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PATH LOSS MODELS FOR TERRESTRIAL BROADCAST IN VHF BAND IN MINNA CITY, NIGER STATE, NIGERIA

Moses Abiodun Stephen*[1], Oyedum Onyedi David[2], Ajewole Moses Oludare[3]
[1,2]Department of Physics, Federal University of Technology Minna, P.M.B. 65 Minna, Niger State, Nigeria
[3]Department of Physics, The Federal University of Technology Akure, P.M.B. 704 Akure, Ondo State, Nigeria
[1]abiodun.moses@futminna.edu.ng*
[2]oyedumod@yahoo.com
[3]oludare.ajewole@futa.edu.ng

* Corresponding author

Abstract

Propagation models are required for proper planning of a network and for accurate interference estimation, or else, it could result in networks with high co-channel interference and a waste of power. This research work aims to adapt a propagation model that is best suitable for Minna city in Niger State, Nigeria. This is done by optimisation of some existing empirical propagation models - Free space, Hata, CCIR and Ericsson path loss models, to suit Minna city using a VHF television signals of Nigeria Television Authority (NTA) Minna, channel 10. The station transmits at 210.25 MHz for video signal. The signal levels of the transmitted signal were measured along five radial routes from the transmitting station with a digital signal level meter and Global Positioning System (GPS) was used to measure the corresponding distances. Data processing and computation were carried out using SPSS and Microsoft software applications. The results show that the Ericsson Model gives more accurate prediction for path loss in Minna city after general modification with the correction factor of -38.72 and Root Mean Square Error of 6.34 dB.

Keywords: Path loss, Propagation models, Signal level, VHF

1. Introduction

Wireless communication involves transfer of information between two antennas (transmitter and receiver) by means of radio wave. Consequently, the interaction between the radio wave and the objects that surround these two antennas severely affect the signal resulting to path loss.

There are numerous path loss prediction models but none of these models can be generalised for all environments and localities, instead, they are suitable for some specific areas, terrain and climate. However, path loss model's parameters can be adjusted according to the specific environment to obtain minimal error between predicted and measured signal strength (Ayeni *et al.*, 2015).

Path loss models are used in network planning, for conducting feasibility studies and in the course of initial deployment. Furthermore, they are important for predicting coverage area, interference estimation and frequency assignments which are basic elements for network planning process in terrestrial broadcast systems (Mardeni and Pey, 2012). Propagation models can be divided into three types of models, namely: the empirical models, deterministic models and semi-deterministic models (Mardeni and Kwan, 2010).

The empirical approach relies on fitting curves or analytical expressions to sets of measured data and has the advantage of implicitly taking into account all factors (known and unknown). Therefore, it does not explain a system but are based on observations and measurements alone (Shahajahan and Abdulla, 2009). Some situations are not possible to be explained by mathematical model, so some data are used to predict the behaviour approximately.

Empirical models were employed in this research work. Free space, Hata, CCIR and Ericsson path loss models were modified and generalised to suit Minna city in Niger State, Nigeria, using VHF television signal of Nigeria Television Authority (NTA), Minna, channel 10. This station transmits at a frequency of 210.25 MHz for video signal and 215.25 for audio signal.

2. Path Loss Models

Path loss means attenuation of radio waves between transmitter and receiver in radio communication system. The effects of reflection, refraction, diffraction, absorption, as well as free space loss between the transmitter and the receiver could lead to path loss (Mardeni and Kwan, 2010). There are many empirical path loss models for radio communication systems but attention will be given to the prediction models by free space, Hata, CCIR and Ericsson model because these models have been widely accepted and therefore will be used to evaluate the propagation measurement results.

2.1 Free Space Propagation Model

In free space, radio wave is not reflected or absorbed but as the power spread over a greater area, the signal attenuate. 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. If the transmitting antenna gain is G_t and the transmitter power is W_t, power density P_r at distance d can be expressed as (Kurniawan, 1997):

$$P_r = \frac{W_t G_t}{4\pi d^2} \qquad (1)$$

Received power W_r at distance d with a receiving antenna gain G_r is therefore

$$W_r = \frac{W_t G_t}{4\pi d^2} \cdot \frac{\lambda^2 G_r}{4\pi} \qquad (2)$$

or $$\frac{W_r}{W_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

$$= G_t G_r \left(\frac{c}{4\pi d f}\right)^2 \qquad (3)$$

where:

G_t: transmitting antenna gain
G_r: receiving antenna gain
d: distance
c: speed of propagation (3×10^8 m/s)
f: carrier frequency.

For isotropic transmitting and receiving antennas, $G_t = G_r = 1$ and if distance d is expressed in km and carrier frequency f in MHz, the ratio between W_r and W_t in dB can be expressed as:

$$L_f = 32.45 + 20\log_{10} f + 20\log_{10} d \qquad (4)$$

where L_f (dB) is free space loss between two isotropic antennas.

