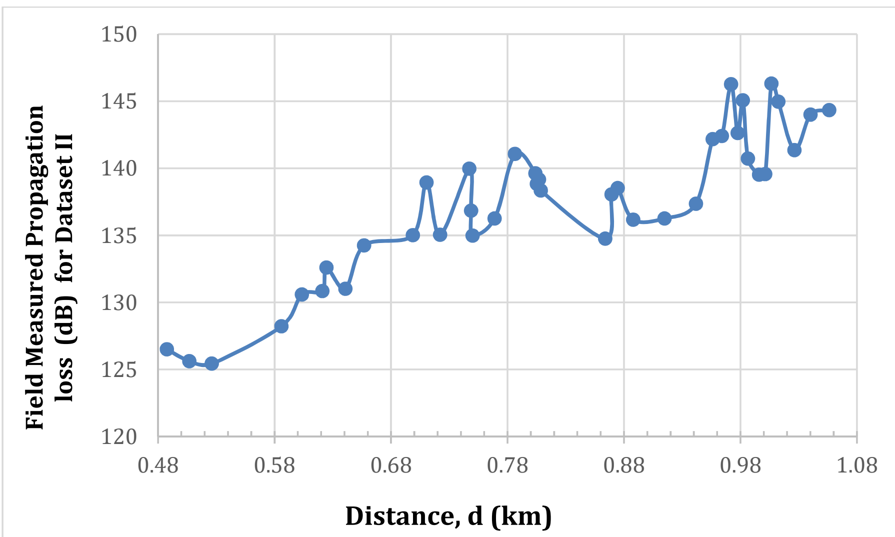


Figure 3 **Field Measured Propagation loss (dB) for Dataset III**

Table 1 The training dataset which is 75 % of the field measured propagation loss data items

S/N	d (km)	Measured loss (dB)	S/N	d (km)	Measured loss (dB)	S/N	d (km)	Measured loss (dB)	S/N	d (km)	Measured (dBm)
1	0.477	124.6	24	0.695	136.9	47	0.805	138.8	70	0.964	142.4
2	0.480	125.4	25	0.699	135.0	48	0.809	138.3	71	0.965	142.6
3	0.488	126.5	26	0.700	137.4	49	0.845	137.4	72	0.972	145.2
4	0.496	126.7	27	0.711	138.9	50	0.851	134.9	73	0.972	146.3
5	0.499	126.1	28	0.731	139.4	51	0.851	137.1	74	0.975	144.6
6	0.507	125.6	29	0.733	137.0	52	0.856	134.9	75	0.978	142.6
7	0.515	126.7	30	0.734	138.6	53	0.864	134.8	76	0.980	145.0
8	0.518	126.6	31	0.736	139.6	54	0.869	137.4	77	0.981	143.5

9	0.526	125.4	32	0.738	138.7	55	0.869	138.1	78	0.986	139.3
10	0.591	130.5	33	0.739	139.7	56	0.875	137.8	79	0.986	140.7
11	0.595	130.2	34	0.747	140.0	57	0.888	136.2	80	0.991	140.0
12	0.604	130.6	35	0.749	136.8	58	0.895	137.5	81	0.996	139.5
13	0.608	128.4	36	0.750	135.0	59	0.901	142.3	82	0.997	142.5
14	0.611	128.9	37	0.770	138.7	60	0.915	136.3	83	1.001	139.6
15	0.612	130.1	38	0.775	140.3	61	0.922	136.2	84	1.004	145.1
16	0.615	130.0	39	0.786	141.1	62	0.928	137.4	85	1.011	140.1
17	0.621	130.8	40	0.787	140.6	63	0.942	137.4	86	1.012	145.0
18	0.625	132.6	41	0.788	137.5	64	0.943	140.0	87	1.018	143.9
19	0.643	132.3	42	0.791	137.1	65	0.950	140.0	88	1.025	142.6
20	0.647	133.9	43	0.792	138.1	66	0.951	145.0	89	1.026	141.4
21	0.657	134.3	44	0.793	140.3	67	0.957	143.0	90	1.040	144.0
22	0.684	134.4	45	0.797	137.2	68	0.957	144.3			
23	0.688	132.6	46	0.804	139.6	69	0.963	143.9			

3. Results and discussion

The training dataset was used to determine the values of the parameters used in the model tuning process. First, the Hata-Okumura model was applied to the training dataset (Figure 4) and a RMSE error of 8.695194 dB was obtained without tuning while the RMSE obtained with the cross validation dataset (Figure 5) was 8.799818dB without tuning model.

