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Empirical Path Loss Model for Terestrial Broadcast Application in UHF Band in the Federal Capital Territory, Abuja, Nigeria

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Abstract

Path loss prediction models are an essential for proper planning, appropriate design and coverage determination in the broadcast frequency band. Propagation path loss models are very much useful mathematical tools to calculate signal attenuation and it can also be used as a controlling factor for the system performance and coverage. In this paper, the study adapted an empirical path loss model for terestrial broadcast application in Ultra High-Frequency Band in the Federal Capital Territory, Abuja, Nigeria by quantitatively measuring the signal level of the signal. The signal levels of transmitting signal were taken along three radial routes from the transmitting station using digital signal level meter and the corresponding distances were also measured using Global positioning system. The measurement results were compared with path loss prediction of four widely used empirical path loss models. The results obtained show that Free space model gave a more accurate prediction for path loss in Abuja City after modification with the correction factor average of - 48.3460 and Root Mean Square Error of 10.9356 dB. Therefore, it is important that collection of data for signal field strength used for path loss estimations should be taken in all seasons of the year in order to have accurate model that is suitable for Abuja environ.

Keywords: Propagation Model, Path Loss, UHF, Signal Level, Radio Propagation

Introduction

Radio signal propagation path loss is the reduction in the power density of an electromagnetic wave as it propagates through the environment at which it is traveling. Path loss prediction models are used to determine the signal strength in various locations. They help to determine signal strength of a location before the installation of equipment. For broadcast station, a coverage survey is important because huge investment is expended. The path loss prediction models enable the problem to be solved before the installation, the cost is considerably reduced [1].

Path loss propagation in urban, suburban, and rural environments has a significant impact on wireless communication networks. Different propagation models have been developed for network locations. The different terrains are unique in their topological features and environmental factors. Therefore, a propagation model suitable for one terrain may not be suitable for another propagation environment for path loss prediction. Path loss radio signal propagation depends on antenna height, frequency, distance and environmental condition such as terrain and building pattern. Accurateness of model in particular environment will depend on relational best fit between different parameters required by model and those existing for related area. An extensive range of techniques have been developed over the years to calculate the coverage by using the propagation models [2].

Radio signal also depends on several factors such as type of propagations, environments, distance between the transmitter and receiver, height and location of antennas. Also, the signal from the transmitting antenna may take multiple paths (multipath) to reach the receiving side, which results in either increase or decrease of received signal level depending on the constructive or destructive interference of the multipath waves [3].

Path loss or radio signal strength prediction models are vital tools for radio coverage estimation, determination of base station location, frequency allocation, antenna selection, and interference feasibility studies during radio network planning [4].

Propagation models can be broadly divided into three categories, namely: empirical, deterministic and semi- deterministic models. Empirical models are those based on observations and measurements alone to predict the behaviour of a system. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive. Examples of empirical models are Hata and ITU-R model. Meanwhile, the reliability of the radio access network depends on the accuracy of the propagation model employed. Hence, the need for significant improvement in the prediction accuracy of empirical models while maintaining model simplicity and ease of use. Deterministic models deploy laws of electromagnetic wave propagation for determination of received signal strength in a definite region of concern. Deterministic models often require a complete 3-D map of the propagation environment. An example of deterministic model is a ray tracing model [5].

Semi-deterministic models are combination of some aspects of both empirical and deterministic models. An example of the model is Cost 231-Walfish Ikegami [4].

Radio propagation environments have been widely categorized into rural, suburban, and urban. These environments are composed of varying unique geographical features with different altitude, terrain, land usage data, building shape and height information, and building surface characteristics. These models account for propagation path loss based on radio parameters such as height of transmitter and receiver antennas, frequency of transmission, and distance between the base station and the mobile station. However, the presence of various sources of clutter in the propagation environment contributes largely to propagation path loss [6]. This study adapt an empirical path loss model for terrestrial broadcast application in Ultra High- Frequency Band in the Federal Capital Territory, Abuja, Nigeria by quantitatively measuring the signal level of the signal.

Path Loss Prediction Propagation Model

Free space Path loss Model

In free space, the wave is not reflected or absorbed. The free space path loss model is used to predict received signal strength when the transmitter and receiver have a clear and unobstructed line of 1signal path between them (Nadir et al; 2008). In free space propagation, a radio wave is free of any object that may cause signal attenuation. However, there is signal attenuation as a result of continuous spread of power over a greater area [7].