2.2 Hata's Propagation Model

Hata model was derived from Okumura field strength curves and various path loss equations for different types of environment were predicted. For Hata model, distance from the base station ranges from 1 km to 20 km, mobile antenna height is between 1 m and 10 m, base station antenna height is between 30 m and 200 m and carrier frequency is between 150 MHz and 1500 MHz (Nadir,, 2011). Furthermore, Hata's model is classified into urban area, suburban and open space models (Mardeni and Kwan, 2010):

Path loss for Hata model is defined as:

$$L_p = A + B\log_{10} d \qquad \text{(urban area)} \tag{5}$$

$$L_p = A + B\log_{10} d - C \quad \text{(Suburban area)} \tag{6}$$

$$L_p = A + B\log_{10} d - D \quad \text{(rural area)} \tag{7}$$

where:

$$A = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \tag{8}$$

$$B = 44.9 - 6.55\log_{10}(h_b) \tag{9}$$

$$C = 5.4 + 2[\log_{10}(\tfrac{f_c}{28})]^2 - 19.33\log_{10}(f_c) \tag{10}$$

The parameter $a(h_m)$ is a "correction factor"

For medium or small city:

$$\mathrm{a(h_m)} = [1.1\log_{10}(\mathrm{f_c})\text{-}0.7]\mathrm{h_m}\text{-}[1.56\log_{10}(\mathrm{f_c})\text{-}0.8] \tag{11}$$

For large city:

$$a(h_m) = 8.23[\log_{10}(1.54h_m)]^2 - 1.1 \quad \text{for} \quad f_c \leq 200\ MHz \tag{12}$$

$$a(h_m) = 3.2[\log_{10}(11.75h_m)]^2 - 4.97 \quad \text{for} \quad f_c \geq 400\ MHz \tag{13}$$

where:

h_m is mobile antenna height above local terrain height (m)
d is distance between the mobile antenna and the base station antenna
h_b is base station antenna height above local terrain height (m) and
f_c is carrier frequency (MHz)

2.3 CCIR Path Loss Model

The *Comit´e International des Radio-Communication* (CCIR), now International Telecommunication Union - Radiocommunication Sector (ITU-R) published an empirical formula for the combined effects of free space path loss and terrain induced path loss given as (Lee and Miller, 1998):

$$L_{CCIR} = 69.55 + 26.16\log_{10}(f_{MHz}) - 13.82\log_{10} h_b - a(h_m) + [44.9 - 6.55\log_{10} h_b]\log_{10}(d_{km}) - B \tag{14}$$

where h_b and h_m are base station and mobile antenna heights in meters respectively, d_{km} is the link distance in kilometers, f_{MHz} is the frequency in megahertz,

$$\mathrm{a(h_m)} = [1.1\log_{10}(\mathrm{f_{MHz}})\text{-}0.7]\mathrm{h_m}\text{-}[1.56\log_{10}(\mathrm{f_{MHz}})\text{-}0.8] \tag{15}$$

$$B = 30 - 25\log_{10}(\%\ of\ areas\ covered\ by\ buildings) \tag{16}$$

This formula is the Hata model for medium-small city propagation conditions with a correction factor, B.

2.4 *Ericsson Model*

Ericsson model is a modified Hata model that gives allowance for changing the parameters according to the propagation environment. Path loss according to this model is given by (Milanovic *et al.*, 2007):

$$L_E = a_o + a_1.\log_{10}(d) + a_2.\log_{10}(h_b) + a_3.\log_{10}(h_b).\log_{10}(d) - 3.2[\log_{10}(11.75h_r)^2)] + g(f) \qquad (17)$$

where $g(f)$ is defined by:

$$g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2 \qquad (18)$$

and

f : frequency (MHz)
h_b: transmission antenna height (m)
h_r: receiver antenna height (m)

The default values of a_o, a_1, a_2 *and* a_3 are 36.2, 30.2, 12.0 and 0.1 respectively for urban terrain.

3. Study Area

Minna is a capital city of Niger State in North Central Nigeria (Figure 1), the most populous black nation in the world with estimated population of 304,113 in 2007 (http://en.wikipedia.org/wiki/Minna, 2016). Minna is surrounded by granite hills to the north and to the east while the west and the southern parts of the town extend on a lowly plain. The city has a moderate weather, with lows of 24°C and highs of 30°C in the dry season, around the month of April. More also, it has a tall grassland vegetation and woody area close to river valleys (http://www.world66.com/africa/nigeria/minna/, 2016).

Figure 1: Location of Minna (9°36'50"N, 6°33'25"E) in Nigeria (http://en.wikipedia.org/wiki/Niger_State, 2016)

4. Data Collection and Analysis

The effective radiating power of the transmitter of the television station during the period of this work was 7.5 kW and the transmitting antenna was mounted on a mast of height 150 m. The signal level of the transmitted video signal was measured along five radial routes from the transmitting station and the routes are designated Route A, Route B, Route C, Route D and Route E as shown in Figure 2. A dipole antenna of 1.5 m high above ground surface was connected to a Digital Signal Level Meter - GE-5499, to measure the signal levels of the transmitted signal from the station along these routes. Each signal level corresponding distance, elevation above the mean sea level and location (Longitude and Latitude) were also measured using Global Positioning System (GPS 72 – Personal Navigator).

Figure 2: The routes along which measurements were taken (http://www.geodata.us/weather/place.php?usaf=651230&uban=99999&c=Nigeria&y=2011, 2016)

Data processing and computation were carried out using SPSS and Microsoft software applications. From the measured signal level, the path loss for each route was obtained and the corresponding path loss as predicted by Free space, Hata, CCIR and Ericsson models were also estimated. The Root Mean Square Error or Deviation (RMSE) for each model along all the routes was determined. Similarly, the Mean Prediction Error (MPE) was estimated and used as a correction factor to modify each model to obtain the least RMSE. To generalise each model for all the routes in Minna, instead of having a number of correction factors for a single model for a city, as a result of different routes considered, the average values of the MPE of the five radial routes were obtained and used as the correction factors to generalise the path loss models.

