A Simple Field Strength Model for Broadcast Application in VHF Band in Minna City, Niger State, Nigeria

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Abstract — It is important to understand the impact of physical surroundings on a propagating signal because the propagation characteristics of any radio channel are severely affected by objects that surround the transmitters and the receivers. So, the propagation characteristics limit the performance of in-building high capacity wireless communications. This research work adapted some field strength models that are best suitable for Minna city in Niger State, Nigeria. This is done by optimising some existing field strength models which are: Free space, Hata, ITU-R P.529-3 and ERC Report 68 models to suit Minna city using a VHF television signal of Nigeria Television Authority (NTA), Minna. This station transmits at a frequency of 210.25 MHz for video signal. The signal levels of the transmitted signal were taken along five radial routes from the transmitting station using a digital signal level meter and the corresponding distances were also measured using Global Positioning System (GPS). Data processing and computation were carried out using MATLAB. The results obtained show that the Hata model gives a more accurate prediction for field strength in Minna city after general modification with the correction factor of 3.08 and Root Mean Square Error of 6.35 dBμV/m.

Keywords — Field strength, propagation model, VHF, attenuation, prediction

I INTRODUCTION

For installation of terrestrial broadcast systems, propagation models are very important to determine the behaviours of the propagating signal. So, during preliminary deployment of a wireless network planning, a propagation models is required. Furthermore, it describes the signal attenuation from the transmitter to the receiver antenna as a function of distance, antenna heights, carrier frequency and some other parameters like terrain profile [1].

More also, electric field strength curves or Propagation curves are essential parameters necessary for the planning of VHF and UHF transmission especially for the determination of the coverage areas and the field strength signal levels desired. The present trend in broadcasting is to use widespread broadcast transmitter of VHF or UHF range of frequencies to serve areas not far away from the transmitter [2].

Since 1978 the VHF/UHF propagation curves which have been used for international planning are those published by the International Telecommunication Union - Radiocommunication (ITU-R) [3]. This Recommendation gives some curves for predicting field strength for 150, 450 and 900 MHz and it also gives analytical expressions that are valid for some frequency ranges and conditions. However, ITU curves suffer inevitably from the fact that they are statistical, so they cannot take full account of the distinctive features of each propagation path. Therefore ITU-R encourages scientists to embark on research to provide propagation data on their countries and localities [4]

Propagation models can be divided into three types of models, namely: empirical, deterministic and semi-deterministic models [5]. In this work, empirical propagation model for field strength will be considered and field strength curves will be generated for Minna city using television VHF 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.

II FIELD STRENGTH MODELS

Attenuation of radio signal might be due to effects such as free space loss, reflection, refraction, diffraction, and absorption between a transmitter and a receiver [5]. There are various empirical field strength models for broadcasting services but attention will be given to free space model, Hata model, ITU-R P.529-3 and ERC Report 68 models.

A. *Free Space Model*

The simplest case of radio propagation is the transmission of wave between a transmitter and a receiver in free space. A transmitter with power, P_T, in free space which radiates isotropically in all directions gives a power flux density, S, at a distance d of [6]

$$S = \frac{P_T}{4\pi d^2} \quad (1)$$

Using logarithmic ratio,

$$S = P_T - 20\log d - 41 \quad (2)$$

where:
S is the power flux density in decibels relative to 1 W.m^{-2}
P_T is the power in decibels relative to 1 kW and
d is the distance in km

The corresponding field strength, E is given by:

$$E = \sqrt{S.120\pi} \quad (3)$$

$$= \frac{\sqrt{30P_T}}{d} \quad (4)$$

or $E\,(mV/m) = \frac{173\sqrt{P_T\,(kW)}}{d\,(km)}$ (5)

$$E = P_T - 20\log d + 104.8 \text{ in dB}(1\mu V/m) \quad (6)$$

This relationship applies when the power radiates isotropically.

B. Hata Model

The original Hata equation is given in terms of a path loss in dB. This equation can be converted to give the field strength with respect to a 1 kW Effective Radiated Power (ERP) transmitter [7]:

$$E = 69.82 - 6.16\log f + 13.82\log h_b + a(h_m) - (44.9 - 6.66\log(h_b)) \times \log d \; (dB\mu V/m) \quad (7)$$

where:
E: field strength at a distance from a 1 kW ERP transmitter in dBµV/m
f: frequency of the transmission in MHz
h_b: height of the base station or transmitter in metres
h_m: height of the mobile or receiver in metres
d: distance between the receiver and transmitter in kilometres

C. ITU-R P.529-3

ITU-R gives modified Hata equations which correspond approximately to some of its propagation curves. This equation does equate to the original Hata equation for distances less than 20km. The equation is [3]:

$$E = 69.82 - 6.16\log f + 13.82\log h_1 + a(h_2) - (44.9 - 6.55\log h_1)(\log R)^b \quad (8)$$

where:
E: Field Strength for 1 kW ERP
f: frequency (MHz)
h_1: base station effective antenna height in the range 30 – 200 m
h_2: mobile station antenna height in the range 1 – 10 m
R: distance (km)

$$a(h_2) = (1.1\log f - 0.7)h_2 - (1.56\log f - 0.8) \quad (9)$$

$b = 1$ for $R \leq 20\ km$ (10)

