I.J. Wireless and Microwave Technologies, **2017, 3, 9-24**
Published Online May 2017 in MECS(http://www.mecs-press.net)
DOI: 10.5815/ijwmt.2017.03.02

Available online at **http://www.mecs-press.net/ijwmt**

Propagation Profile and Signal Strength Variation of VHF Signal in Ekiti State Nigeria

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Abstract

This paper presents the experimental results of a study on radio frequency attenuation path loss conducted in Ekiti State, Nigeria. The objective of the study is to develop a path loss model comparable to the existing path loss models through a real time application of outdoor VHF signal propagation measurements of the Nigeria Television Authority (NTA) Channel 5 and carrier frequency of 175.25 MHz located in Ado-Ekiti, Ekiti State, Nigeria. Experimental measurements were taken in three routes covering the entire state. Analysis of the data collected from the experiments resulted in models which are in agreement with the existing standard models. Root Mean Square Errors were calculated for all the path loss models. Results show that the signal of the station was generally poor along the routes considered as the deviations of the measured path losses from the free space path loss exceed 6 dB in most cases.

Index Terms: Path loss, signal propagation, attenuation, signal strength

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1. Introduction

Wireless communication system relies on the propagation of signal waves and data transmission through the free space, hence wireless communication provides mobility for users and satisfies the demand of the subscribers at any location covered by the wireless network [Mardeni R and Kwan K.F, 2010].

Good quality and high capacity networks together with accurate estimation of coverage is extremely important , therefore, accurate design coverage of modern cellular networks and signal strength measurements must be taken into consideration in order to provide an efficient and reliable coverage area.

Several path loss prediction models have been proposed in the literatures but none of these models can be generalized for all environments and localities, instead they are suitable for some specific areas, terrain and climate. Path loss model's parameters can however be adjusted according to the specific environment to obtain

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minimal error between predicted and measured signal strength values [Mardeni R and Kwan K.F, 2010]. The work by Mardeni and Kwan (2010) proposed the optimized Hata path loss empirical model using the least square method for Malaysia while Nadir (2011) investigated seasonal path loss model prediction for Oman. The work by Nadir (2011) calculated the MSE between the measured and the predicted values based on the Okumura-Hata model for the area considered. Similar works were also done by Fagbohun O. O. (2014), Isabona J. &Konychea C.(2013), Medeisi A &Kajackas A.(2000), Nadir Z., Elfadhil N &Touati F.(2008) and Akinbolati *et al* (2016) with the aims of optimizing the path losses for the investigated cities.

Path loss models are required in network planning, more importantly during the feasibility studies as well as the process of the initial deployment of the network system. They are also used in the prediction of the coverage areas, interference estimation and frequency assignments which are basic elements for network planning process in terrestrial broadcast systems (Nadir 2011). Propagation models can be classified into three types, namely: the empirical models, deterministic models and semi-deterministic models (Oyetunji, S.A,2013)

In this research work, empirical models were employed, Free space, Hata, CCIR and Ericsson path loss models were modified and generalized to suit some routes in Ekiti State of Nigeria, using VHF television signal of Nigeria Television Authority (NTA), Ado Ekiti, channel 5 transmitting at 175.25MHz frequency band. The research is motivated by the encouragement given by international telecommunication union radio(ITU-R) that scientists and engineers should carry out researches in their localities leading to the development of signal propagation profile in their geographical locations (CCIR Report 239-6,1986).

The organization of this paper is as follows; section II discussed the existing propagation path loss models from literatures as fundamentals to this study. The description of environment where this study was conducted was presented in section III, this was crucial to validate the environment specificity effect on this study .While an adequate explanation on the materials and procedures engaged in achieving the results presented in this study was given in section IV, the results and discussions were presented in section V and section VI concluded on the outcomes and the importance of the research.

2. Propagation Path Loss Prediction Models

Quite a number of propagation models exists in literatures and these had been engaged by various researches to analyze the propagation path losses in their different geographical locations. Research being environment specific, and to the best of our knowledge, little or no research have been carried out in this area in the chosen geographical region under consideration in this study. Some of the existing propagation path loss models as reviewed from literature are discussed below.

A. Free Space Propagation Model

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. The free space model takes only into consideration distance and frequency, hence, it is limited in its ability to accurately predict path loss in most environments (Mardeni and Kwan, 2010, Femi-Jemilohun and Stuart,2014). If the transmitting antenna gain is G_t and the transmitting power is W_t, power density P_r at distance *d* can be expressed as ,

$$P_r = \frac{W_t G_t}{4\pi d^2} \tag{1}$$

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

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

Where:

G_t is the transmitting antenna gain and G_r is the receiving antenna gain, d is distance is speed of propagation (3×10^8 *m/s*) and f is carrier frequency.

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

$$L_{fs} = 32.45 + 20\log_{10} f + 20\log_{10} d \qquad (3)$$

Where L_{fs} (dB) is free space loss between two isotropic antennas.

B. Okumura Propagation Model

This is a mathematical model developed by Okumura. It is the most extensively used for signal propagation prediction model in mobile communication and is recognized by the International Telecommunication Union (ITU) (CCIR Report 1145, 2000),

The Okumura model for urban area is a radio propagation model that was built into three modes which are urban, sub -urban, and open areas. This model assumes that the path loss between the transmitter and receiver in the terrestrial propagation environment can be mathematically expressed as:

$$L = L_{FSL} + A_{FSL} - H_{TU} - H_{RU} - \sum K_{correlation} \qquad (4)$$

Where L is median path loss between the transmitter and receiver expressed in dB, L_{FSL} ; Path loss of the free space in dB, A_{FSL} : Basic median attenuation, H_{TU} transmitter height gain correction factor in dB, H_{RU} receiver height gain correction factor in dB and $K_{correlation}$: correction factor gain (such as type of environment, water surfaces, isolated obstacles).