5. Results

The path loss models and the measured path loss for each route are shown in Figure 3 to Figure 7. All the models follow the same trend for all the routes. The Free space model has the lowest path loss prediction while Ericson model has the highest path loss prediction. At this frequency (210.25 MHz), the path loss predicted by Hata model for large city and Hata model for small city have almost the same values, consequently, the two graphs overlapped.

The RMSE of all the path loss models for each route are shown in Table 1. Hata model for suburban environment has the least error for route A, B, C and E (6.01 dB, 7.17 dB, 5.70 dB and 5.04 dB respectively) while Hata model for large city has the least error (5.82 dB) for route D. Each route has different path loss because of the irregular elevation of the surface of the ground. The ground elevation is high in some parts of the city and low in some other parts, moreover, there are also hills in some part of the city (Ajewole *et al.*, 2013).

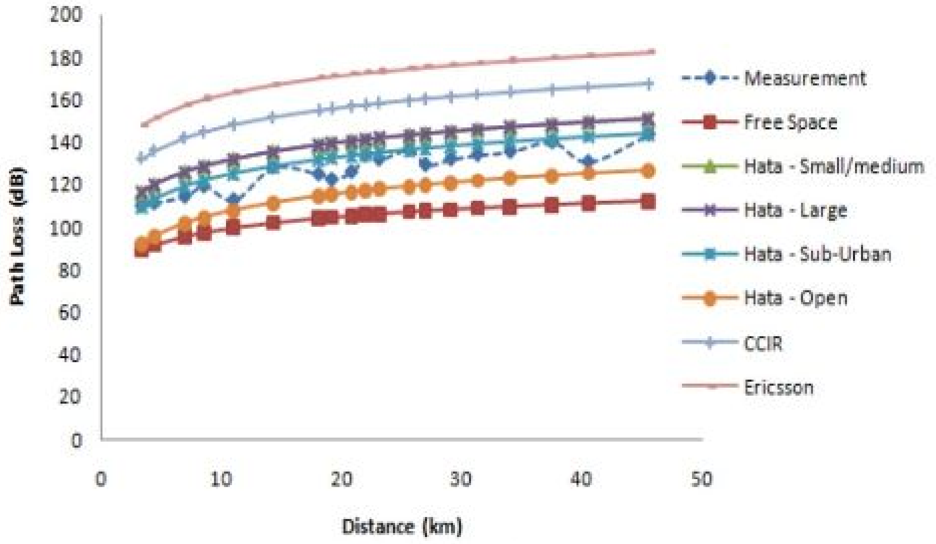