Free Space propagation between transmitting and receiving antennas may be assumed when both antennas are sufficiently high, so that only the direct signal gets to the receiving antenna.

$$PL = 20\ log_{10}(d) + 20\ log10(f) + 32.4 \qquad (1)$$

Where: PL is the free space path loss in dB, is Frequency in MHz and is the distance between transmitter and receiver in km.

Hata Path Loss Model

The Hata model is an empirical model that is used to estimate or anticipate route loss. It is a propagation model that is frequently used in determining radio propagation planning and interference estimation. It is founded on an empirical link uncovered in Okumura's research on signal strength variability measurements [8]. The model is most appropriate to frequencies ranging from 150 MHz to 1500 MHz, base station height of 30 m to 200 m with distances ranging from 1 km to 20 km between the transmitter and receiver. The model is classified into three models: rural, suburban and urban area. The standard formula for median path loss (dB) prediction of Hata model for urban macro cellular environment is mathematically given by:

$$L_{Hata}\,(Urban) = 69.25 + 26.16\ log\ (fc) - 13.82\ log\ (hr) - (hr) + (44.99 - 6.55\ log\ (h_t))\ log\ (d) \quad (2)$$

Where L_{Hata} is the path loss in dB, f_c is the operating frequency in MHz which ranges from 150 MHz to 1500 MHz, h_t and h_r are the height of the base station or transmitter and height of the mobile or receiver antennas in meters respectively, is in km which is the distance between the transmitter from the receiver, and (h_r) is the antenna height correction factor for the receiver antenna as a function of coverage area.

For a small or medium city:

$$(h_r) = (1.1log - 0.7)\ h_r - (1.56\ log\ fc - 0.8)\ dB$$

For large city:

$$(h_r) = 3.2\ (log11.75\ hr)\ 2 - 4.97\ dB \qquad for\ f_c \geq 300MHz$$

$$(h_r) = 8.29\ (log1.54\ hm)2 - 1.1\ dB \qquad for\ f_c \leq 300MHz$$

Suburban areas:

$$(dB) = L_{Hata}\ (urban) - 2\ [log\ (f_c/28)]^2 - 5.4 \qquad (3)$$

Open areas:

$$L_{Hata}\ (dB) = (urban) - 4.78\ (logf_c)2 + 18.33\ logf_c - 40.94$$

CCIR (ITU-R) Path loss Model

CCIR model is an empirical formula for the combined effect of free space path loss and terrain induced path loss and is given by Lee and Miller (1998) as:

$$L_{CCIR} = 69.55 + 26.26log10(f) - 13.82\ log\ (h_b) - a(h_m) + [44.9 - 6.55log10\ h_b]log10(d) - B \qquad (4)$$

Where: h_t and h_r are the base station and mobile antenna heights in meters respectively, d is the distance in km, is the frequency in MHz.

Also,

$$(h_m) = [1.1log10\ (f_{FMHz}) - 0.7] - [1.56log10\ (f_{FMHz}) - 0.8]$$

$$B = 30 - 25log10(\text{Percentage of area covered by buildings})$$

This formular is the Hata model for medim-small city propagation conditions, with the correction factor, B

Ericsson Path loss Model

This model is based on the software supplied by Ericson Company. It is also based on the updated Okumura – Hata model to permit the room by varying in parameters in consonance with the propagation environment. The path loss model for Ericson model is given as:

$$L_{Ericsson} = M_0 + M_1 log10(d) + M_2 log10(h_b) + M_3 log10\,(h_b)\,log10\,(d) - 3.2\,[log10\,(11.75h_r)2] + g(f) \quad (5)$$

where:

$(f) = 44.49log10\,(f) - 4.78[log\,(f)]^2$, f_2, is the frequency in MHz, hr is the receiving antenna height in meter, hb is the transmitting antenna height in the meter.

The Study Area

Abuja, the Federal Capital Territory of Nigeria is located in the geographical center of Nigeria. It has a land area of 8,000 square kilometers. It is bounded on the north by Kaduna State, on the west by Niger State, on the east and southeast by Nasarawa State and on the southwest by Kogi State.