The three tuning approaches were applied to the training dataset and the RMSE values, the minimum error, the maximum error, the range of error and the maximum absolute error were determined for each tuning approach. The results of the tuning of the training dataset using the three tuning approaches are shown in Table 2 and Figure 6. According to the results in Table 1, the tuning method III has the best results with the lowest RMSE of 2.3856 dB (Figure 7), the lowest range of error value of 8.8903 dB (Figure 8), and the lowest maximum absolute error value of 4.6528 dB (Figure 9). The tuning approach I has the worst results compared to the other two methods. The first approach has the highest RMSE of 2.9850 dB, the highest range of error value of 11.6966 dB and the highest maximum absolute error value of 6.2742dB.

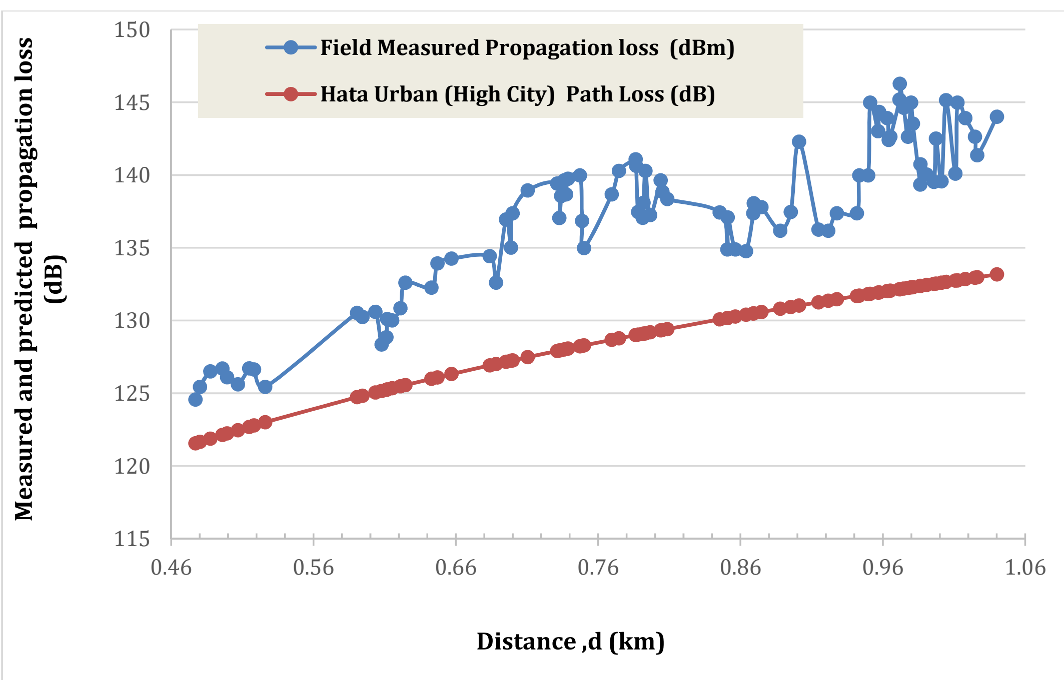


Figure 4 **Measured and predicted propagation loss (dB) based on the training dataset**

