Development Of Radioclimatic Parameter-Based Optimization Technique For Okumara-Hata Pathloss Model

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***Abstract*— In this paper an approach to Okumara-Hata pathloss model optimization that utilizes radioclimatic parameters, namely; temperature, pressure and relative humidity is presented. In the optimization approach network site survey data were collected in two days, specifically, in the morning, afternoon and evening of each day, which gives rise to six different site survey dataset. The empirical survey measurement was conducted for global system for mobile communication (GSM) network at 900 MHz frequency band that is located, in Akwa Ibom State, Nigeria. Multi-parameter tuning approach was used to tune two constant values in the original Okumara-Hata model for the six different site survey datasets. The mean temperature, mean pressure and mean relative humidity from the six different site survey datasets were used to develop two multiple linear regression models that relate temperature, pressure and relative humidity to the Okumara-Hata model. The results showed that for the six different site survey datasets, the Root Mean Square Error (RMSE) value of the original Okumara-Hata model predicted pathloss varied from a minimum of 58.1758 dB to a maximum of 61.6716 dB. On the other hand, the RMSE value of the original Okumara-Hata model predicted pathloss varied from a minimum of 2.5084 dB to a maximum of 4.0535 dB. In all, the results showed that by tuning the Okumara-Hata model with radioclimatic parameters the RMSE was maintained below 4.5 dB irrespective of the variations in the atmospheric parameters and their attendant effect on the pathloss.**

Keywords*— *Radioclimatic Parameters, Pathloss Model, Model Optimization, Okumara-Hata l Model, Mobile Radio Communication, RMSE-Based Tuning , Multi-Parameter Tuning

I. INTRODUCTION

In mobile radio communication networks pathloss models are important for estimating coverage area, frequency assignments, interference analysis and other cell parameters which are basic elements for such network planning process [1, 2, 3, 4, 5]. Generally, there are three categories of pathloss models, namely the empirical models, semi-deterministic models and deterministic models [4, 6, 7, 8, 9]. While empirical models are based on empirical measurement data, statistical properties and few parameters, the semi-deterministic models are based on empirical models and deterministic aspects. On the other hand, the deterministic models are site-specific, requires enormous number of geometry information about the city, computational effort and more accurate model. In all, the empirical pathloss models are the most widely used because of their simplicity [10, 11, 12, 13, 14, 15]. Furthermore, Okumara-Hata has proven to be the most popular empirical model for urban areas, suburban areas, as well as rural and open areas.

In any case, the major drawback of empirical model is that the models give much prediction error when they are employed in areas other than the ones where the empirical data used in the model development were taken [14, 15, 16, 17, 18, 19, 20]. In this wise, the model parameters are usually tuned or adjusted based on empirical data collected in the specific area where the empirical model are to be employed. Several tuning methods have been employed for this purpose. One method use the Root

Mean Square Error (RMSE) obtained from the measured and the model predicted pathloss values to optimize the model prediction. Particularly, the RMSE is added or subtracted from each model predicted pathloss depending on the value of the sum of prediction error; if the sum of errors is positive, the RMSE is added to each model predicted pathloss whereas if the sum of errors is negative , the RMSE is subtracted from each model predicted pathloss [21, 22, 23, 24, 25, 26]. Other tuning methods use different approaches to one or more model parameters such that the RMSE obtained is minimal. When more than one model parameters are tuned to minimize the RMSE such method can be referred to as multi-parameter tuning method [22, 26, 27, 28, 29]. Such methods in many cases leads to better (smaller) RMSE between the measured and the tuned model predicted pathloss.

In all, these model tuning methods have failed to address one common problem prevalent in the wireless communication industry, namely; radioclimatic parameters such as temperature, atmospheric pressure and relative humidity significantly affect the pathloss [30 , 31, 32, 33, 34]. As such, the measured pathloss at any given location differs when the pathloss is measured at the same location at different time of the day with different values of the radioclimatic parameters. Consequently, in this paper a new pathloss model tuning method that accounts for the effect of the radioclimatic parameters is presented. The tuning method combines multi-parameter tuning method with a multiple linear regression model the effectively relates the radioclimatic parameters to the tuned parameters of the pathloss model. As such, the tuned pathloss maintains acceptable pathloss value irrespective of the variations in the radioclimatic parameters and their attendant effect on the pathloss.