$b = 1 + (0.14 + 1.87 \times 10^{-4} f + 1.07 \times 10^{-3} h_1)\left(\log \frac{R}{20}\right)^{0.8}$ for $20\ km < R < 100\ km$ (11)

where:

$$\acute{h}_1 = \frac{h_1}{\sqrt{1+7\times10^{-6}{h_1}^2}} \quad (12)$$

This model is suitable for use over the ranges:
Frequency range, 150 − 1500 MHz
Base station height, 30 − 200 m
Mobile height, 1 − 10 m
Distance range, 1 − 100 km

D. *ERC REPORT 68*

There are many equations for different frequency ranges in this model but the equation given here covers the same frequency range as the original Hata equation. The equation is [7]:

$$E = 69.75 - 6.16\log(f) + 13.82\log(h_b) + \alpha \times (44.9 - 6.55\log(h_b)) \times (\log(d)) + a(h_m) + b(h_b) \quad (13)$$

where

$$\alpha = 1 \text{ if } d <= 20\ km \quad (14)$$

$$\alpha = 1 + (0.14 + 1.87\times10^{-4}\times f + 1.07\times10^{-3}\times h_m)\times(\log(d/20))^{0.8} \text{ if } d > 20\ km \quad (15)$$

$$a(h_m) = (1.1\log(f) - 0.7)\times minimum(10, h_m) - (1.56\log(f) - 0.8) + maximum(0, 20\log(h_m/20)) \quad (16)$$

$$b(h_b) = minimum(0, 20\log(h_b/30)) \quad (17)$$

This model is suitable for use over the ranges:
Frequency range 150 - 1500 MHz
Base station height 1 - 200 m
Mobile height 1 - 200 m
Distance range 1 - 100 km

III STUDY AREA

Minna is a capital city of Niger State in North Central Nigeria (Fig. 1) with estimated population of 304,113 in 2007 [8]. Granite hills walled the city to the east and to the north and also the west and the southern parts of the town extend on a lowly plain down the Niger river valley. Minna weather is moderate, having 24^{o}C lows and 30^{o}C highs in the dry season, around the month of April. Furthermore, it has woody area close to river valleys and tall grassland vegetation [9].

Fig. 1 Location of Minna (9.6139^{o}N, 6.5569^{o}E) in Nigeria [10]

IV DATA COLLECTION AND ANALYSIS

This work was done in Minna, Niger State, Nigeria, using the local VHF television station signal, NTA Minna, Channel 10. The television station transmits signals at frequency of 210.25 MHz for video signal.

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 4, Volume 2 (April 2015) www.ijirae.com

The output power of the transmitter during the period of this work was 7.5 kW and the transmitting antenna is mounted on a mast of height 150 m. The transmitted video signal levels were measured along five radial routes from the transmitting station and the routes are designated Route A, B, C, D and E as shown in Fig. 2. A dipole antenna of 0 dB gain and height 1.5 m above ground surface was connected to a Digital Signal Level Meter - GE-5499, to measure the signal level of the transmitted signal from the station along these routes. The corresponding distances away from the base of the transmitting antenna were also measured using Global Positioning System (GPS 72 – Personal Navigator).

Data processing and computation were carried out using MATLAB software application. From the measured signal levels, the field strength values in dBµV/m are calculated for a 1 kW Effective Radiated Power (ERP) transmitter to aid comparison with other models. The field strength for each route was obtained and the corresponding field strength as predicted by free space, Hata, ITU-R P.529-3 and ERC Report 68 were also estimated. For each model, the Root Mean Square Error (RMSE) was determined along all the routes. Also, the Mean Prediction Error (MPE) was determined and used as a correction factor to modify each model to get the least RMSE. As a result of different routes considered, there are a number of correction factors for each model for the city. So, to generalise each model for all the routes in Minna, the average values of the MPE of the five radial routes were estimated and used as the correction factors to generalise the field strength models.

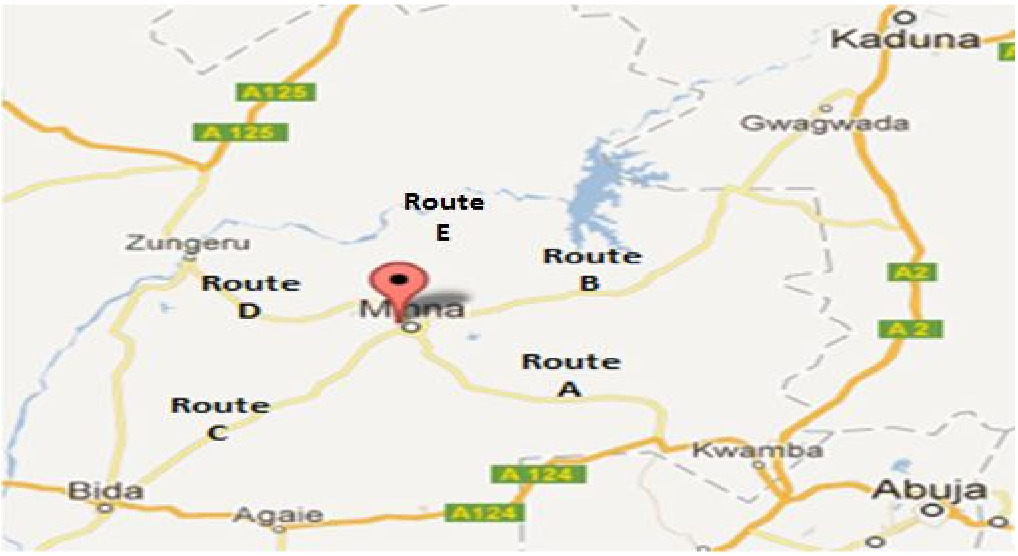

Fig. 2 Satellite map of Minna showing the routes along which measurements were taken [11].