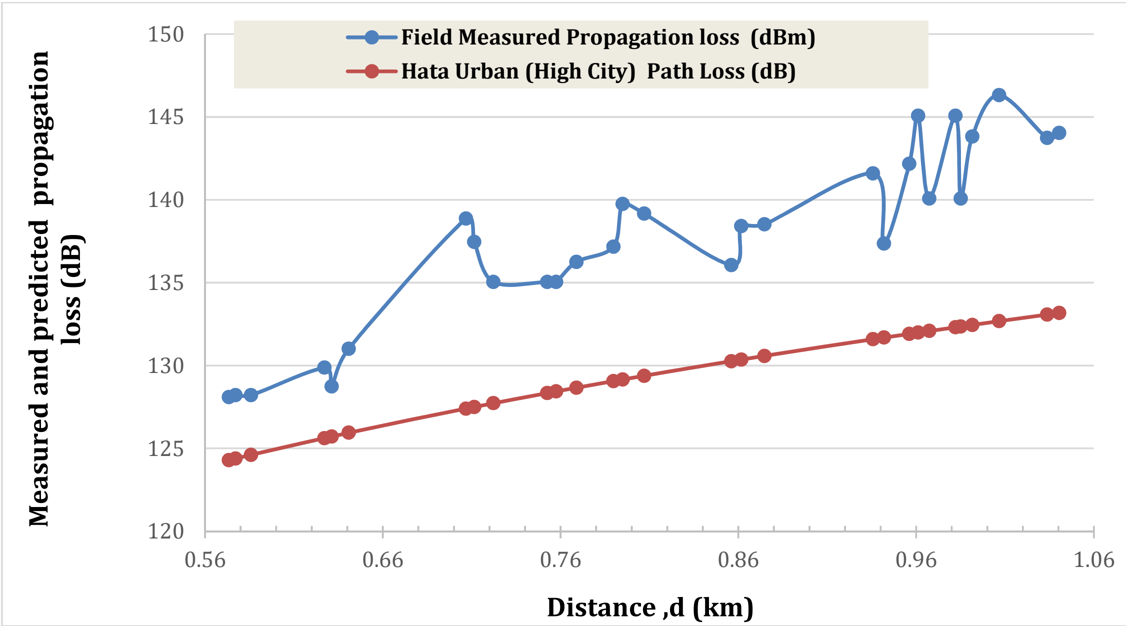


Figure 5 **Measured and predicted propagation loss (dB) based on the cross validation dataset**

Table 2 The results of the tuning of the training dataset using the three tuning approaches

	RMSE (dB)	Minimum Error , $e_{(}$ (dB)	Maximum Error, $e_{(max)}$ (dB)	Range of Error (dB)	Maximum Absolute Error, $eAMAX$ (dB)
Not tuned	8.6952	2.4210	14.1176	11.6966	14.1176
Tuning method I	2.9850	-6.2742	5.4224	11.6966	6.2742
Tuning method II	2.4790	-4.3888	4.7013	9.0901	4.7013
Tuning method III	2.3856	-4.6528	4.2376	8.8903	4.6528