II. METHODOLOGY

A combination of empirical and simulation research approaches are used in the study. The empirical entails field measurements to acquire requisite data as well as process the acquired data for the simulation process. The simulation process involves the use of Mathlab program to carryout multi-parameter tuning of Okumara-Hata pathloss model and the generation and application of a multi-linear regression model that relates pathloss to the radio climatic parameters, namely; temperature, pressure and relative humidity.

Basically, the study started with the selection of the specific Cellular Network Base Station (CNBS). The empirical survey measurement was conducted for global system for mobile communication (GSM) network at 900 MHz frequency band. The measurement survey route within the selected CNBS network coverage area is selected and the specific points where the measurements are to be taken along the route are identified and marked. Then the measurement campaign is carried out at different times on different days. However, measurements are taken only on clear sky condition; that means no rain or fog. In this study, the field measurement is conducted within University of Uyo main campus. The measurements were conducted on two different days and at different times in each of the days.

The key data measured during the measurement campaign are the network data (the received signal strength (RSS) in dBm); the spatial data (including longitude, latitude and altitude) and the primary radioclimatic parameters (including atmospheric temperature, atmospheric pressure and relative humidity). The following steps are used to process the field measured data and to achieve the desired objectives:

(i) The RSS and spatial data (longitude and latitude) are further processed to obtain the measured pathloss ($PL_{m(i)}$) and the transmission distance (d_i) for each of the locations where data is collected.

(ii) The distance (d_i) data is used in the Okumara-Hata pathloss model to generate the predicted pathloss.

(iii) The prediction accuracy of the Okumara-Hata pathloss model is evaluated with respect to the measured pathloss.

(iv) The optimized Okumara-Hata pathloss model is then develop to improve on its prediction accuracy. Particularly, multi-parameter tuning method is employed in carrying out tuning of two parameters (two constant; 69.55 in Equation4 and 44.9 in Equation5) in the original Okumara-Hata model.

(v) The average values of the measured temperature, pressure and relative humidity are obtained along with the values of the two tuned parameters in Okumara-Hata model. The two tuned parameters are denoted as $\mathrm{K1_i}$ and $\mathrm{K2_i}$ whereas the average temperature, pressure and relative humidity are denoted as $\mathrm{T_i}$, $\mathrm{P_i}$ and $\mathrm{H_i}$ respectively.

(vi) The step i to step v are repeated for each of the six datasets captured at different time, of the day and on different days.

(vii) Eventually, the set of data $\mathrm{K1_i}$, $\mathrm{K2_i}$, $\mathrm{T_i}$, $\mathrm{P_i}$ and $\mathrm{H_i}$ are used to develop a multi-linear regression model that relates $\mathrm{K1_i}$to $\mathrm{T_i}$, $\mathrm{P_i}$ and $\mathrm{H_i}$ and also relates $\mathrm{K2_i}$to $\mathrm{T_i}$, P_i and H_i Essentially, the desired, optimized Okumara-Hata model is the one that uses $\mathrm{K1_i}$and $\mathrm{K2_i}$ in its prediction of the pathloss , where $\mathrm{K1_i}$and $\mathrm{K2_i}$ are obtained from the multi-linear regression model in step vii.

A. Okumara-Hata Pathloss model

The following equations are used for the computation of the pathloss (in dB) according to the Okumara-Hata model [11, 35, 36, 37, 38]:

$$LP_{HATA(urban)} = A + B * \log_{10}(d) \quad for\ Urban\ Area \quad (1)$$

$$LP_{HATA(suburban)} = A + B * \log_{10}(d) - C \quad for\ Suburban\ \text{Area} \quad (2)$$

$$LP_{HATA(open/rural)} = A + B * \log_{10}(d) - D \quad for\ Open\ Area/\text{Rural} \quad (3)$$

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (4)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (5)$$

$$C = 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 \quad (6)$$

$$D = 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) \quad (7)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (8)$$