V RESULTS

A. Field Strength Models

The comparison of the field strength models with the measured field strength for all the routes are shown in Fig. 3 to Fig. 7. The models follow the same trend for all the routes. The ERC Report 68 model has the lowest field strength prediction while free space model has the highest field strength prediction. The RMSE of the field strength models for each route is shown in Table I.

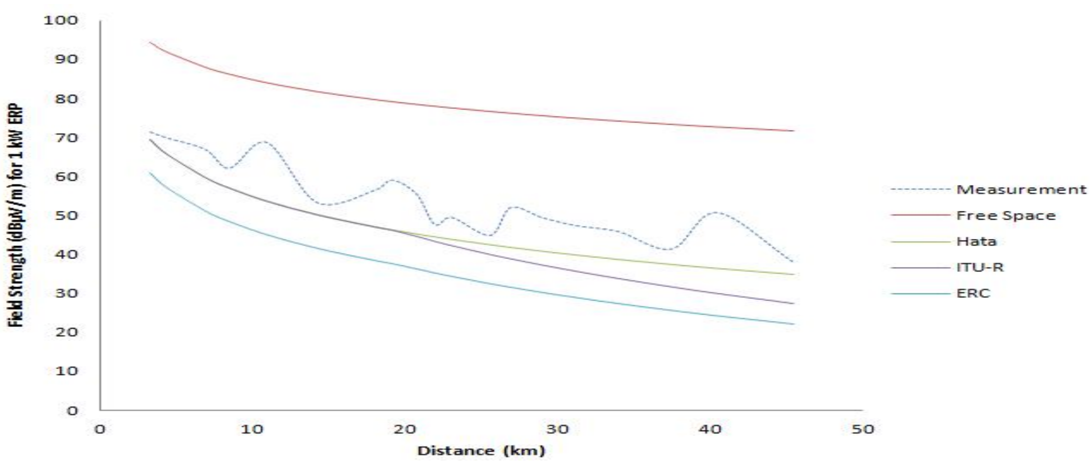

Fig. 3 Field strength models for route A

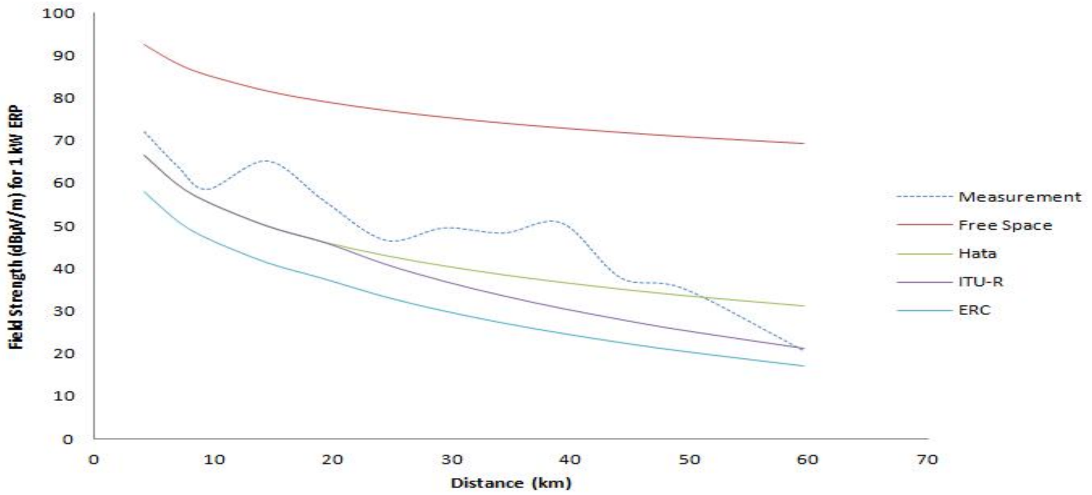

Fig. 4 Field strength models for route B

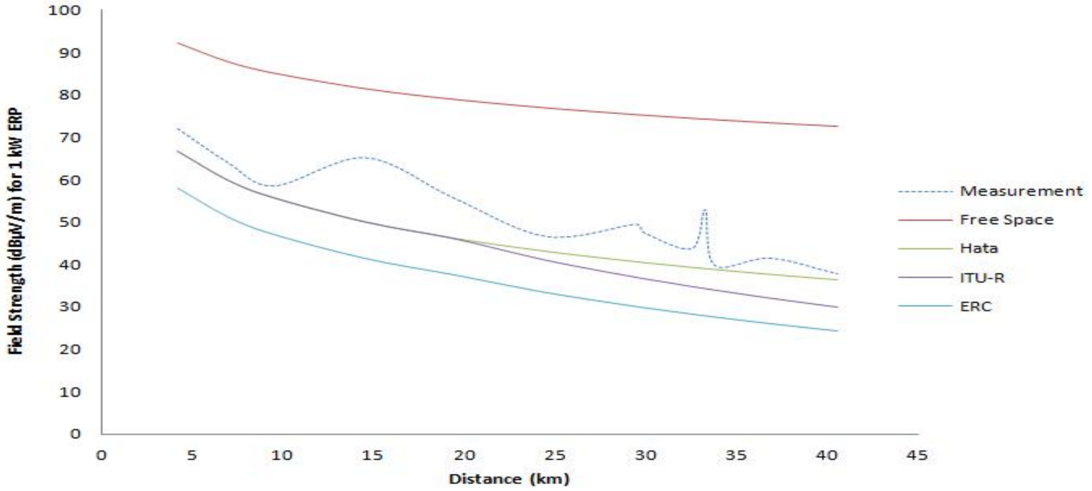

Fig. 5 Field strength models for route C

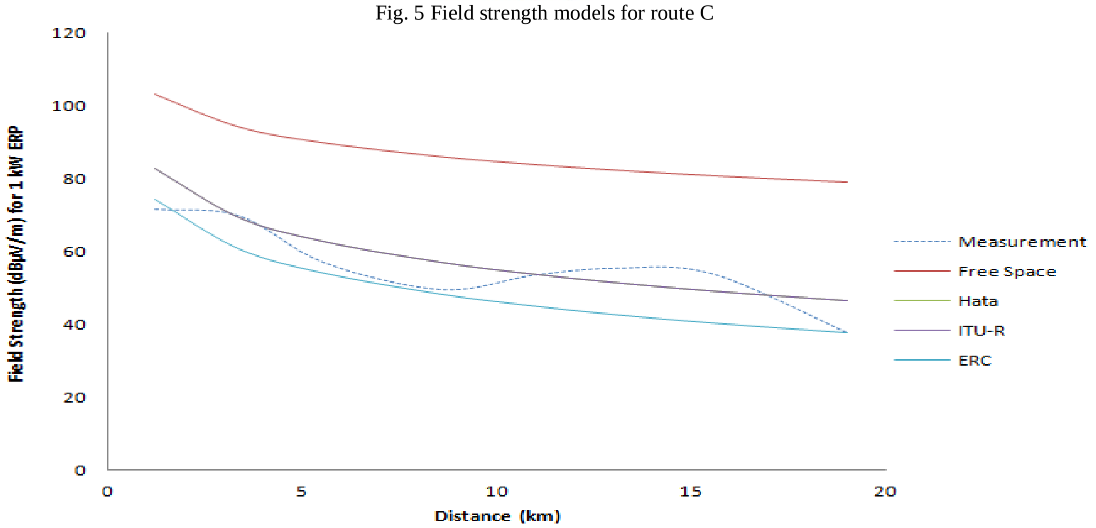