It falls within latitude 7° 25' N and 9° 20° North of the Equator and longitude 5° 45'E and 7° 39'E of the meridian [9]. FCT experiences two weather conditions annually; these are the rainy season (the equivalent of winter in the temperate region) and the dry season (the equivalent of summer in the temperate climate). The rainy season begins in April and ends in October Within this period, there is a brief interlude of harmattan occasioned by the North East Trade Wind, with the main feature of dust haze, intensified coldness and dryness. Fortunately the high altitudes and undulating terrain of the FCT act as moderating influences on the weather of the territory. The temperature ranges from 25° C to 30°C [10].

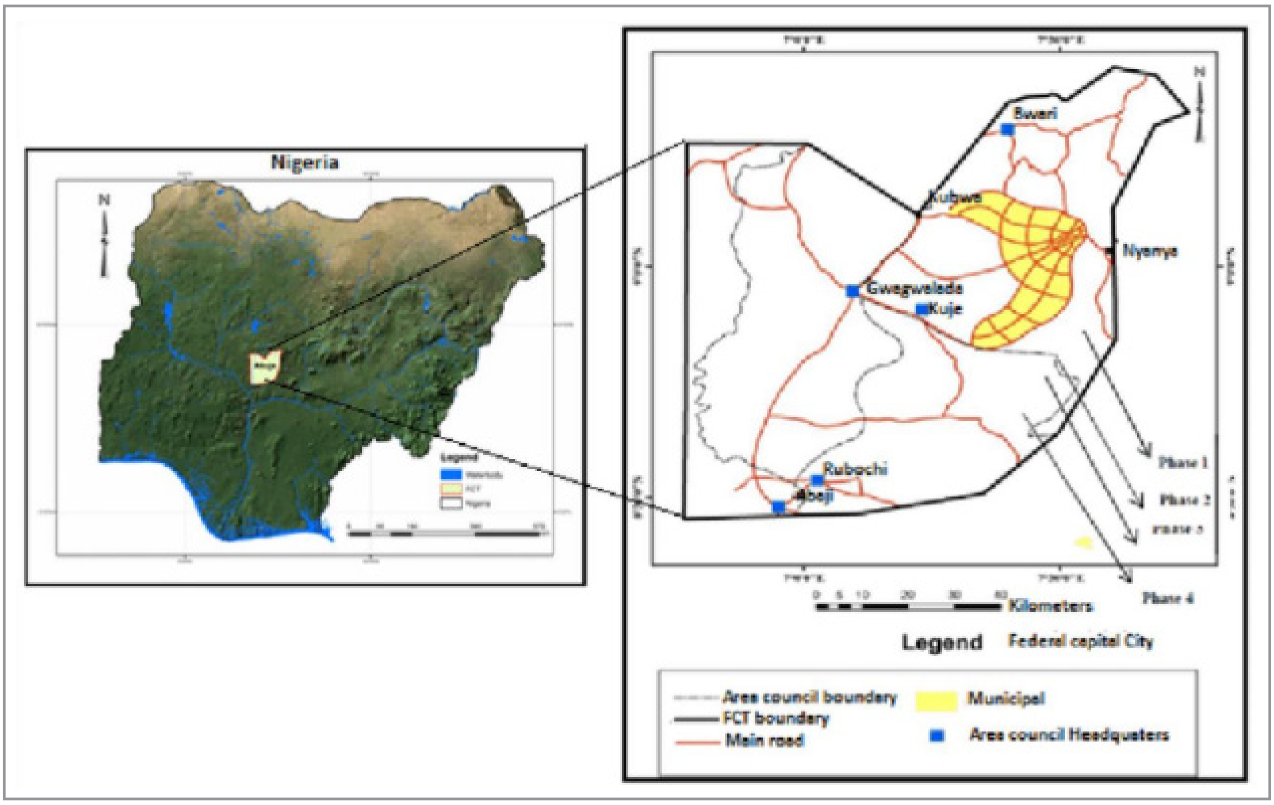

Figure 1: Location of FCT (Ciroma et al., 2021)

Results and Discussion

Path Loss

The path loss obtained using the models and the one obtained from the measured data are given in Figures 2 to 4. All the models for each route have the same trend. Generally, the model with lowest path loss prediction is Free space while the model with highest path loss prediction is Ericsson model. The path losses predicted by Hata model for large city and Hata model for small city have almost the same trends. Consequently, the graph overlapped. Tables 1 show the values of the RMSE for the models along the entire routes. From the Table, Free space model has the lowest prediction error while the Ericsson model also has highest prediction along the entire routes considered.