Eq 8 is for small city, medium city, open area, rural area and sububan area

$$a(h_m) = 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \quad for\ large\ city\ \text{f} \leq 200\text{MHz} \quad (9)$$

$$a(h_m) = 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \quad for\ large\ city\ \text{f} \geq 400\text{MHz} \quad (10)$$

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

C and D are used to correct the small city formula for suburban and open areas

150 MHz≤ f≤ 1000MHz

30m ≤h_b ≤ 200m

1m≤ h_m≤ 10 m1 km ≤ d ≤ 20km

Hence, from Eq 1, Eq 4 and Eq 5 Okumara-Hata model for urban area is given as

$$LP_{HATA(urban)} = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) + (44.9 - 6.55 * \log_{10}(h_b)) * (\log_{10}(d)) \quad (11)$$

B. Data Collection and Processing

Site survey data collection was conducted using SAMSUNG GALAXY S4 mobile phone which has the following android application software; Cellmapper android application, Netmonitor android application and MYGPS coordinate android application. Also, Microsoft Excel data recording template and Haversine Distance Calculator software are installed on the laptop used in the data processing.

The Netmonitor android application is used to detect and locate the GSM mast within the study area. The GSM mast coordinate is captured using MYGPS android application. Then the measurement points are marks at about 30 m to 70m apart, starting from a distance of about 60 m from the base station or GSM mast. The distance between the measurement points geo-coordinates are determined using Haversine distance calculator software based on the Haversine formula in Equation 12 ;

$$d = 2r\left\{\sqrt[2]{\sin\left(\frac{LAT_2-LAT_1}{2}\right)^2 + \cos(LAT_1)\cos(LAT_2)\sin\left(\frac{LONG_2-LONG_1}{2}\right)}\right\} \quad (12)$$

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

$$\text{LONG in Radians} = \frac{(\text{LONG in Degrees} * 3.142)}{180} \quad (14)$$

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

The measure point coordinates are logged on the Microsoft Excel data recording template along with the distance between the measurement point and the base station or GSM mast. The Cellmapper android application is used to capture the received signal strength (RSS) in dBm. Each of the RSS value is converted to measured pathloss $(PL_{m(dB)})$ using the formula in Equation 15:

$$PL_{m(dB)} = \text{EIRPt (dBm)} - \text{Pr (dBm)} = \text{EIRPt (dBm)} - \text{RSS (dBm)} \quad (15)$$

where $PL_{m(dB)}$ is the measured pathloss for each measurement location at a distance d(km) ; Pr is the mean Received Signal Strength (RSS) in dBm = the measured received signal strength and EIRPt is the Effective Isotropic Radiated Power in dBm . In this study EIRPt = 53.5 dBm. The pathloss values measured in dB are obtained by substituting the given value of EIRPt (dBm) and the measured values of RSS (in dBm) into Equation 15.Finally, the SAMSUNG GALAXY S4 phone was also used to capture the temperature, pressure and relative humidity at each measurement point. The measurements were conducted on two different days and at different times (morning, afternoon and evening) in each of the days. In all a total of six set of site survey data were used in the analysis.

C .Prediction Performance of the Models

The prediction performance of the models was evaluated using the Mean Absolute Error (MAE) in Equation 16, Root Mean Square Error (RMSE) in Equation 17, and Prediction Accuracy (PA) in Equation 20.

$$\text{MAE} = \frac{1}{n}\left(\sum_{i=1}^{i=n}\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|\right) \quad (16)$$

where: $PL_{(measured)(i)}$ is the measured pathloss (dB) and $PL_{(predicted)(i)}$ is the predicted pathloss (dB),

$$\text{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}\left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|^2\right]\right\}} \quad (17)$$

where

$$\text{SQUARE ERROR} = \left|PL_{(measured)(i)} - PL_{(predicted)(i)}\right|^2 \quad (18)$$

$$\therefore \quad \text{MSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=i}^{i=n}(\text{SQUARE ERROR})\right]\right\}} \quad (19)$$

PL (measured) (i) is the measured pathloss (dB), PL (predicted) (i) is the predicted pathloss (dB), $\frac{\text{PL (measured}}{n}$ is the mean of measured pathloss and n is the number of measured data points.