Fig. 6 Field strength models for route D

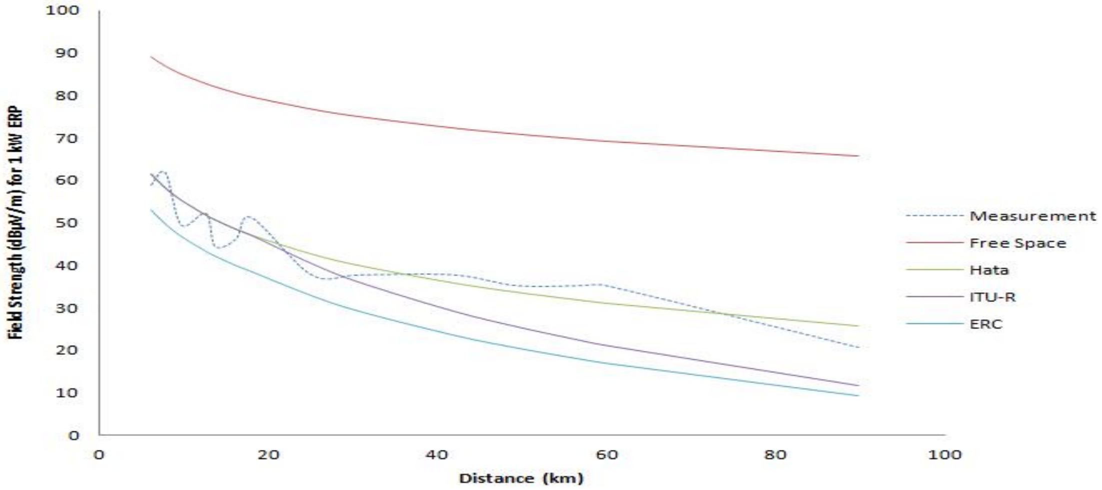

Fig. 7 Field strength models for route E

TABLE I: Root Mean Square Error of the Field Strength Models

	Free Space (dBµV/m)	**Hata** (dBµV/m)	**ITU-R** (dBµV/m)	**ERC** (dBµV/m)
Route A	17.39	8.17	10.30	17.39
Route B	28.93	8.61	10.70	17.15
Route C	27.29	7.68	9.98	16.92
Route D	31.87	6.44	6.44	7.96
Route E	34.73	3.85	7.24	11.16

B. Modified Field Strength Models

Table II shows the correction factors used for the modified field strength and Fig. 8 to Fig. 12 show the modified field strength models for all the routes. Also, the RMSE of all the field strength models for each route is shown in Table III.