Figure 3: Path loss models for route A

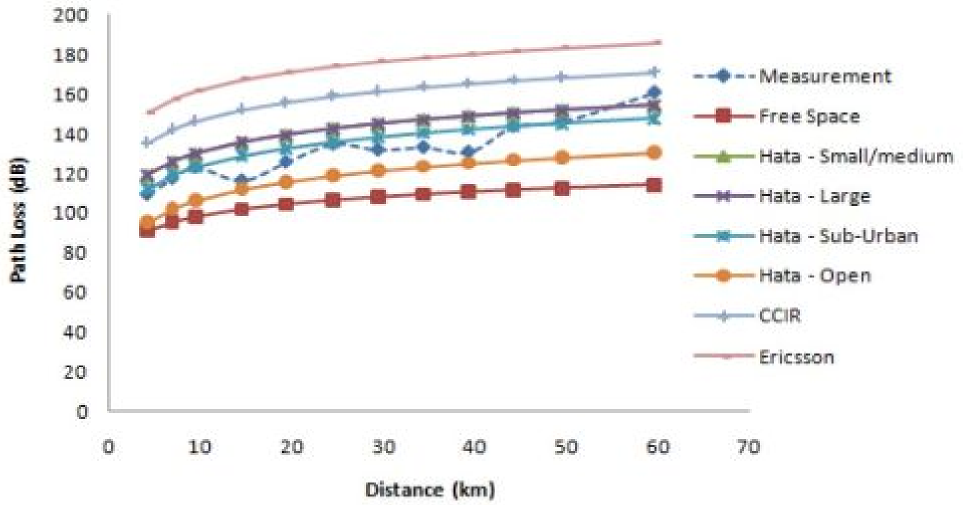

Figure 4: Path loss models for route B

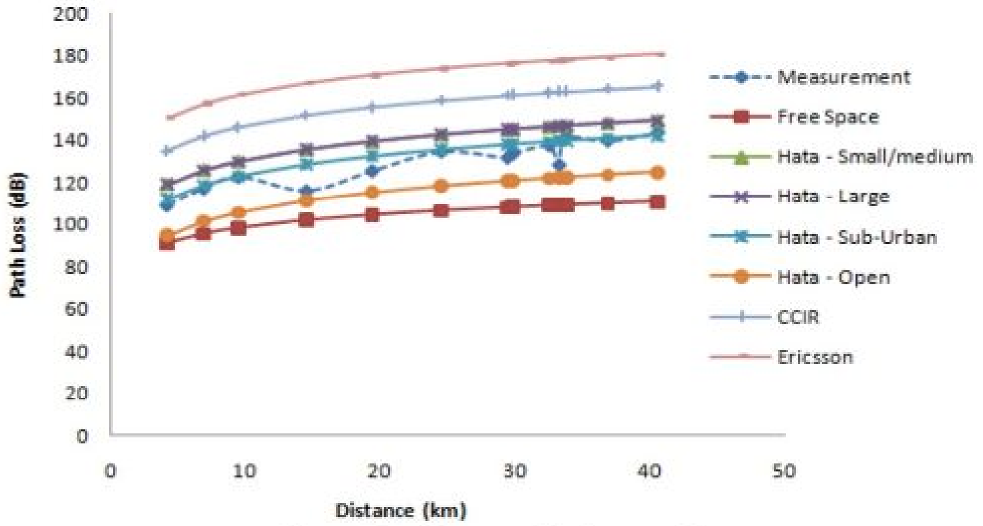

Figure 5: Path loss models for route C

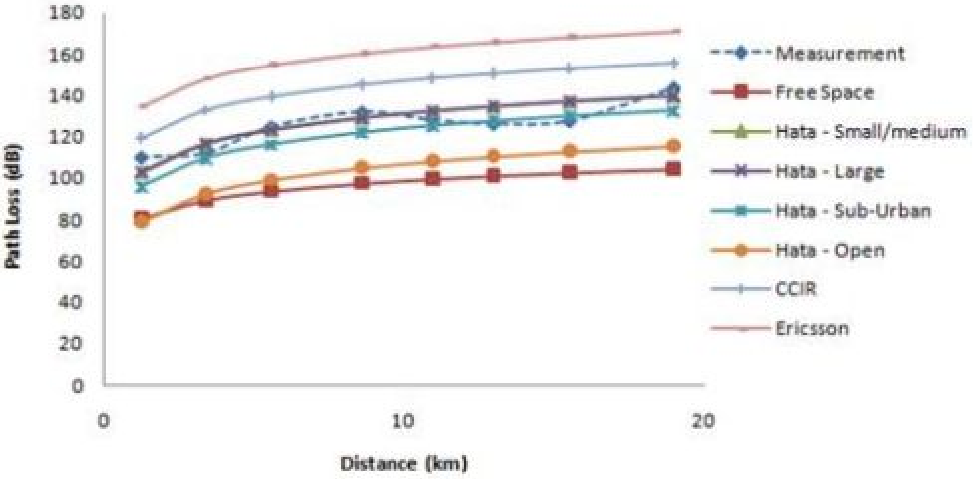

Figure 6: Path loss models for route D

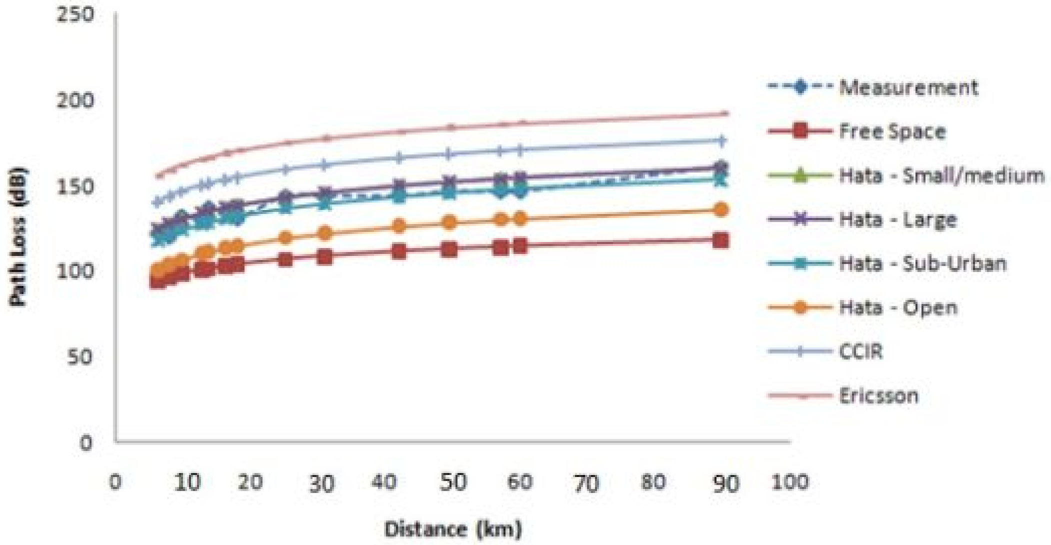

Figure 7: Path loss models for route E

Table 1: Root Mean Square Error of the Path Loss Models

	Free Space	Hata (Small/medium)	Hata (Large)	Hata (Sub-Urban)	Hata (Open)	CCIR	Ericsson
Route A	23.76	12.10	12.08	6.01	13.31	27.86	42.95
Route B	26.88	11.90	11.86	7.17	15.60	26.89	41.78
Route C	25.19	11.50	11.46	5.70	14.17	27.13	42.19
Route D	29.75	5.83	5.82	8.01	23.56	18.32	33.18
Route E	32.60	5.22	5.19	5.04	20.90	20.08	35.09

5.1 Modified Path Loss Models

Table 2 shows the correction factors used for the modified path loss and Figure 8 to Figure 12 show the modified path loss models for all the routes. After the modification, all the Hata models and CCIR model become the same, hence, the graphs overlapped and have the same RMSE.