$$\text{PA}(\%) = \left\{1 - \frac{1}{n}\left(\sum_{i=i}^{i=n}\left|\frac{|PL(measured)(i) - PL\,(peredicted)(i)\;|}{PL\,(measured)(i)}\right|\right)\right\} * 100\% \quad (20)$$

D. Model Optimization

Multi-parameter-tuning method is used. In this case the value of the two constants 69.55 in Equation 4 and 44.9 in Equation 5 of Okumara-Hata model are adjust so as to minimize the RMSE between the actual (measured) pathloss and the Okumara-Hata model predicted pathloss. The two constants 69.55 and 44.9 are referred to as K1 and K2 respectively. However, since there are six different site survey datasets to be analyzed for the two days empirical measurements, the value of the tuned constants are represented as $K1_i$ and $K2_i$ where i =1,2,3,4,5,6. Hence, Equation 4 and Equation 5 are rewritten as follows;

$$A = K1_i + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (21)$$

$$B = K2_i - 6.55 * \log_{10}(h_b) \quad (22)$$

Particularly, Microsoft Excel solver tool is used to adjust and obtain the values of $K1_i$ and $K2_i$ that minimize the RMSE obtained from the actual (measured) pathloss and the Okumara-Hata model predicted pathloss for each of the six different site survey datasets.

The average values of the measured temperature, pressure and relative humidity are obtained and they are denoted as T_i , P_i and H_i respectively. The step i to step iv are repeated for each of the six datasets captured. Eventually, the set of data K1i, K2i, Ti, Pi and Hi are used to develop a multi-linear regression model given as;

K1 = a1 + a2(T) + a3(P) + a4(H) (23)

K2= b1 + b2(T) + b3(P) + b4(H) (24)

where K1 and K2 are the tuned constant from the Okumara-Hata model, a1 to a4 are the regression constants while T, P and H are temperature, pressure and Relative humidity respectively. From Eq 10, Eq 23 and Eq 24, the optimized Okumara-Hata model is then given as;

$$LP_{HATA(urban)} = \mathrm{K1} + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) + (\mathrm{K2} - 6.55 * \log_{10}(h_b)) * (\log_{10}(d))$$

where K1 and K2 are first determined from the multi-linear regression model of Eq 23 and Eq 24 respectively.

III. RESULTS AND DISCUSSION

A. The Measured Pathloss

The measured pathloss (dB) from the six site survey conducted for the two days (morning, afternoon and evening on each of the two days) is shown in the Table 1.

Table 1: The measured pathloss (dB) from the six site survey conducted for the two days (morning , afternoon and evening on each of the two days)

i	1	2	3	4	5	6
Distance (km)	Measured Pathloss (dB) for Day one Morning	Measured Pathloss (dB) for Day one Afternoon	Measured Pathloss (dB) for Day one Evening	Measured Pathloss (dB) for Day two Morning	Measured Pathloss (dB) for Day two Afternoon	Measured Pathloss (dB) for Day two Evening
0.71	143	139	139	140	137	144
0.65	144	144	143	145	146	146
0.61	146	143	142	146	143	149
0.57	149	144	143	147	144	149
0.53	144	144	143	145	144	150
0.50	148	144	136	150	142	147
0.48	149	148	144	143	141	147
0.44	141	144	144	141	144	144
0.40	145	138	140	142	143	139
0.31	141	137	137	140	134	140
0.27	141	137	141	143	139	141
0.23	146	142	143	144	138	142
0.18	134	132	129	129	140	136
0.16	145	143	141	144	141	144
0.12	138	136	139	140	137	140
0.10	138	135	133	136	134	136
0.09	141	134	136	137	136	138
0.07	140	138	135	137	136	136

From Table 1 and figure 1 it can be seen that the measured pathloss (dB) at each location is different at different time of the day and at different days. The mean values of the atmospheric parameters are shown in figure 2. It can be seen that the mean values of the atmospheric parameters varied at each time of the day the measurements are taken. The individual values of the atmospheric parameters at each measurement location are different at each of the measurement instance.