C. Okumura-Hata Propagation Model

This model was derived from Okumura field strength curves and various path loss equations for different types of environments predicted. For Hata model, distance from the base station ranges from 1km to 20 km, mobile antenna height is between 1 m and 10 m, base station antenna height is between 30m and 200m and the carrier frequency is between 150 MHz and 1500 MHz, .it is classified into urban area, sub-urban area and open space models. Path loss for Hata Model is defined as:

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

$$L_p = A + B\log_{10} d - C \text{ (Sub-urban Area)} \qquad (6)$$

$$L_p = A + B\log_{10} d - D \text{ (Rural- Area)} \qquad (7)$$

where:

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

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

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

$$D = 4.78[\log_{10}(f)]^2 - 18.33\log 10(f) + 40.94 \tag{11}$$

The parameter $a(h_m)$ is a “correction factor”

For medium or small city:

$$a(h_m) = [1.1\log 10\, f_c - 0.7]h_m - [1.56\log_{10}(fc) - 0.8] \tag{12}$$

For large city:

$$a(h_m) = [8.23\log_{10} 1.54 h_m]^2 - 1.1 \tag{13}$$

For

$$fc \le 200\, MHz$$

$$a(h_m) = 3.2\log_{10}(11.75 h_m]^2 - 4.97 \tag{14}$$

For

$$f \ge 400\, MHz$$

Where:

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

D. CCIR Path Loss Model

Comité consultatif international pour la radio (CCIR), which in English means Consultative Committee on International Radio was founded in 1927 and over the years merged with the original ITU and several other organisations. In 1992, CCIR now known as International Telecommunication Union Radio Communication Sector (ITU-R) published an empirical formula for combined effects of free space path loss and terrain induced path loss given as (CCIR Report 567-3, 2000),

$$L_{CCIR} = 69.55 + 26.16\log_{10}(f_{MHz}) - 13.82\log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log_{10} h_b]\log_{10}(d_{km}) - B \tag{15}$$

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

$$a(h_m) = [1.1\log_{10}(f_{MHZ}) - 0.7] - [1.56\log_{10}(f_{MHZ}) - 0.8] \tag{16}$$

$$B = 30 - 25\log_{10}(\% of area\ covered by buildings) \tag{17}$$

E. 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 as (CCIR Report 567-3, 2000):

$$L_E = a_0 + a_1\log_{10}(d) + a_2\log_{10}(h_b) + a_3\log_{10}(h_b).\log_{10}(d) - 3.2[\log_{10}(11.75h_r)^2] + g(f) \tag{18}$$

Where $g(f)$ is defined by

$$g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2 \tag{19}$$

and f: frequency (MHz), h_b: transmission antenna height (m), h_r: receiver antenna height (m). The default values of a_0, a_1, a_2 , a_3. are 36.2, 30.1, 12.0 and 0.1 respectively for urban terrain.

3. Study Area

Ekiti State of Nigeria (Fig. 1) was chosen for this research, it is one of the 36 states in Nigeria, situated in the western part of the country. Ado -Ekiti is the capital of Ekiti State where NTA Channel 5 base station used for the study is situated. The parameters of this broadcasting station are given in Table.1. Three routes were considered, covering the northern and the western part of the state. The effective isotropic radiated power (EIRP) of the transmitter of this television station during the period of this investigation was 3.5 KW and the transmitting antenna was mounted on a mast of height 167.5 m.