The RMSE of all the path loss models for each route are shown in Table 3. Ericsson model has the least error for route A and E (3.95 dB and 3.76 dB respectively). Likewise, Hata and CCIR models have the least error for routes B and C (6.5 dB and 4.31 dB respectively) and Free space model has the least RMSE for route D (5.19 dB).

Table 2: Correction Factors used for the Modified and the Generalised Path Loss

	Free Space	**Hata (Small/medium)**	**Hata (Large)**	**Hata (Sub-Urban)**	**Hata (Open)**	**CCIR**	**Ericsson**
Route A	23.30	-11.40	-11.40	-4.52	12.70	-27.58	-42.77
Route B	25.60	-9.96	-9.93	-3.03	14.19	-26.09	-41.27
Route C	24.60	-10.70	-10.60	-3.73	13.49	-26.79	-41.97
Route D	29.29	-1.29	-1.25	5.64	22.86	-17.42	-32.70
Route E	32.25	-3.59	-3.56	3.34	20.56	-19.72	-34.89
AVERAGE	27.01	-7.39	-7.35	-0.46	16.76	-23.52	-38.72

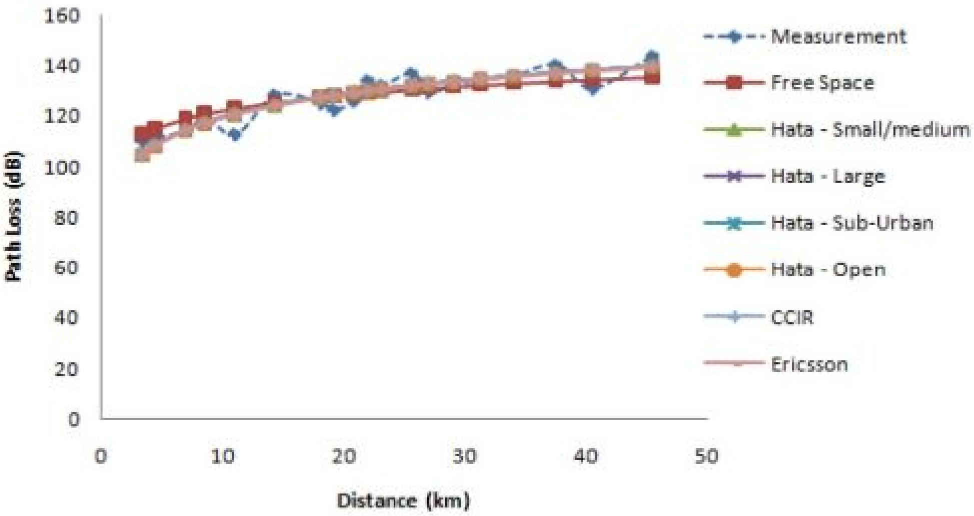

Figure 8: Path loss models for route A

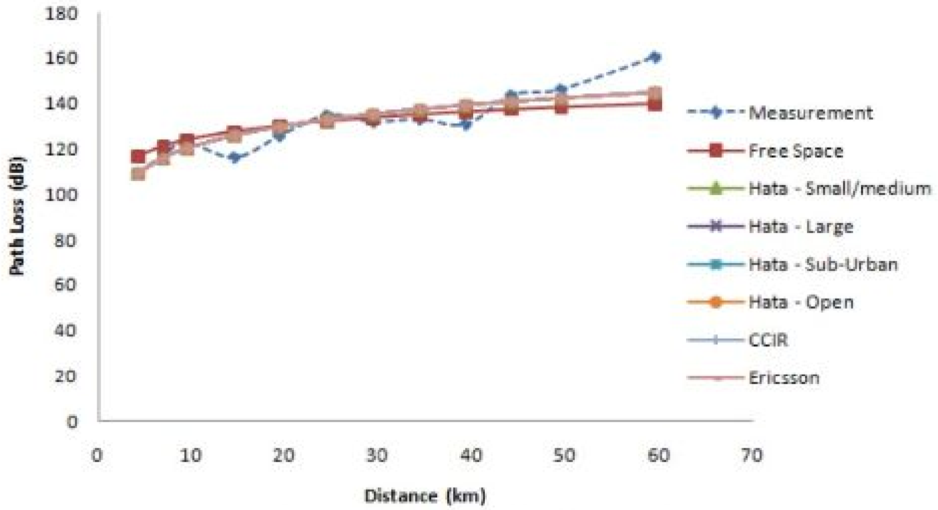

Figure 9: Path loss models for route B

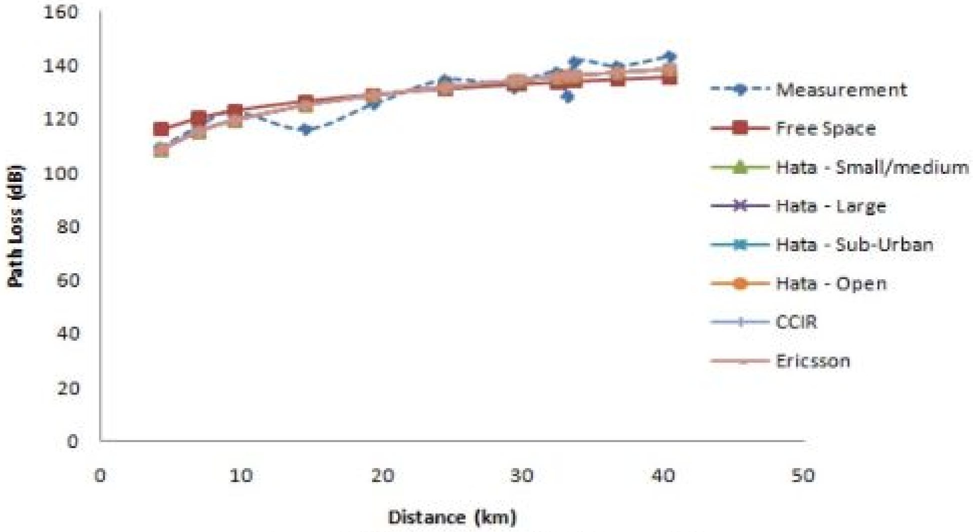

Figure 10: Path loss models for route C

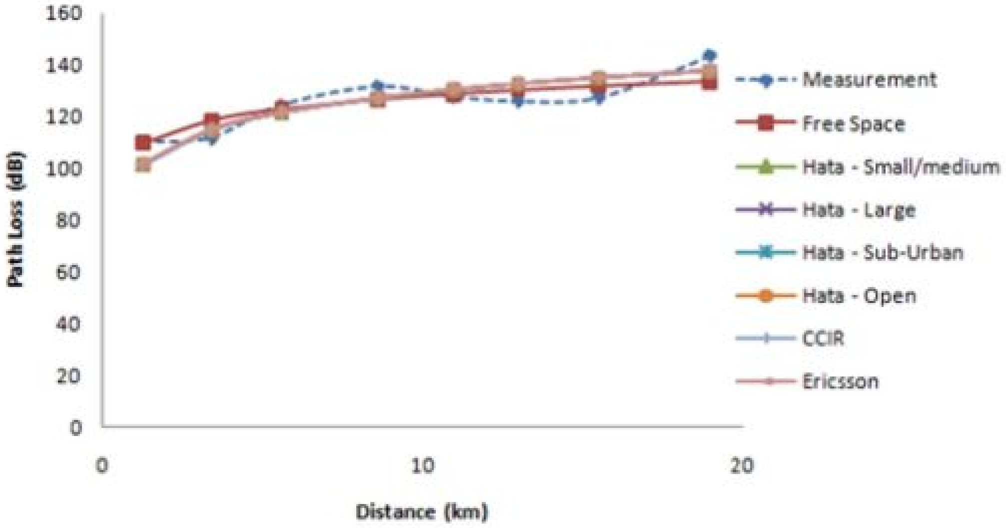

Figure 11: Path loss models for route D

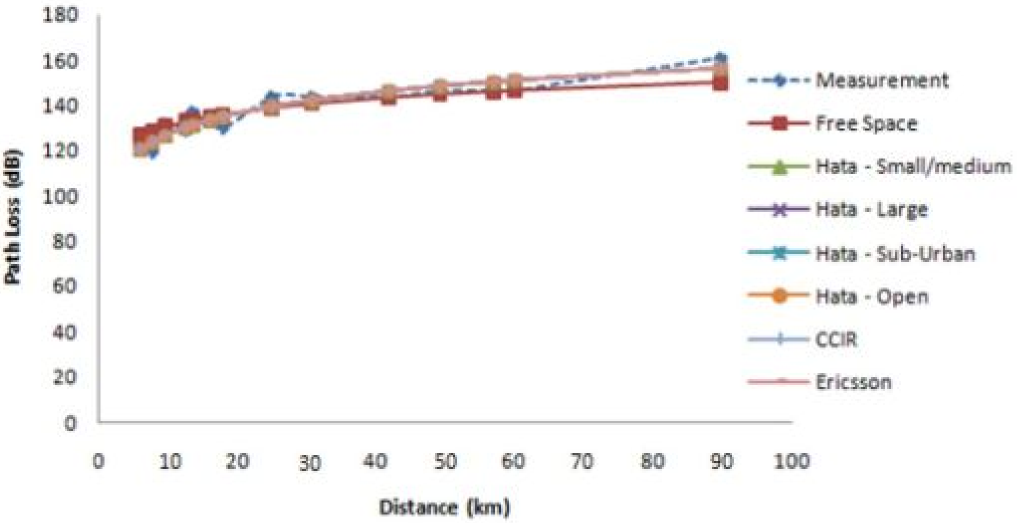