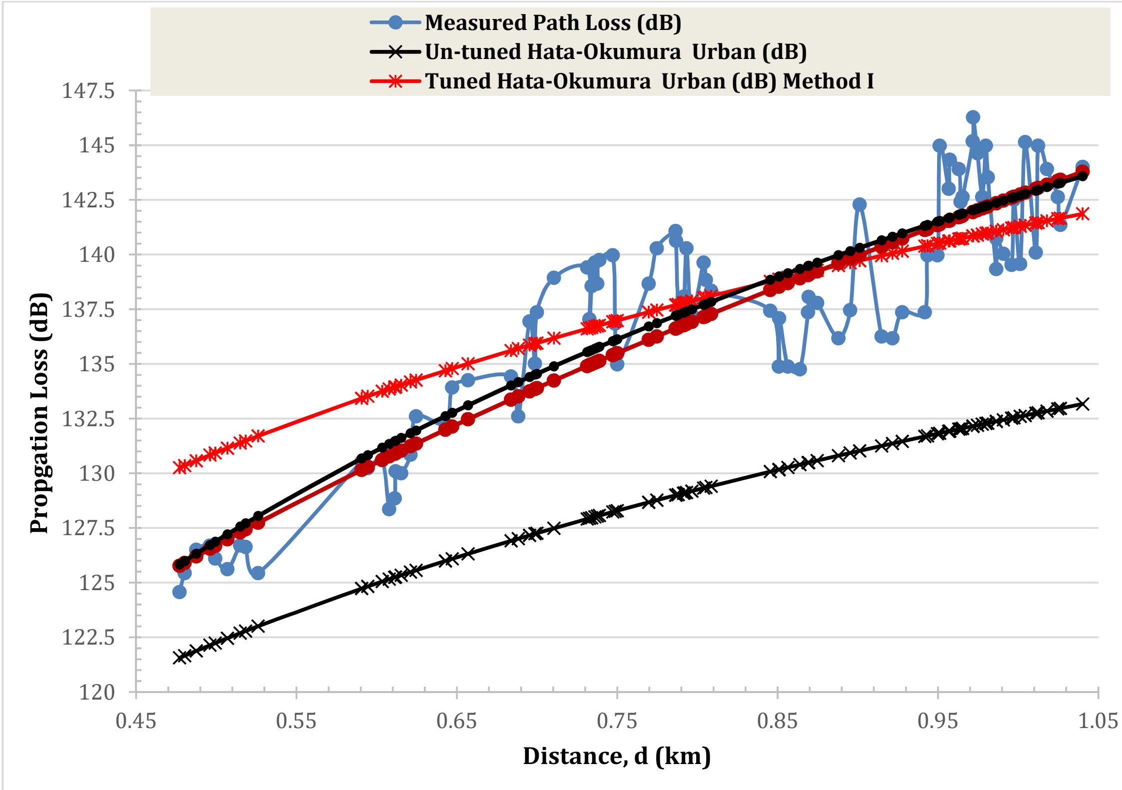
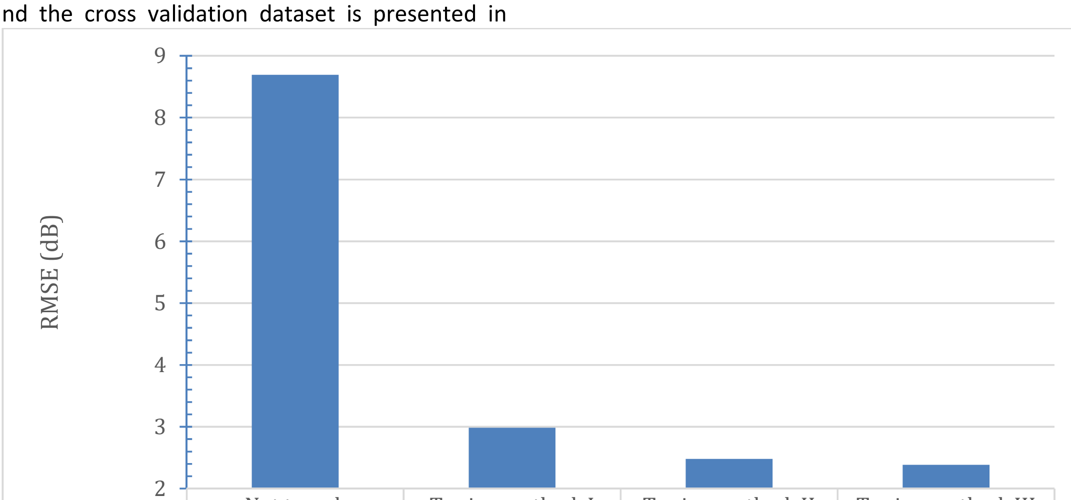


Figure 6 **Measured , tuned and un-tuned Hata-Okumura model predicted propagation loss (dB) based on the training dataset**

The cross validation dataset and the un-tuned Hata-Okumura model applied to the cross validation dataset is shown in Table 3. Also, the results of the three tuned Hata-Okumura model applied to the cross validation dataset are shown in Table 4 and Figure 10. The bar chart of the RMSE of the three tuned Hata-Okumura based on the training dataset and the cross validation dataset is presented in Figure 11. The results showed that the tuned Hata-Okumura model using the second and third tuning methods predicted the cross validation data better than the training data. In essence, the tuned model effectively characterized the propagation loss in the case study market.