TABLE II: Correction Factors used for the Modified and the Generalised Field Strength Models

	Free Space	**Hata**	**ITU-R**	**ERC**
Route A	-25.45	7.14	9.23	16.88
Route B	-27.75	5.66	9.11	16.15
Route C	-26.75	6.35	9.01	16.40
Route D	-31.44	-3.02	-3.02	5.57
Route E	-34.41	-0.72	3.14	10.00
AVERAGE	-29.16	3.08	5.49	13.00

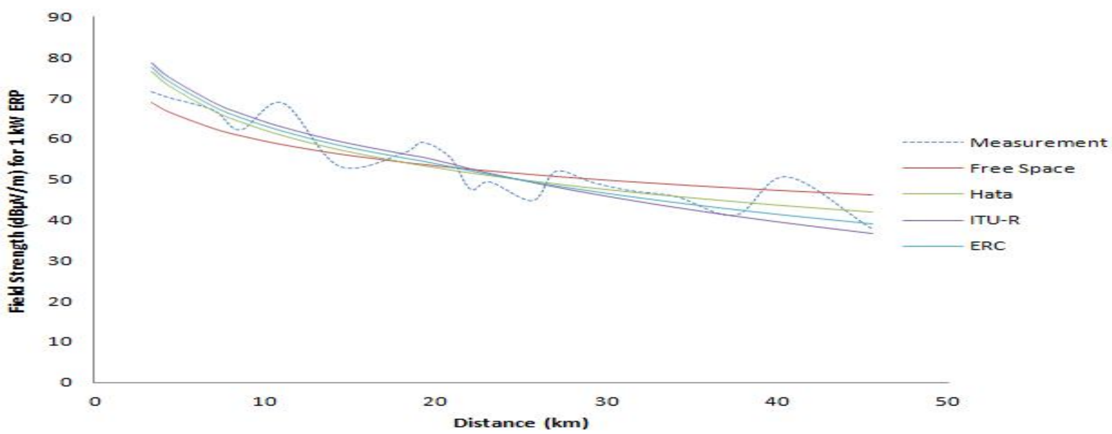

Fig. 8 Modified field strength models for route A

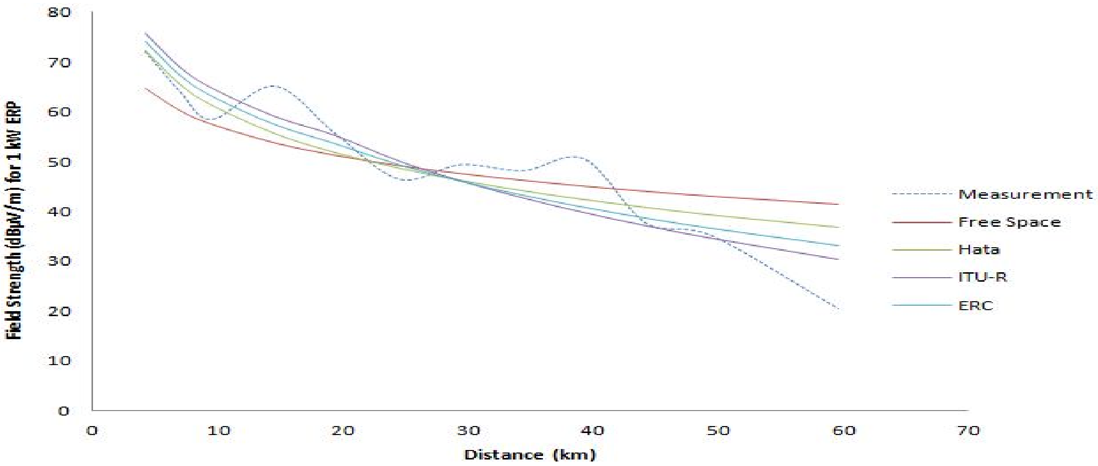

Fig. 9 Modified field strength models for route B

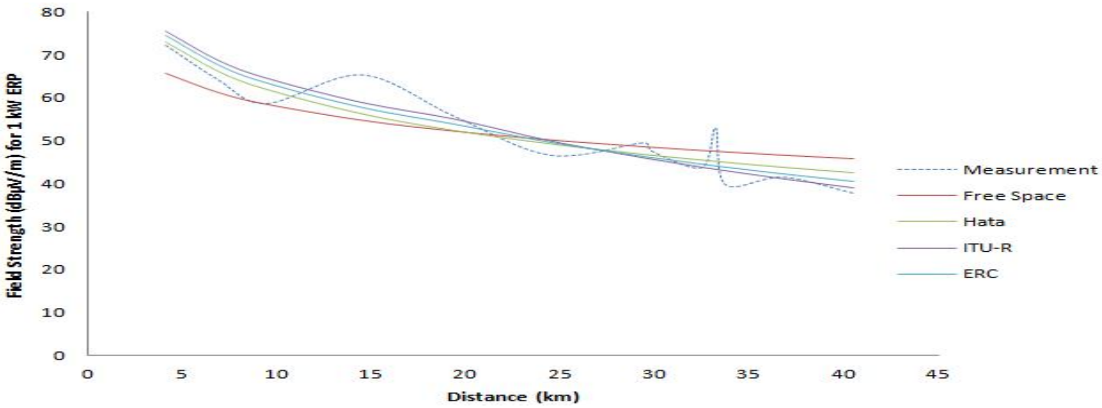

Fig. 10 Modified field strength models for route C

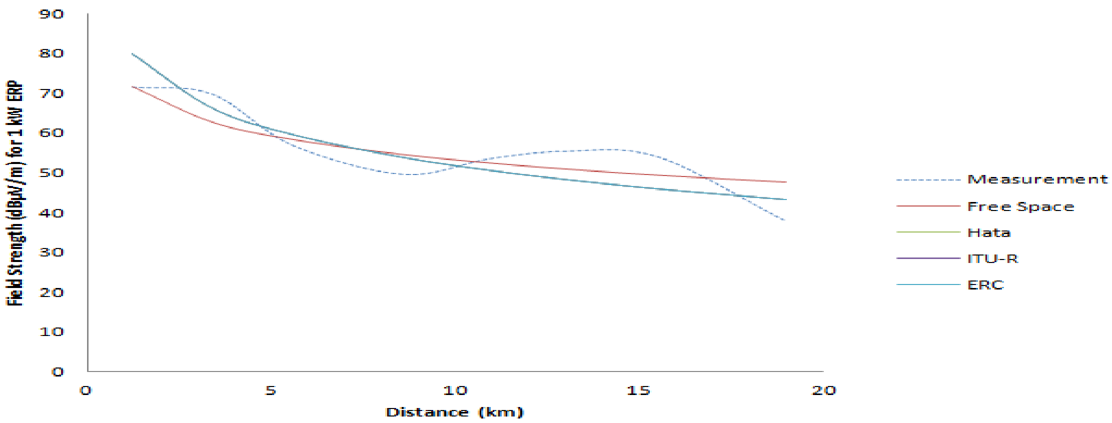

Fig. 11 Modified field strength models for route D

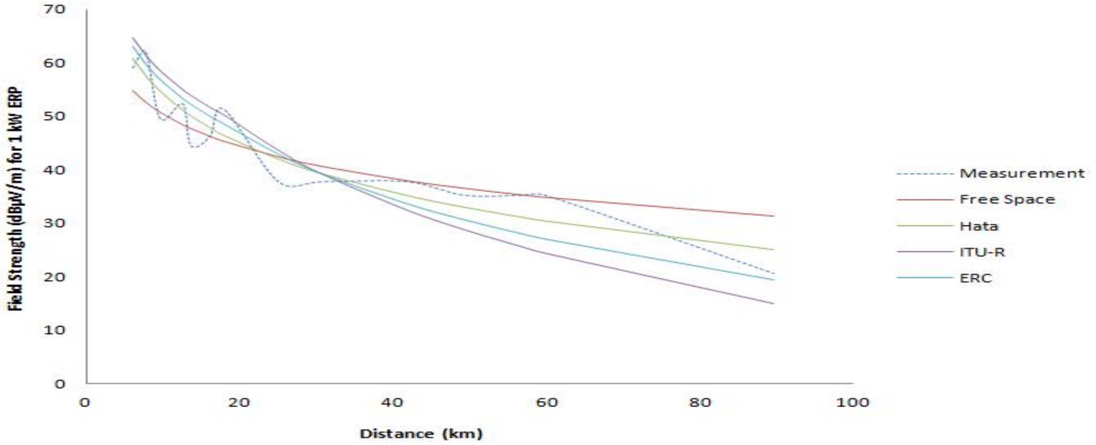

Fig. 12 Modified field strength models for route E

TABLE III: Root Mean Square Error Values of the Modified Field Strength Models

	Free Space (dBµV/m)	**Hata** (dBµV/m)	**ITU-R** (dBµV/m)	**ERC** (dBµV/m)
Route A	4.64	3.96	4.60	4.16
Route B	8.20	6.50	5.64	5.79
Route C	5.43	4.31	4.31	4.16
Route D	5.19	5.69	5.69	5.69
Route E	4.73	3.78	6.52	4.95

C. Generalised Field Strength Models

The generalised field strength model for Minna city is shown in Fig. 13 to Fig. 17. The average values of the MFE of all the routes are used as the correction factors. The RMSE values of the field strength models for each route are shown in Table IV. The average values of the RMSE of the generalized field strength models for all the routes are taken as the RMSE values for Minna city.