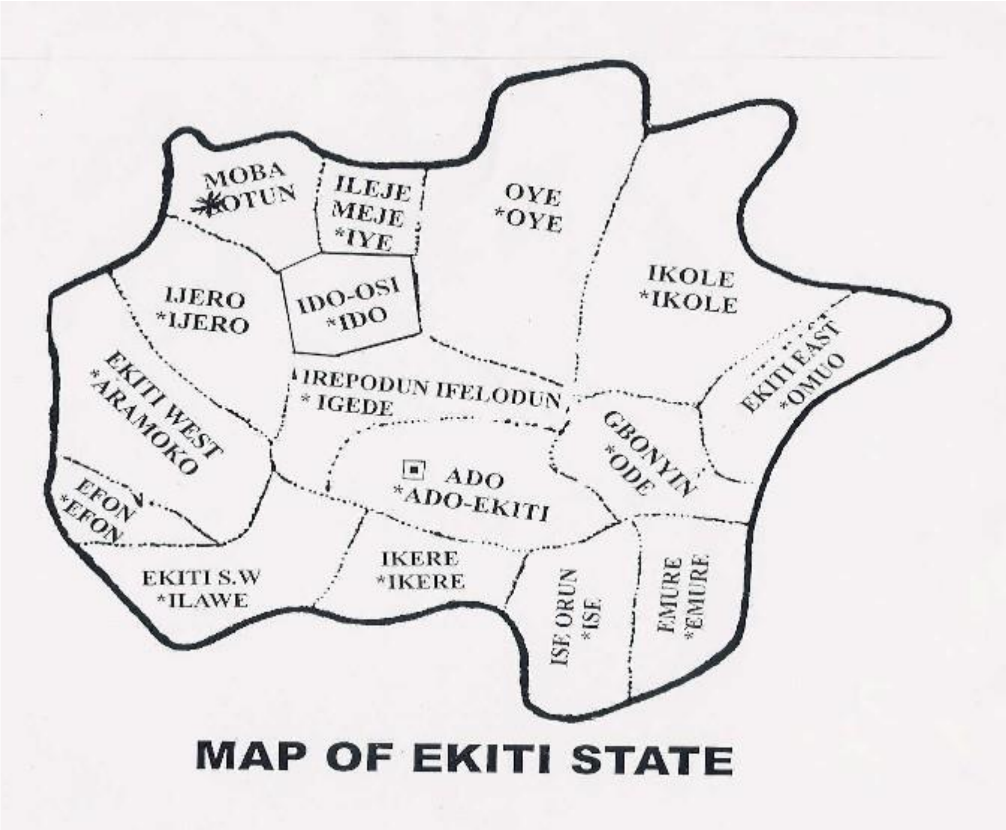

Fig.1. Map of Ekiti-State (www.earth google /map gallery)

Table 1. Parameters of the N.T.A. Channel 5 Ado-Ekiti Broadcasting Station

Parameters	Value
Frequency of Operation	Very High Frequency
Frequency Bandwidth	175.25MHz
Transmitting Power	5 KW
Effective Isotropically Radiated Power	3.5KW
Antenna Directivity	Omni-directional
Antenna Polarization	Vertical
Antenna gain	12dB
Maximum height of the transmitting antenna	167.5m

4. Materials and Method

The Measurements of the electric field strength were taken at selected points along three routes in Ekiti-State using a Digital signal strength meter, BC1173, 75 ohms input, A/c $100V_{r.m.s}$ max, DC 9V from DBC Technologies. Measurements were carried out in all the towns and villages in the three routes. The measured field strength values, the location coordinate of each point of measurements, the elevation above sea level and the line of sight distance from the base station were recorded for analysis.

5. Results and Discussion

Tables 2, 3 and 4 show the measurements of signal propagation of NTA along the three routes considered. The tables show the distances from the base stations along the path of measurements, the elevations above sea levels at the point of measurements, the measured signal strength at each point of measurement and the path loss along the routes.

Fig.2, Fig.4, and Fig.6 show the elevations and the propagation path losses along Route A, B and C respectively. It is observed that there is a slight correlation along the routes between the path losses and the elevations. Locations with higher elevations appear to have reduced path losses as compared with locations with lower elevations. Fig.3, Fig.5 and Fig.7 show the propagation path losses along routes A,B and C respectively.

It is observed from the three plots that the path losses along the routes increase with distances from the base stations. This is in accordance with the inverse square law for signal propagation. The plots of the propagation path losses are however observed to be pronouncedly uneven due to irregular elevations of the surfaces of the grounds, the presence of hills, vegetations and atmospheric factors such as refraction, absorption along the routes of measurements.

Table 2. Signal Propagation Data for Route A

S/N	Distance (km)	Elevation (m)	Field Strength (dB µV)	Path loss (dB)	Location	Town
1.	0.00	516.00	79.200	0.000	Base Station	Ado-Ekiti
2.	17.00	409.10	37.980	41.220	EKSU Campus 1	Ado-Ekiti
3.	17.50	418.40	36.800	42.400	EKSU Campus 2	Ado-Ekiti
4.	19.00	432.12	32.720	46.480	Central Mosque	Iworoko-Ekiti
5.	32.40	551.42	32.560	46.640	Ayegbaju-Ekiti	Ayegbaju-Ekiti
6.	34.10	564.12	38.440	40.760	UBA	Oye-Ekiti 1
7.	37.80	531.52	37.900	41.300	Oye-Ekiti	Oye-Ekiti 2
8.	51.60	525.05	33.800	45.480	FGC	Ikole-Ekiti
9.	54.20	523.00	24.860	54.340	St. Patrick catholic church	Oke-Ayedun
10.	57.10	524.16	23.740	55.460	Methodist Church	Odo-Ayedun
11.	77.10	546.00	32.020	47.180	Omuo Comm Gram	Omuo-Ekiti

Table 3. Signal Propagation Data for Route B

S/N	Distance (km)	Elevation (m)	Field Strength (dB µV)	Pathloss (dB)	Location	Town
1.	0.00	516.00	79.200	0.000	Base station	Ado-Ekiti
2.	17.00	409.10	37.980	41.220	EKSU Campus 1	Ado-Ekiti
3.	17.50	418.40	36.800	42.400	EKSU Campus 2	Ado-Ekiti
4.	19.00	432.12	32.720	46.480	Central Mosque	Iworoko-Ekiti
5.	37.80	531.52	37.900	41.300	Oye-Ekiti 2	Oye-Ekiti 2
6.	48.00	589.30	25.540	53.660	Itaji Community	Itaji-Ekiti
7.	52.00	603.40	26.280	52.920	Skye Bank	Ayede-Ekiti
8.	57.50	574.50	21.06	57.140	Central Mosque	Isan-Ekiti

Table 4. Signal Propagation Data for Route C

NO.	Elevation	Distance (km)	Field Strength (dB µV)	Path Loss (dB)	Town
1.	516.00	0	79.3	0.00	Ado Ekiti
2	409.12	17	37.60	41.7	Ado Ekiti
3.	418.42	17.5	37.30	42	Ado Ekiti
4.	432.12	19.0	32.6	46.7	Iworoko Ekiti
5.	574.42	25.7	30.7	48.6	Ifaki
6.	588.52	34.4	30.1	49.2	Ido Osi
7.	561.52	38.1	29.3	50	Ido Osi
8.	564.22	39.4	29.3	50	Ido Osi
9.	595.52	43.7	28.7	50.6	Usi Ekiti
10.	554.52	45.1	28.6	51.3	Usi Ekiti
11.	567.22	47.8	28.0	51.3	Ayetoro Ekiti
12.	602.62	52.1	27.6	51.7	Otun Ekiti
13.	602.62	53.0	27.3	52	Otun Ekiti