	Not tuned	Tuning method I	Tuning method II	Tuning method III
RMSE (dB)	8.6952	2.985	2.479	2.3856

Figure 7 **Bar chart of the RMSE of the three tuned Hata-Okumura based on the training dataset**

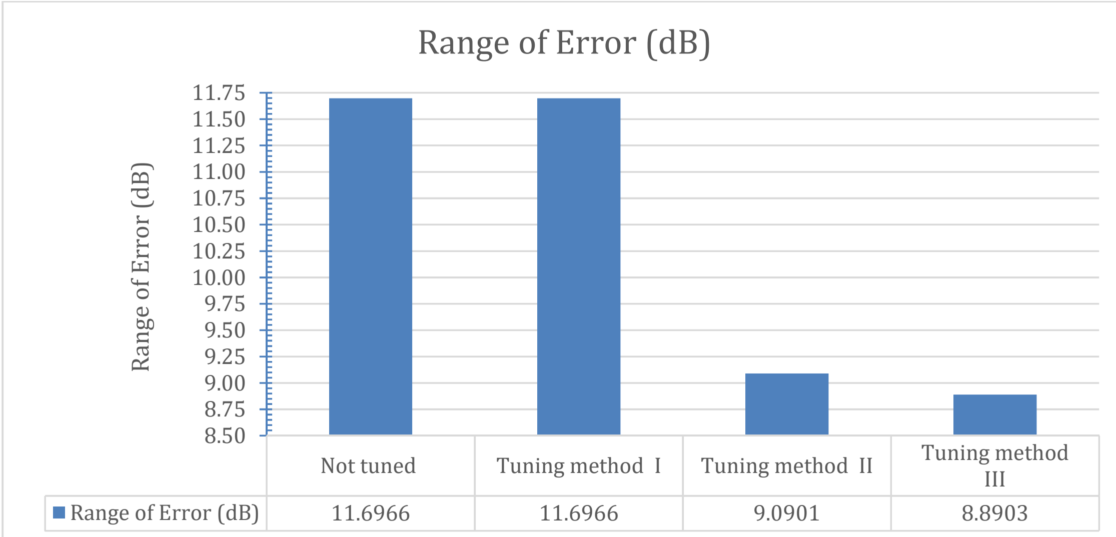


Figure 8 **Bar chart of the range of error of the three tuned Hata-Okumura based on the training dataset**

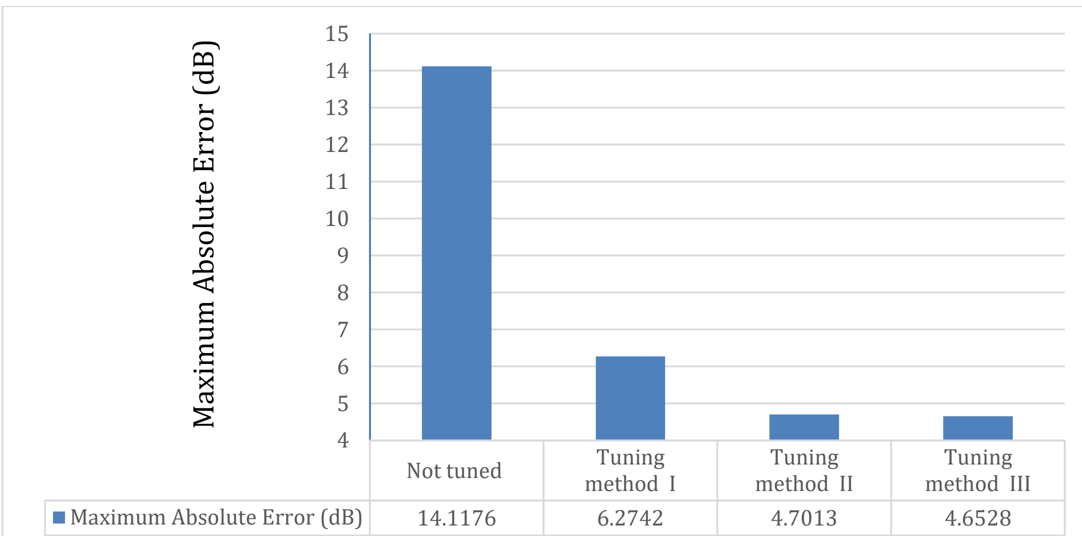


Figure 9 **Bar chart of the maximum absolute error of the three tuned Hata-Okumura based on the training dataset**