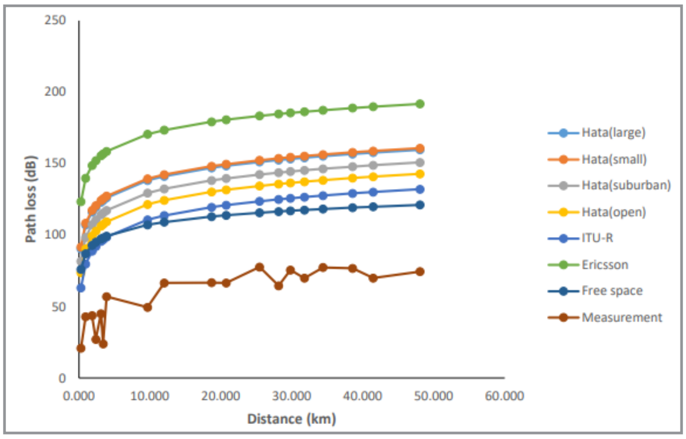

Figure 2: Path loss for route A

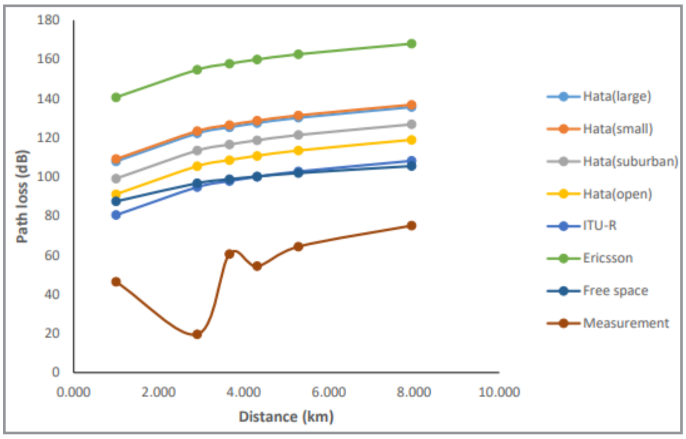

Figure 3: Path loss model for route B

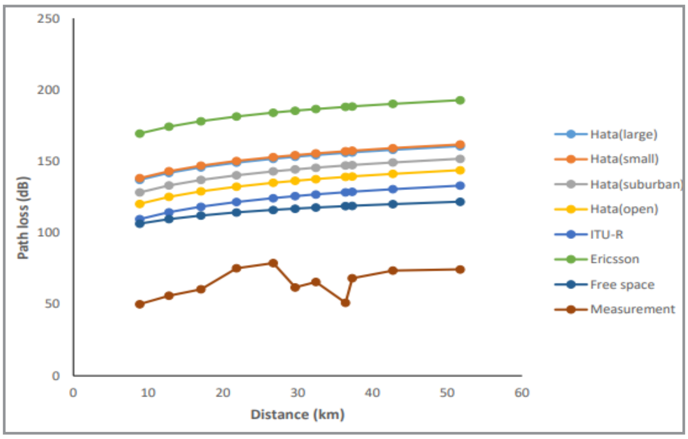

Figure 4: Path loss model for route C

Table 1: Root mean square error of the path loss model

Routes	Hata(large)	Hata(small)	Hata(suburban)	Hata(open)	ITU-R	Ericsson	Free space
A	80.7876	81.950	72.0306	64.1213	53.5303	113.0030	50.1796
B	72.8575	74.0037	64.2444	56.5051	46.2785	104.8979	47.5139
C	86.6045	87.7688	77.8328	69.9058	59.2448	118.7179	51.2442
Average	80.0832	81.2409	71.3693	63.5107	53.0179	112.2063	49.6459

Modified Path Loss Models

The correction factors used to modify the models are shown in Table 1.2 and the modified models are shown in Figures 5 to 7. After the modification, Hata model for suburban give a highest prediction value and Hata model for large city, Hata model for small city have the same value for route A, B and C respectively, and hence, the graphs overlapped and have almost the same RMSE values. The RMSE values for the modified models along the entire routes are given in Table 2

Table 2: Root mean square error of the modified path loss model

Routes	Hata(large)	Hata(small)	Hata(suburban)	Hata(open)	ITU-R	Ericsson	Free space
A	8.6964	8.6964	63.2683	47.5253	44.1713	8.6301	9.0293
B	14.5367	14.5367	55.6957	40.5084	48.2863	14.5443	15.0833
C	8.0771	8.0771	69.0665	53.2636	46.7545	8.0636	7.9647
Average	10.4367	10.4367	62.6768	47.0991	46.4040	10.4126	10.6925