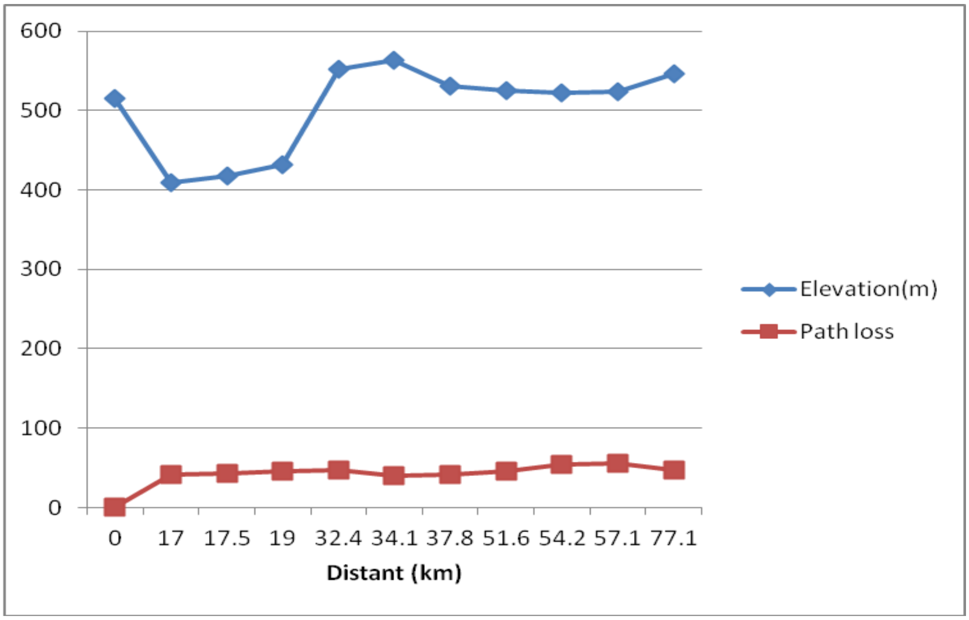

Fig.2. Elevation and propagation path loss for route A

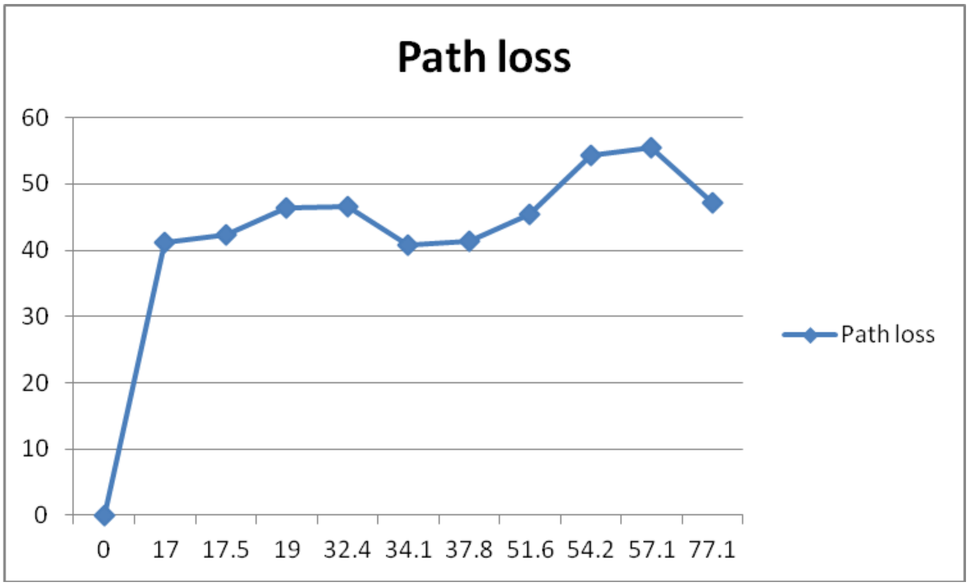

Fig.3. Measured propagation path loss for route A

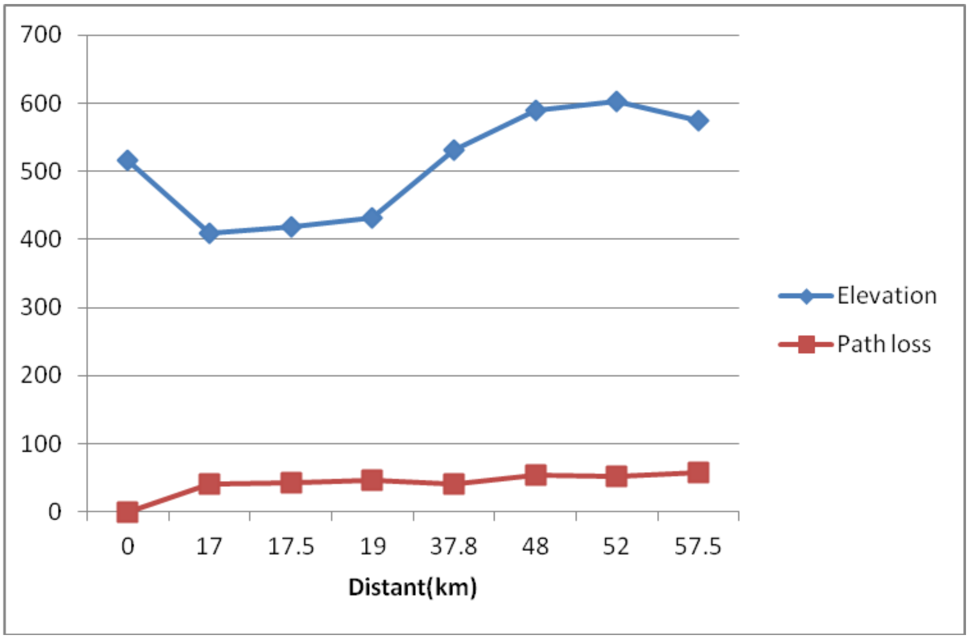

Fig.4. Elevation and propagation path loss for route B

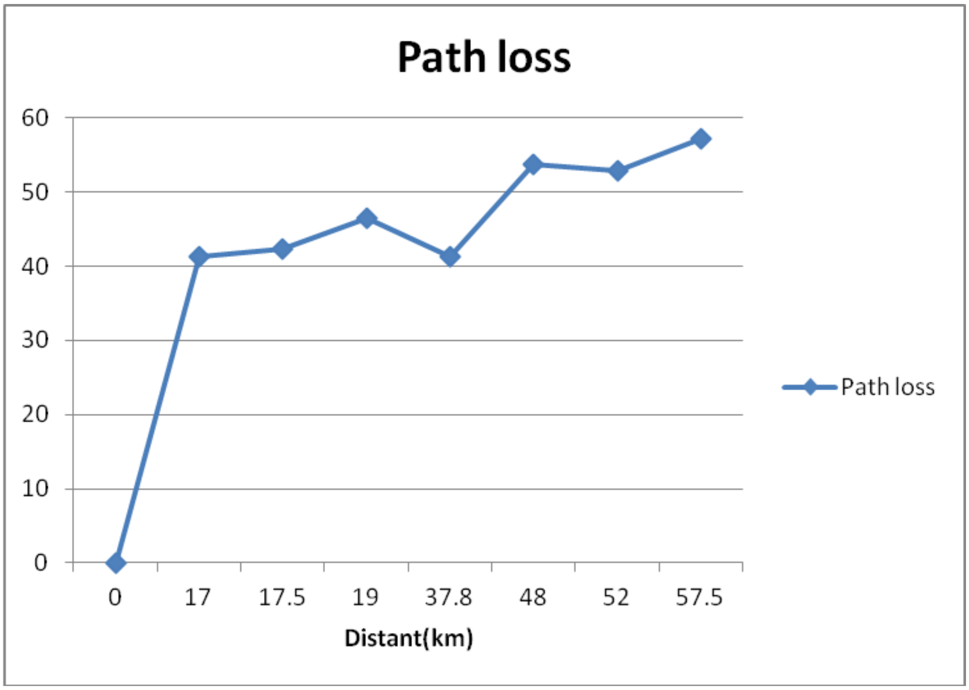

Fig.5. Measured propagation path loss for route B

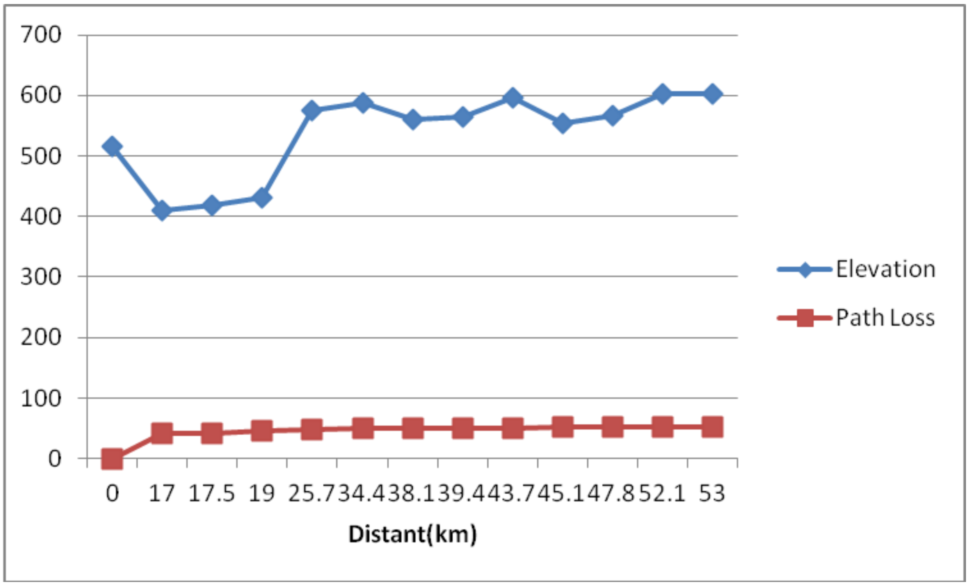

Fig.6. Elevation and propagation path loss for route C

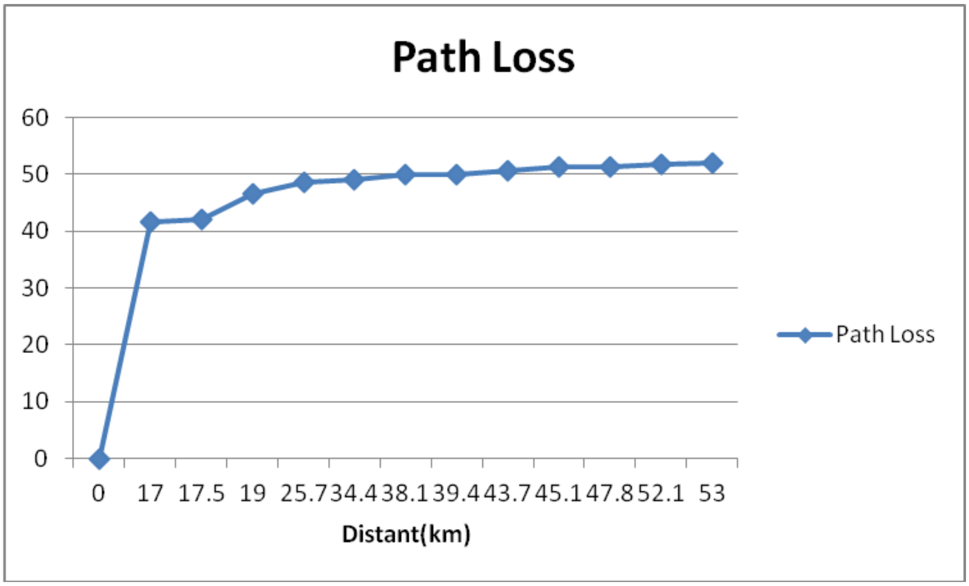

Fig.7. Measured propagation path loss for route C

Tables 5, 6 and 7 show the results of the calculated path losses using the existing models. While Fig. 8, 9 and 10 show the plots of the measured path losses along route A, B and C respectively against the existing empirical models. It can be observed from the plots that measured path losses are uneven as compared with those of the empirical models because of the presence of hills and mountains along the routes. In table 8, the least root mean square errors were computed for the three routes. It is observed from the table that the Hata (sub-urban) has the least root mean square errors for routes A, B and C while the free space model has the highest least mean square errors for the three routes as expected. It can therefore be concluded that the Hata (sub Urban) is the closest among path loss models considered to predict the signal path loss for the VHF signals in all the routes covered in this study.