Table 3 The cross validation dataset and the un-tuned Hata-Okumura model applied to the cross validation dataset

S/N	d (km)	Field Measured Propagation loss (dBm)	Un-tuned Hata-Okumura Urban (dB)	Tuned Hata-Okumura Urban (dB) Method I	Tuned Hata-Okumura Urban (dB) Method II	Tuned Hata-Okumura Urban (dB) Method III
1	0.573	128.1	124.3	133.0	129.5	130.0
2	0.577	128.2	124.4	133.1	129.7	130.2
3	0.586	128.2	124.6	133.3	130.0	130.5
4	0.627	129.9	125.6	134.3	131.4	132.1
5	0.631	128.7	125.7	134.4	131.6	132.2
6	0.641	131.0	125.9	134.6	131.9	132.5
7	0.707	138.9	127.4	136.1	134.1	134.8
8	0.711	137.5	127.5	136.2	134.3	134.9
9	0.722	135.0	127.7	136.4	134.6	135.3
10	0.752	135.0	128.3	137.0	135.6	136.2
11	0.757	135.0	128.4	137.1	135.7	136.4
12	0.769	136.3	128.7	137.4	136.1	136.7
13	0.790	137.2	129.1	137.8	136.7	137.3
14	0.795	139.7	129.2	137.9	136.9	137.5
15	0.807	139.2	129.4	138.1	137.2	137.8
16	0.856	136.1	130.3	139.0	138.7	139.1

17	0.862	138.4	130.4	139.1	138.8	139.3
18	0.875	138.5	130.6	139.3	139.2	139.6
19	0.936	141.6	131.6	140.3	141.0	141.2
20	0.942	137.4	131.7	140.4	141.1	141.3
21	0.956	142.2	131.9	140.6	141.5	141.7
22	0.961	145.1	132.0	140.7	141.7	141.8
23	0.967	140.1	132.1	140.8	141.8	141.9
24	0.982	145.1	132.3	141.0	142.2	142.3
25	0.985	140.1	132.4	141.1	142.3	142.3
26	0.992	143.8	132.5	141.1	142.5	142.5
27	1.007	146.3	132.7	141.4	142.9	142.8
28	1.034	143.7	133.1	141.8	143.6	143.4
29	1.040	144.0	133.2	141.9	143.8	143.6
30	1.056	144.3	133.4	142.1	144.2	143.9