Table 3: Correction factors used for modified path loss model

Routes	Hata(large)	Hata(small)	Hata(suburban)	Hata(open)	ITU-R	Ericsson	Free space
A	-80.3182	-81.4875	-71.5037	-63.5288	-52.8223	-112.673	-49.3605
B	-71.3926	-72.5619	-62.5781	-54.6032	-43.9355	-103.885	-45.0562
C	-86.2270	-87.3963	-77.4125	-69.4376	-58.6922	-118.444	-50.6214
Average	-79.3126	-80.4819	-70.4981	-62.5232	-51.8167	-111.667	-48.3460

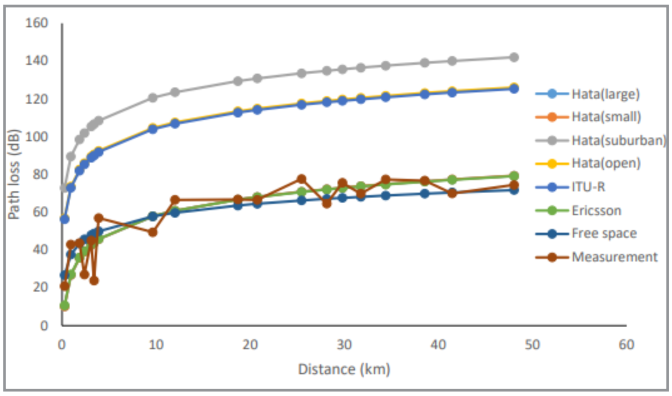

Figure 5: Modified path loss model for route A

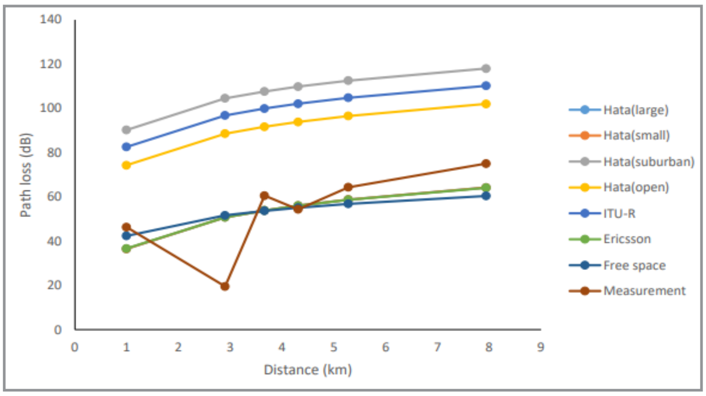

Figure 6: Modified path loss model for route B

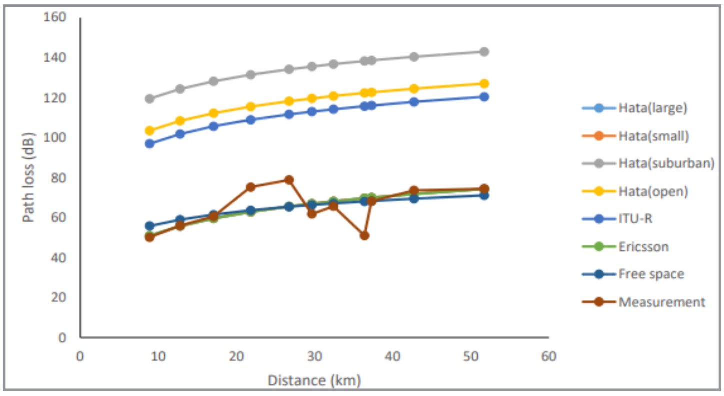

Figure 7: Modified path loss model for route C

Generalised Path Loss Models

The average of the Mean Prediction Error values along each route are taken as the correction factors to generalize the path loss model for each model as shown in Figure 8 to 10. Table 4 gives the RMSE values for the models along the entire routes.

The average of the RMSE values for the generalized path loss models along the three radial routes considered are used as the RMSE for all the routes in Abuja City. Hence, Free space model has the least average RMSE value of 10.9356 dB.