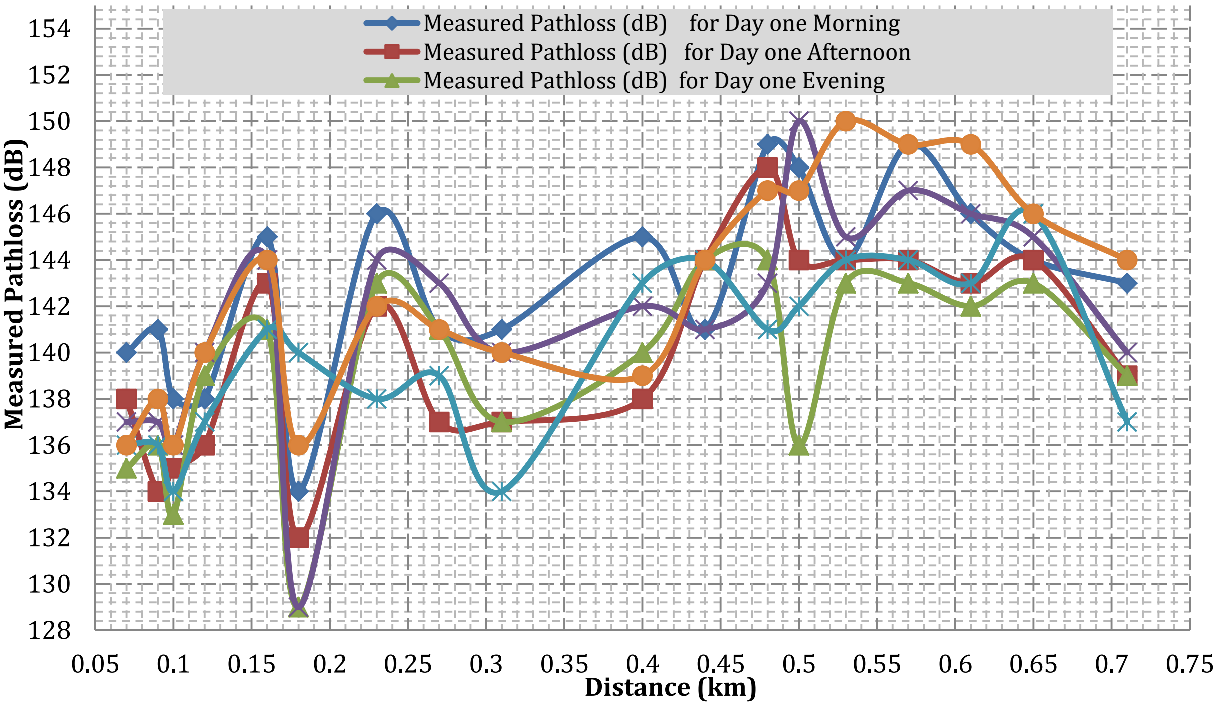
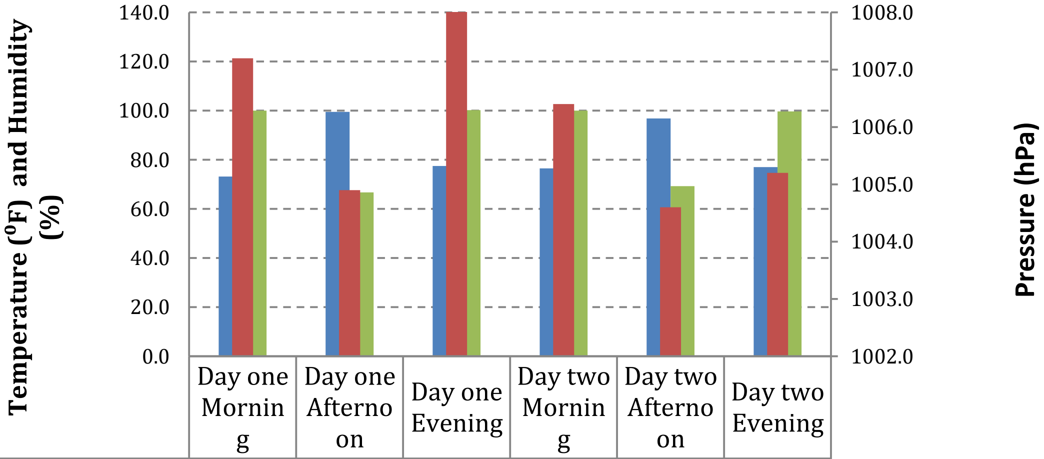