In Fig. 8, a deviation of the measured path loss from the free space path loss of 6 dB is noticeable for route A except at Oke Ayedun and Odo Ayedun where the deviation is more that 6 dB. This could be attributed to a low elevation between these two towns, hence weak signal reception. In Route B, the deviation of the measured path loss from the free space path loss is greater than 6 dB at a distance greater than 48 km from the base station as revealed in Fig.9. At this distance the signal was very weak hence reception became very poor. While in route C, the deviation of the measured path loss from the free space path loss is greater than 6 dB at a distance of greater than 25 km from the base station as depicted in Fig.10. The distance at which the deviation exceeds 6 dB was shorter in comparison with other routes because of the elevation of this route being highly hilly; therefore, the signal strength along this route was generally poor.

Table 5. Result of the Path Loss obtained using Ericsson, Hata-Suburban, Hata-Open, Free Space, and CCIR Path Loss Prediction Model for Route A

S/N	Distant (Km)	Measured(dB)	Ericsson Model (dB)	Hata-Sururban Model (dB)	Hata-Open Model (dB)	Free Space Model (dB)	CCIR Model (dB)	Town
1.	0.00	0.000	0	0	0	0	0	Ado-Ekiti
2.	17.00	41.220	44.60401	44.40248	40.45927	40.16622	39.02251	Ado-Ekiti
3.	17.50	42.400	44.61432	44.43867	40.51618	40.18765	38.78299	Ado-Ekiti