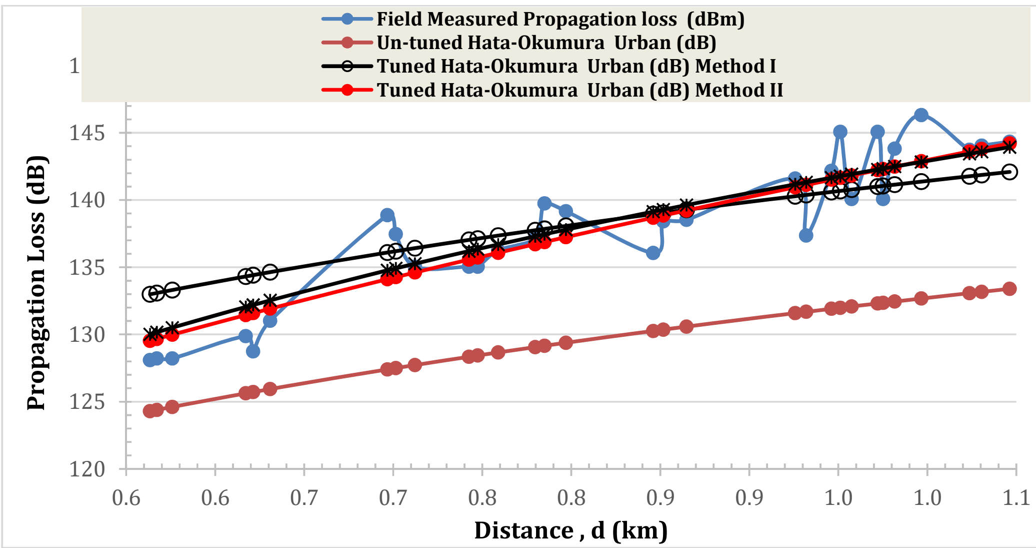


Figure 10 **Measured , tuned and un-tuned Hata-Okumura model predicted propagation loss (dB) based on the cross validation dataset**

Table 4 The results of the three tuned Hata-Okumura model applied to the cross validation dataset

	RMSE (dB)	$e_{(min)}$ (dB)	$e_{(max)}$ (dB)	Error Range (dB)	Absolute Maximum Error, $eAMAX$ (dB)
Not tuned	8.7998	3.0183	13.6398	10.6216	13.6398
Tuning method I	2.9976	-5.6769	4.9446	10.6216	4.9446
Tuning method II	2.0709	-3.7610	4.7559	8.5169	4.7559
Tuning method III	2.1178	-3.9562	4.0998	8.0560	4.0998

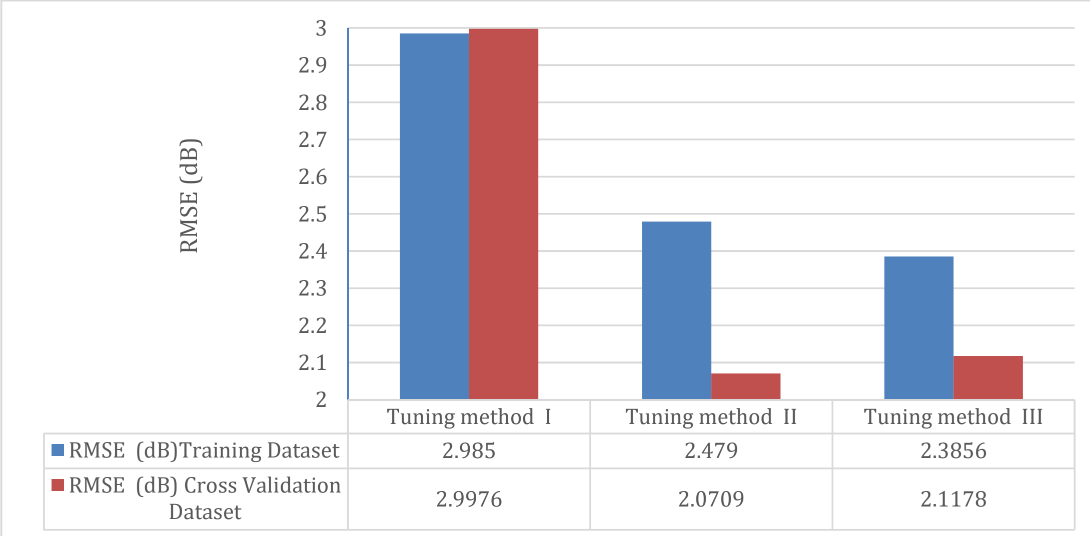


Figure 11**Bar chart of the RMSE of the three tuned Hata-Okumura based on the training dataset and the cross validation dataset**

4. Conclusion

The propagation loss in a market was studied and characterized using the popular Hata-Okumura model. The received signal strength intensity was measured using android phone and three datasets were captured. The three datasets were merged and a portion of the merged dataset was used to train the Hata-Okumura model. Specifically, three different tuning approaches were used to tune the Hata-Okumura model and the models performance was cross validated using another portion of the field measured dataset that was set aside for cross validation. The results showed that two out of the three tuning methods performed very well in both the training dataset and in the cross validation dataset.

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