Figure 1: The measured pathloss (dB) from the six site survey conducted for the two days (morning , afternoon and evening on each of the two days)



	Day one Morning	Day one Afternoon	Day one Evening	Day two Morning	Day two Afternoon	Day two Evening
Mean Temperature (^{0}F)	73.2	99.5	77.5	76.5	96.8	77.0
Mean Humidity (%)	100.0	66.7	100.2	100.0	69.3	99.7
Mean Pressure (hPa)	1007.2	1004.9	1008.2	1006.4	1004.6	1005.2

Figure 2: The mean values of the atmospheric parameters for the six site survey conducted for the two days (morning , afternoon and evening on each day)

Consequently, the variation in the measured pathloss at each of the measurement point can be explained by the variation in the atmospheric parameters by relating the pathloss to the atmospheric parameters. Table 2 shows the Mean values of the atmospheric parameters denoted T_i, P_i and H_i along with the tuned Okumara-Hata model parameter 1 and 2 denoted as $K1_i$ and $K2_i$. The data in Table 2 is for the six (i = 1,2,3,4,5,6) site survey conducted for the two days (morning , afternoon and evening on each day).

Table 2 : Mean values of the atmospheric parameters denoted T_i, P_i and H_i along with the tuned Okumara-Hata model parameter 1 and 2 denoted as $K1_i$ and $K2_i$

i	Days	Mean Temperature (ºC)	Mean Pressure (hPa)	Mean Humidity (%)	Tuned Okumara-Hata Model Parameter 1	Tuned Okumara-Hata Model Parameter 2
		T_i	P_i	H_i	$K1_i$	$K2_i$
1	Day one Morning	22.9	1007.2	100	113.8897	14.7114
2	Day one Afternoon	37.5	1004.9	66.7401	113.5434	18.6641
3	Day one Evening	25.3	1008.2	100.2	114.7463	20.1962
4	Day two Morning	24.7	1006.4	100	114.951	18.0321
5	Day two Afternoon	36.0	1004.6	69.2584	113.5007	17.3512
6	Day two Evening	25.0	1005.2	99.6733	115.3381	17.8779

B. The Result of the Atmospheric Parameters-Tuned Okumara-Hata Model

From the data in Table 2 Xuru's online regression tool (available at http://www.xuru.org/rt/MLR.asp#CopyPaste) was used to fit a multiple linear regression model for K1 and K2 and the models are as follows;