Figure 12: Path loss models for route E

Table 3: Root Mean Square Error of the Modified Path Loss

	Free Space	Hata (Small/medium)	Hata (Large)	Hata (Sub-Urban)	Hata (Open)	CCIR	Ericsson
Route A	4.64	3.96	3.96	3.96	3.96	3.96	3.95
Route B	8.20	6.50	6.50	6.50	6.50	6.50	6.52
Route C	5.43	4.31	4.31	4.31	4.31	4.31	4.32
Route D	5.19	5.69	5.69	5.69	5.69	5.69	5.65
Route E	4.73	3.78	3.78	3.78	3.78	3.78	3.76

5.2 Generalised Path Loss Models

The average values of the MPE of all the routes obtained are used as the correction factors to generalise the path loss model for each model as shown in Figure 13 to Figure 17. The RMSE of the path loss models for each route are shown in Table 4. For route A and route C, Ericsson model has the least error (5.66 dB and 5.4 dB respectively). For route B and route E, Hata and CCIR models has the least errors (6.99 dB and 5.36 dB respectively) while Free space model has the least error (5.67 dB) for route D. The average values of the RMSE of the generalized path loss models for the five radial routes considered are taken as the RMSE values for all the routes in Minna city. Consequently, Ericsson model has the least average RMSE value (6.34 dB).