4.	19.00	46.480	44.65544	44.51901	40.64204	40.24816	39.46451	Iworoko-Ekiti
5.	32.40	46.640	44.83947	45.18419	41.66022	40.63092	40.16058	Ayegbaju-Ekiti
6.	34.10	40.760	44.84652	45.26683	41.78391	40.66673	40.56538	Oye-Ekiti 1
7.	37.80	41.300	44.97655	45.21302	41.70344	40.73840	40.35264	Oye-Ekiti 2
8.	51.60	45.480	45.22038	45.41065	41.99782	40.98460	40.25935	Ikole-Ekiti
9.	54.20	54.340	45.25129	45.44641	42.05074	41.01964	40.72311	Oke-Ayedun
10.	57.10	55.460	45.18619	45.38675	41.96238	40.95143	40.77041	Odo-Ayedun
11.	77.10	47.180	45.40122	45.70471	42.42993	41.21881	41.06800	Omuo-Ekiti

Table 6. Result of the Path Loss obtained using Ericsson, Hata-Suburban, Hata-Open, Free Space, and CCIR Path Loss Prediction Model for Route B

S/N	Distant (Km)	Measured (dB)	Ericsson Model (dB)	Hata-Sururban Model (dB)	Hata-Open Model (dB)	Free Space Model (dB)	CCIR Model (dB)	Location
1.	0.00	0.000	0	0	0	0	0	Base Station
2.	17.00	41.220	44.60401	44.40248	40.45927	40.16622	39.02251	EKSU Campus 1
3.	17.50	42.400	44.61432	44.43867	40.51618	40.18765	38.78299	EKSU Campus 2
4.	19.00	46.480	44.65544	44.51901	40.64204	40.24815	39.46451	Central Mosque
5.	37.80	41.300	44.97655	45.21302	41.70344	40.73840	40.35264	Oye-Ekiti 2
6.	48.00	53.660	45.00726	45.60142	42.27893	40.90238	40.53898	Itaji Community
7.	52.30	52.920	45.02069	45.73516	42.47429	40.96053	40.77707	Skye Bank
8.	57.50	57.140	45.16061	45.64102	42.33691	41.02432	40.80375	Central Mosque