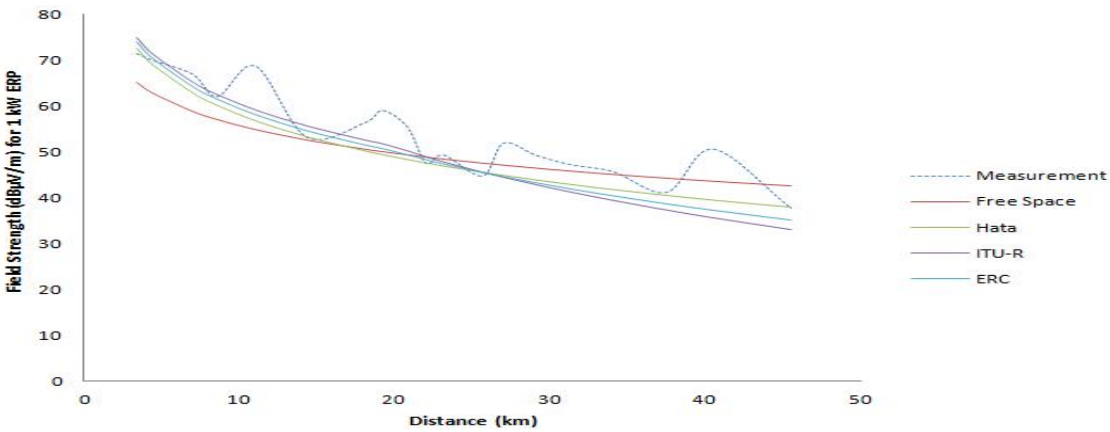

Fig. 13 Generalized field strength models for route A

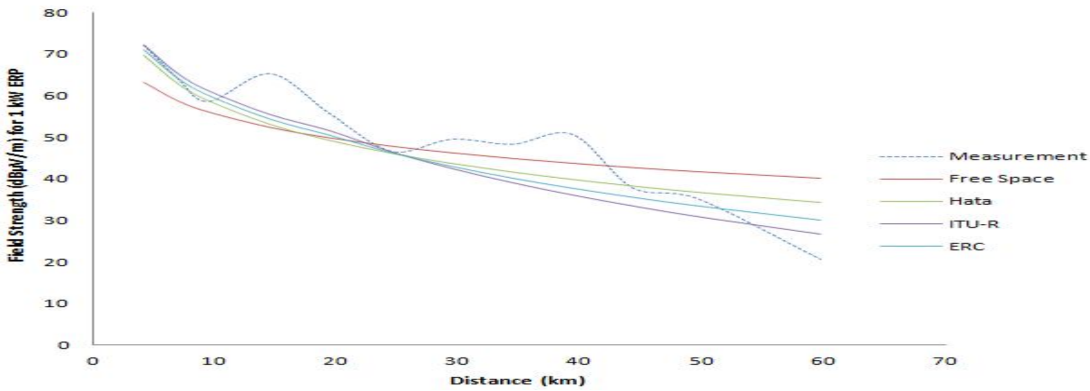

Fig. 14 Generalized field strength models for route B

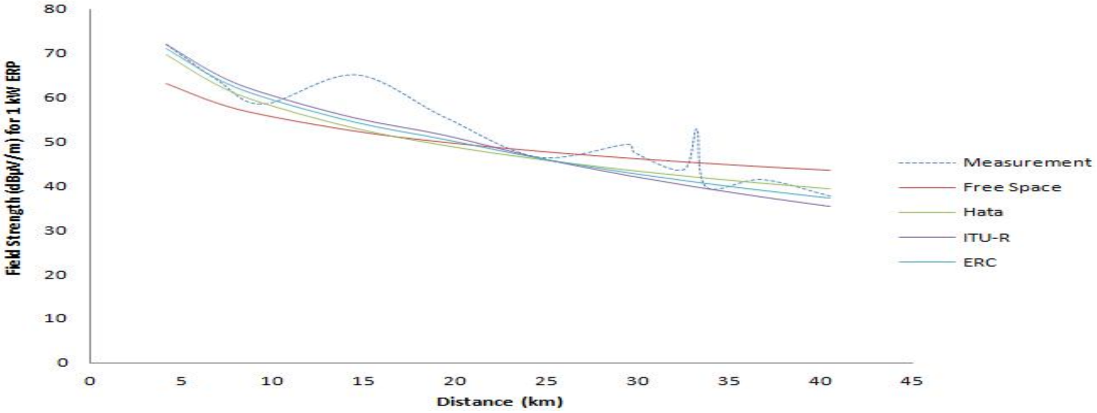

Fig. 15 Generalized field strength models for route C

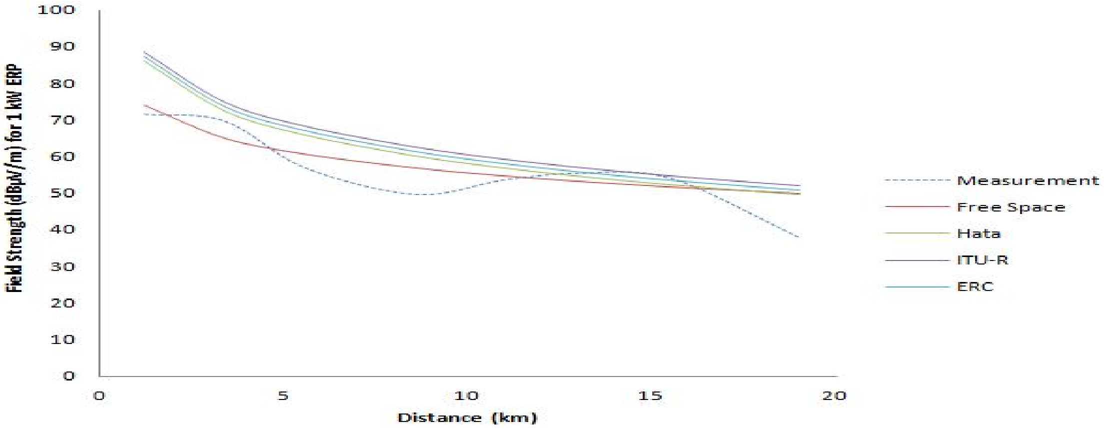

Fig. 16 Generalized field strength models for route D

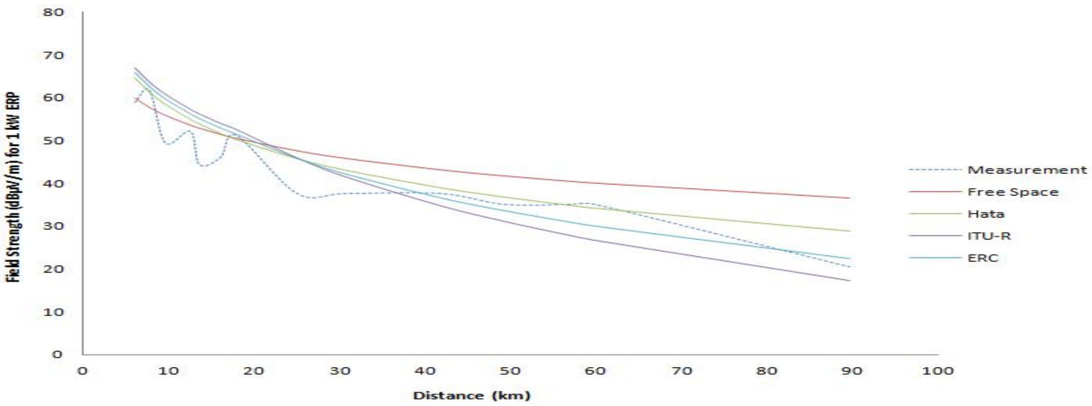

Fig. 17 Generalized field strength models for route E

TABLE IV Root Mean Square Error Values of the Generalised Field Strength Models

	Free Space (dBµV/m)	**Hata** (dBµV/m)	**ITU-R** (dBµV/m)	**ERC** (dBµV/m)
Route A	5.94	5.67	5.93	5.69
Route B	8.32	6.99	6.70	6.59
Route C	5.94	5.41	5.56	5.37
Route D	5.67	8.34	10.20	9.36
Route E	7.07	5.36	6.93	5.79
AVERAGE	6.59	6.35	7.07	6.56

VI SUMMARY AND CONCLUSIONS

Field strength models with least RMSE values for Minna city are obtained by using the average of the MPE of the five routes considered as the correction factors for each model. The average values of the RMSE of the generalized field strength models for the five routes are taken as the RMSE values for Minna city. The correction factors used for all the field strength models consider are: -29.16 for Free space, 3.08 for Hata, 5.49 for ITU-R P.529-3 and 13.0 for ERC Report 68 models with average RMSE of 6.59 dBμV/m for Free space, 6.35 dBμV/m for Hata, 7.07 dBμV/m for ITU-R P.529-3 and 6.56 dBμV/m for ERC Report 68 models. Thus, the generalized Hata field strength model gives more accurate prediction for field strength in Minna city compared to other models considered.