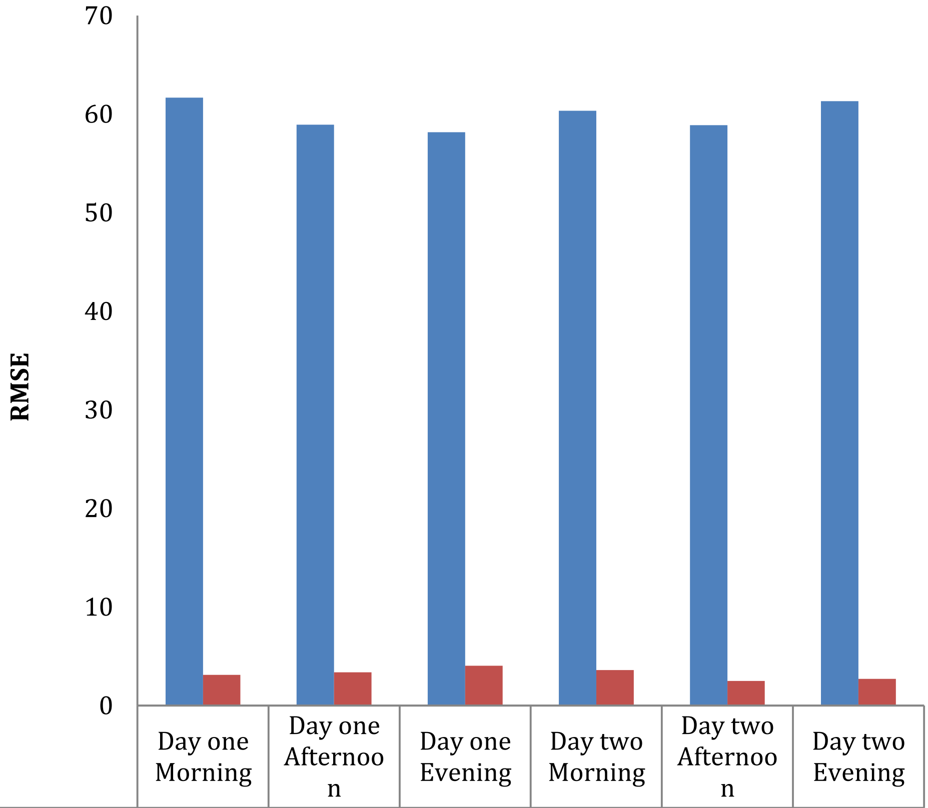
$$K1 = 0.4526813053\,T - 0.2774698435\,P + 0.2291066031\,H + 360.092209 \quad (26)$$

$$K2 = 2.014557362\,T + 0.4633367776\,P + 0.7356268646\,H - 571.6003707 \quad (27)$$

Where T, P, and H are temperature in ºC, P is atmospheric pressure in hPa and H is relative humidity in % while K1 and K2 are the first and second tuned Okumara-Hata model parameters. While Eq 26 and Eq27 are the derived Okumara-Hata model tuning multiple linear regression expression which will be used in the Okumara-Hata model of Equation 25 to determine the optimized Okumara-Hata pathloss prediction. Table 3 and Figure 3 show the RMSE before tuning and after further tuning with atmospheric parameters.

Table 3 : RMSE before tuning and after further tuning with atmospheric parameters

i	Days	RMSE before tuning	RMSE after further tuning with atmospheric Parameters
1	Day one Morning	61.6716	3.1157
2	Day one Afternoon	58.9299	3.3752
3	Day one Evening	58.1758	4.0535
4	Day two Morning	60.3463	3.6114
5	Day two Afternoon	58.8923	2.5084
6	Day two Evening	61.3248	2.7139



	Day one Morning	Day one Afternoon	Day one Evening	Day two Morning	Day two Afternoon	Day two Evening
RMSE before tuning	61.6716	58.9299	58.1758	60.3463	58.8923	61.3248
RMSE after further tuning with atmospheric Parameters	3.1157	3.3752	4.0535	3.6114	2.5084	2.7139

Figure 2: RMSE before tuning and after further tuning with atmospheric parameters

From the results in Table 3 and figure 3 show that by tuning with atmospheric parameters the RMSE is kept within the acceptable threshold value of 6 dB irrespective of the variations in the atmospheric parameters and their attendant effect on the pathloss.

IV CONCLUSION

A new approach for optimization of Okumara-Hata pathloss model is present. The new approach that utilizes radioclimatic parameters, namely; temperature, pressure and relative humidity it also requires that network site survey data should be collected on different days and at different time on each day, specifically, in the morning, afternoon and evening of each day. Also, the network site survey data should be collected at the same location on each round of measurement. In this paper network site survey data were collected in two days, specifically, in the morning, afternoon and evening of each day, which give rise to six different site survey dataset. The empirical survey measurement was conducted for global system for mobile communication (GSM) network at 900 MHz frequency bands that is located, in Akwa Ibom State, Nigeria. Multi-parameter tuning approach and the mean temperature, mean pressure and mean relative humidity six different site survey dataset were used to develop two multiple linear regression models that relate temperature, pressure and relative humidity to the Okumara-Hata model. The results showed that irrespective of the variations in the atmospheric parameters and their attendant effect on the pathloss, by tuning the Okumara-Hata model with radioclimatic parameters the RMSE was maintained below the generally accepted maximum value of 6 dB for pathloss models.

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