Table 7. Results of the Path Loss obtained using Ericsson, Hata-Suburban, Hata-Open, Free Space Path Loss Prediction Model for Route C

S/N	Distance(km)	Measured	Free space	Ericsson	Hata(suburban)	Hata(open)
1	17.00	41.22	40.17	44.740	44.40248	40.45927
2	17.5	42.40	40.19	44.747	44.43867	40.51618
3	19.00	46.48	40.25	44.788	44.51901	40.64204
4	25.70	48.50	40.47	44.767	45.12642	41.5734
5	34.40	49.10	40.67	44.723	45.38401	41.95832
6	38.10	49.90	40.74	44.856	45.32731	41.84707
7	39.40	49.90	40.78	44.887	45.35975	41.92231
8	43.70	50.50	40.84	44.861	45.43812	42.23804
9	45.10	50.60	40.86	44.980	45.59532	41.99161
10	47.80	51.20	40.9	44.990	45.44296	42.12199
11	52.10	51.60	40.95	45.086	45.47241	42.08914
12	53.00	51.90	40.97	44.964	45.73882	42.47962

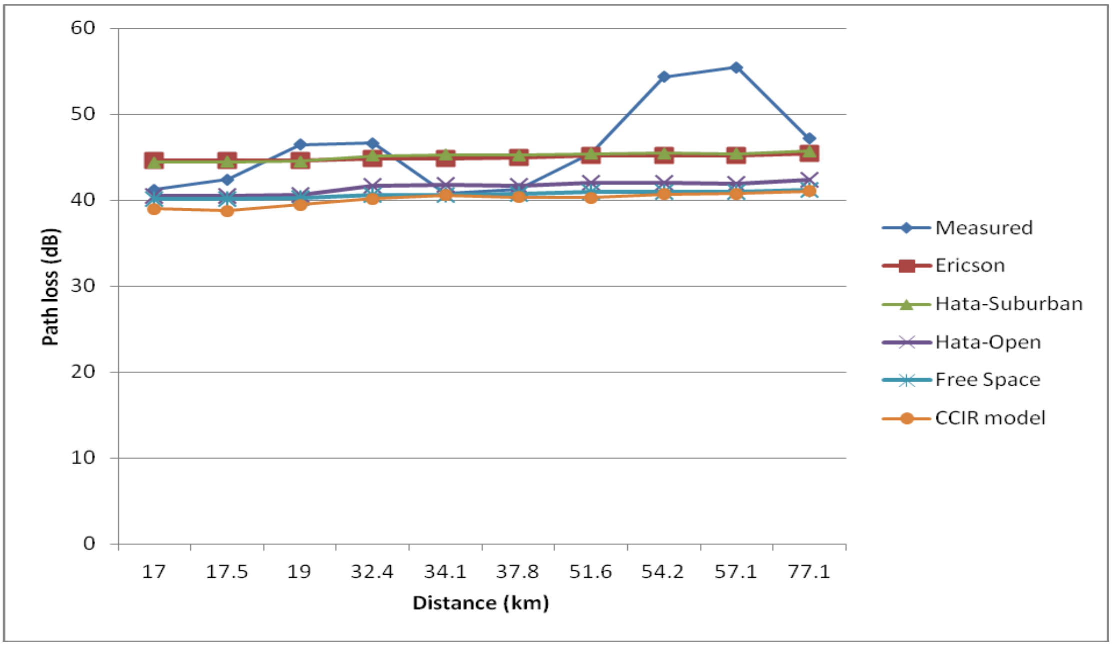

Fig.8. Comparison f Empirical and Measured Path loss for Route A

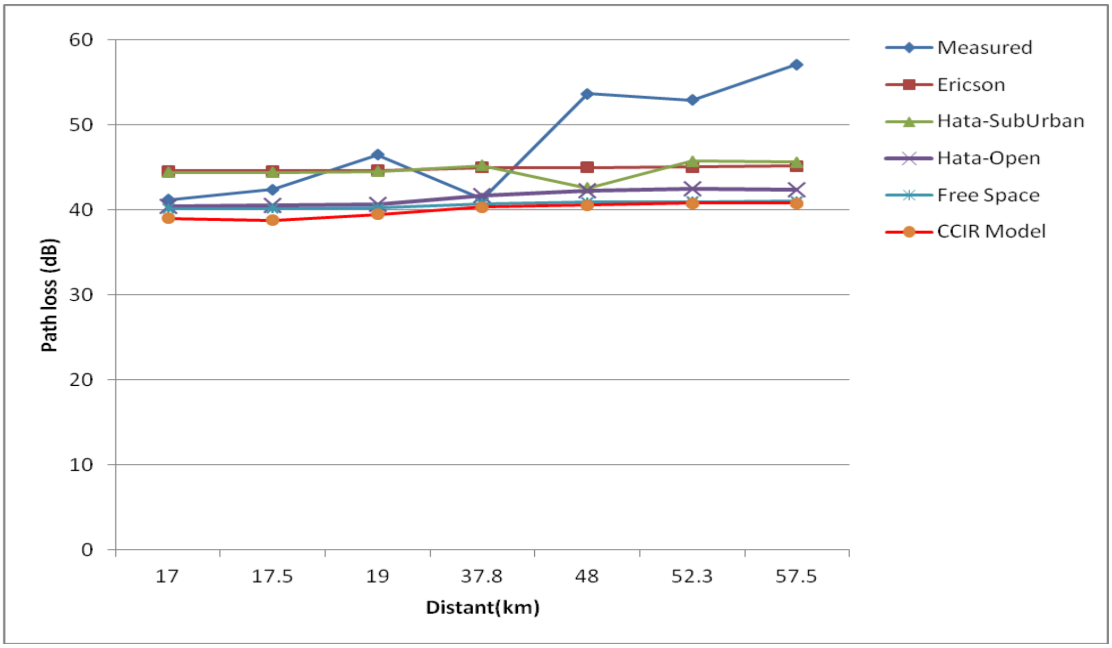

Fig.9. Comparison f Empirical and Measured Path loss for Route B

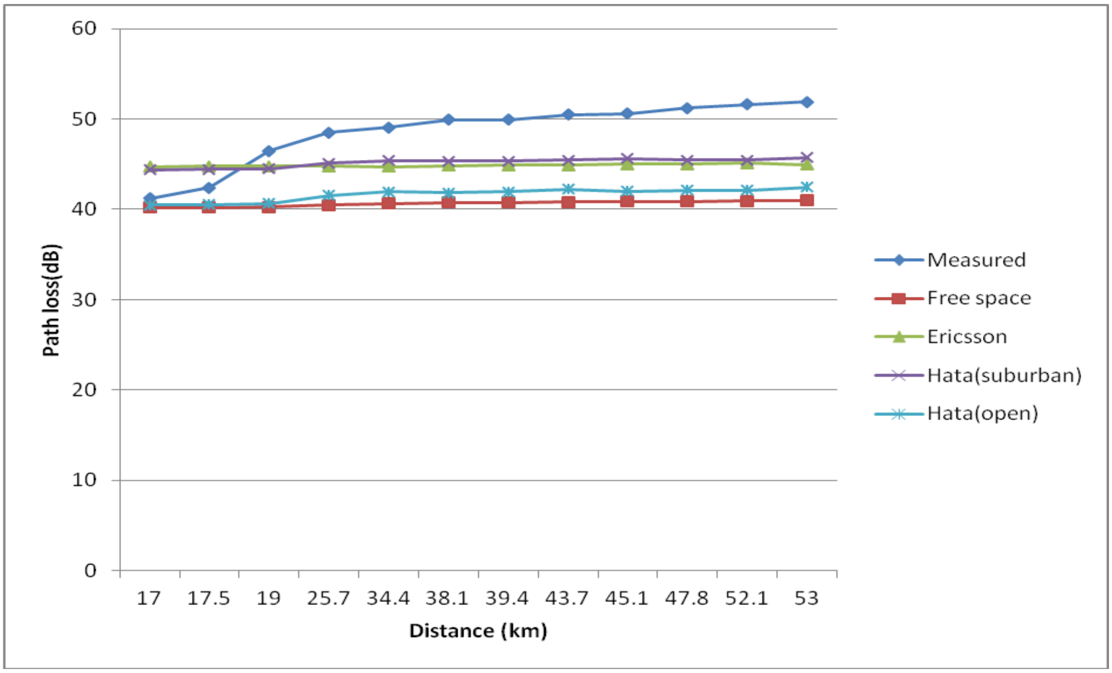

Fig.10. Comparison f Empirical and Measured Path loss for Route C

Table 8 shows the root mean square errors (RMSE) of the path loss models for the three routes considered. For route A, the RMSE is too large for all the models. The results indicate that none of the models can be uses to predict the path loss in the route. The Hata model is howver observed to have the least RSME. The large value of the RMSE can be attributed to the terrain of the route. The route is highly hilly with lot of valley along the path of measurement. For route B, it can be observed from the table that Hata model have the least RMSE with a value that is less than 6dB. This implies that the Hata(Sub-Urban Model) can be used to predict the path loss alonge this route. For route C, the Hata(Sub-Urban Model) is also observed to have