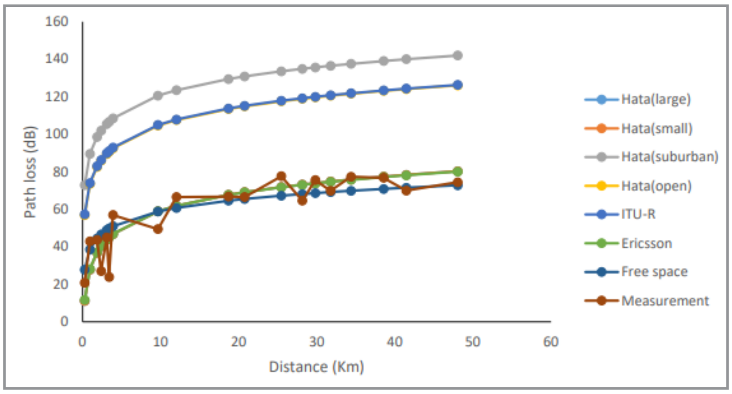

Figure 8: Generalised path loss model for route A

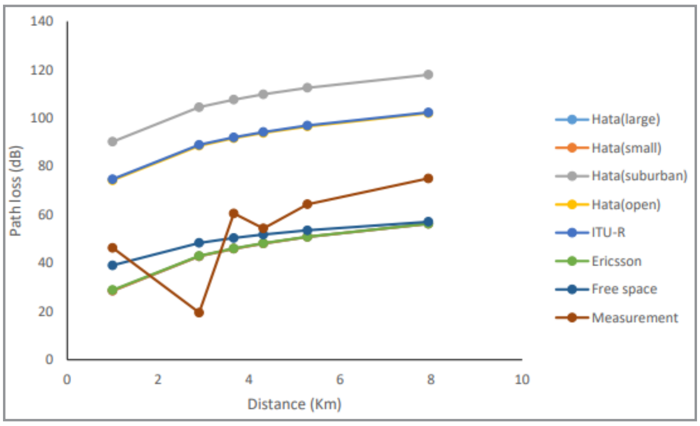

Figure 9: Generalised path loss model for route B

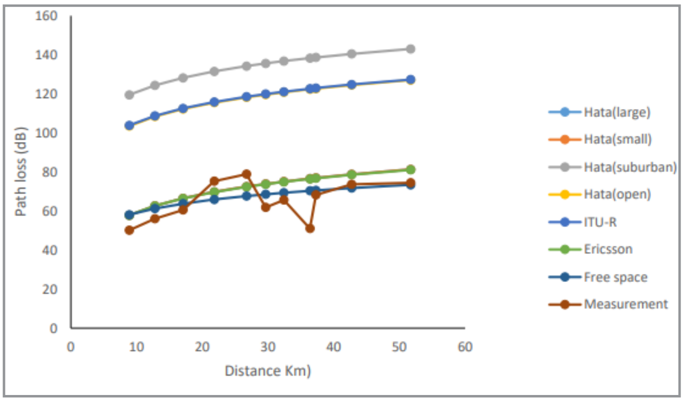

Figure 10: Generalised path loss model for route C

Table 1: Root mean square error of the path loss model

Routes	Hata(large)	Hata(small)	Hata(suburban)	Hata(open)	ITU-R	Ericsson	Free space
A	8.7547	8.7546	63.2841	47.5410	47.8498	8.6881	9.0857
B	16.5529	16.5533	55.6889	40.5112	40.8447	16.4968	15.4388
C	10.6342	10.6337	69.0665	117.9031	53.5385	10.5312	8.2823
Average	11.9806	11.9806	62.6798	68.6518	47.4110	11.9054	10.9356

Conclusion

The generalized path loss models for terrestrial television broadcast were obtained by using the average of mean prediction errors of the three routes considered as a correction factor for each model. So, the average prediction values of the RMSE of the generalized path loss model for the routes taken are considered as the RMSE value of NTA. The average correction factors used for all the path loss models are -79.3126 for Hata (large) model, -80.4819 for Hata (small) model, - 70.4981 for Hata (suburban) model, -62.5232 for Hata (open) model, -51.8167 for ITU-R model, -111.667 for Ericsson model and -48.3460 for Free space model respectively. Hence, the generalized Free space path loss model gave a better prediction of the path loss in NTA Abuja as compared to other models used with RMSE of 10.9356 dB. So it is important that collection of data for signal field strength used for path loss estimations should be taken in all seasons of the year in order to have accurate model that is suitable for Abuja environ.

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