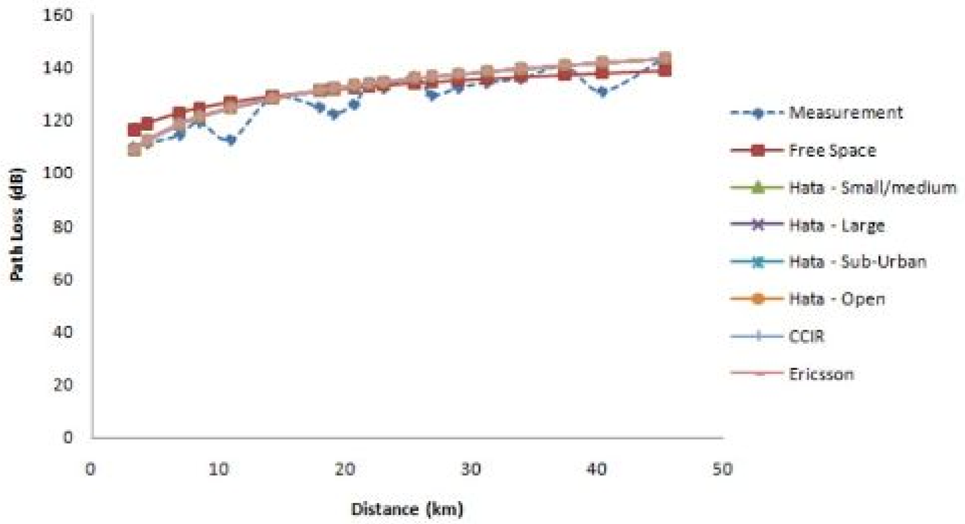

Figure 13: Path loss models for route A

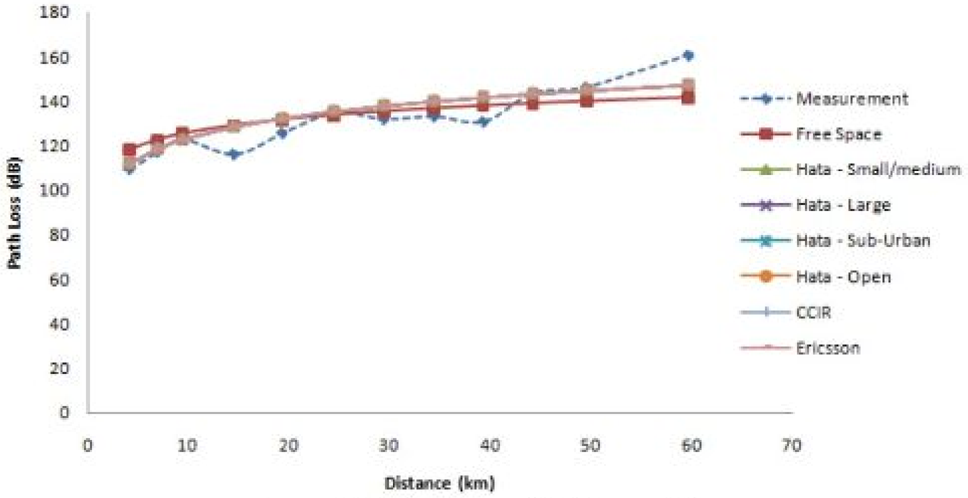

Figure 14: Path loss models for route B

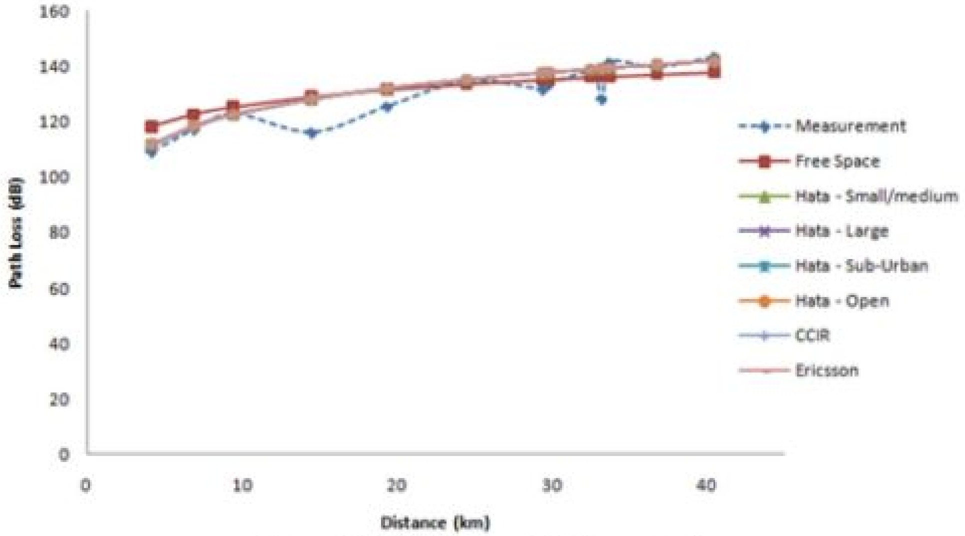

Figure 15: Path loss models for route C

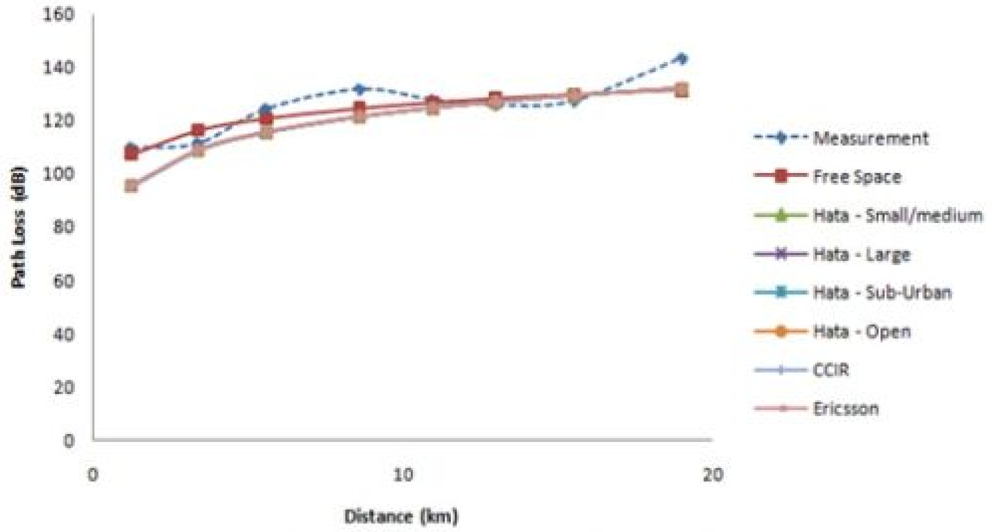

Figure 16: Path loss models for route D

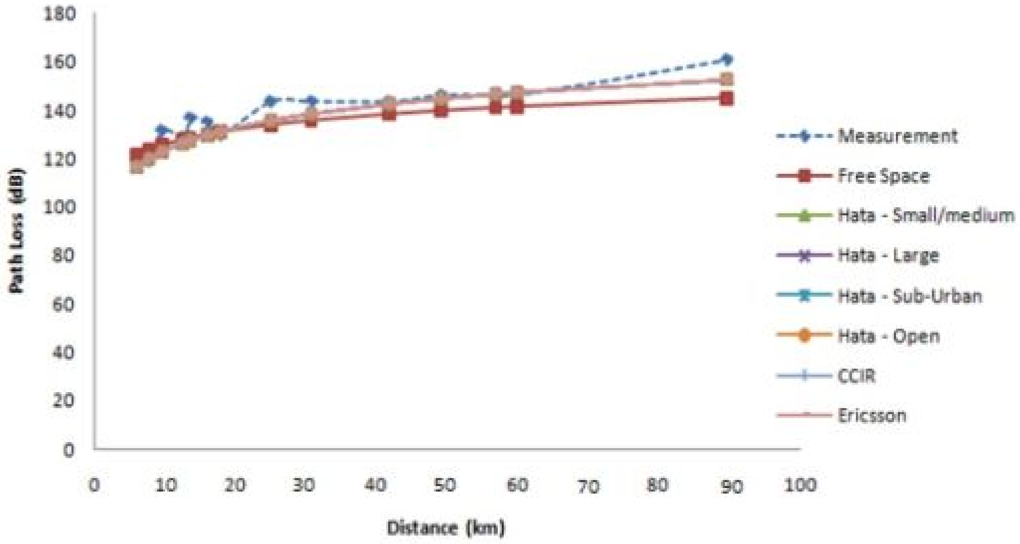

Figure 17: Path loss models for route E

Table 4: Root Mean Square Error of the Generalised Path Loss

	Free Space	**Hata (Small/medium)**	**Hata (Large)**	**Hata (Sub-Urban)**	**Hata (Open)**	**CCIR**	**Ericsson**
Route A	5.94	5.67	5.67	5.67	5.67	5.67	5.66
Route B	8.32	6.99	6.99	6.99	6.99	6.99	7
Route C	5.94	5.41	5.41	5.41	5.41	5.41	5.4
Route D	5.67	8.34	8.34	8.34	8.34	8.34	8.25
Route E	7.07	5.36	5.36	5.36	5.36	5.36	5.37
AVERAGE	6.59	6.35	6.35	6.35	6.35	6.35	6.34

6. Summary and Conclusion

The generalized path loss models for Minna city with least RMSE were obtained by using the average values of the MPE of the five radial routes considered, as the correction factors for each model. The average values of the RMSE of the generalized path loss models for the five radial routes are taken as the RMSE values of all the routes in Minna city.

The correction factors used for all the path loss models considered are: 27.01 (Free space), -7.39 (Hata - small/medium city), -7.35 (Hata - large city), -0.46 (Hata - suburban), 16.76 (Hata - open area), -23.52 (CCIR) and -38.72 (Ericsson models) with average RMSE of 6.59 for Free space, 6.34 for Ericsson models and all the Hata models and CCIR model have the same average RMSE, 6.35, because they all become the same after modification.

Ericsson model gives the least RMSE for Minna city. Therefore, the generalized Ericson model for urban environment gives more accurate prediction for path loss in Minna city compared to other models considered.

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Weather in Minna, Nigeria 2011, map, taken from http://www.geodata.us/weather/place.php?usaf=651230&uban=99999&c=Nigeria&y=2011