the least RMSE. It is also observed from the table that the Ericson model also have a RMSE of less than 6dB. This implies that both the Ericson and the Hata(Sub-Urban Model) can be used to predict the path loss along this route but with the HATA model giving a better result.

Table 8. Root Mean Square Errors of the Path Loss Models

S/N	Routes	Ericsson Model	Hata(Sub-Urban Model)	Hata(Open- Model)	Free Space Model	CCIR model
1.	A	35.29061	34.95069	42.14418	42.96479	40.13408
2.	B	6.296998	5.961859	8.991424	9.330689	8.069566
3	C	4.97000	4.51000	7.47000	8.56000	7.01

6. Conclusions

This work focuses on the analysis of VHF propagation path loss for Ekiti State, Nigeria. The field strengths of NTA broadcasting station, Ado Ekiti were measured in some selected locations along three routes in the state. Results show that the propagation signal of the station was generally poor along the routes considered. The deviation of the measured path loss with the free space path loss exceeded 6 dB in most cases. It is therefore needful for the broadcasting station to increase their transmitting power or build a repeater stations along the routes considered if they are to serve the communities effectively. Some prediction models was also used to predict the path loss in these selected locations .The Hata (sub-urban) path loss prediction models have the lowest Root Mean Square Errors for the three routes considered and may be used to predict the signal propagation path loss for the state at this frequency.

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How to cite this paper: I. B. Oluwafemi, O. J. Femi-Jemilohun,"Propagation Profile and Signal Strength Variation of VHF Signal in Ekiti State Nigeria", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.7, No.3, pp.9-24, 2017.DOI: 10.5815/ijwmt.2017.03.02