REFERENCES

[1] K. Mandeep, and S. Deepak, "Review of path loss models in different environments," *International Journal of Innovative Research in Technology (IJIRT)*, 1(10): 181-185 (2014).

[2] M. O. Ajewole, O. D. Oyedum, A. S. Moses and J. O. Eiche, (2010), "Measurement of Electric Field Strength to Determine the Coverage Areas of VHF and UHF Television Signals in Niger State", *Proceeding of the Annual Conference of Nigeria Union of Radio Science*, pp. 113 -118 (2010).

[3] *Recommendation, ITU-R P.529-3*, "Prediction methods for the terrestrial land mobile service in the VHF and UHF bands," pp. 6-7 (1999).

[4] *Recommendation, ITU-R P.530-15 (09/2013)*, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems," pp. 2 (2013).

[5] R. Mardeni and K. F. Kwan, "Optimization of Hata propagation prediction model in suburban area in Malaysia," *Progress in Electromagnetics Research C*, Vol. 13, pp. 91-106 (2010).

[6] L.W. Barclay, "Basic radio system parameters", In Hall, M. (Ed); Radio Wave Propagation - (IEE Electromagnetic Wave Series). Peter Peregrinus Ltd, London, United Kingdom, Pp. 43-44 (1991).

[7] Spectrum Planning Report, "Investigation of Modified Hata Propagation Models," *Spectrum Planning Team, Radiofrequency Planning Group*, Document: SP 2/01, Australian Communications Authority, 2001.

[8] Minna. Available: http://en.wikipedia.org/wiki/Minna

[9] Minna Travel Guide. Available: http://www.world66.com/africa/nigeria/minna/

[10] Niger State. Available: http://en.wikipedia.org/wiki/Niger_State

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

