Empirical Field Strength Model for Terrestrial Broadcast in VHF Band in Makurdi City, Benue State, Nigeria

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Abstract - *The ability to predict the minimum power a transmitter must radiate to give an acceptable quality of coverage over a predetermined service area is very imperative. This work adapted some field strength models that are best suitable for Makurdi city in Benue State, Nigeria. Some existing field strength models are optimised to suit Makurdi city using a VHF television signal of Nigeria Television Authority (NTA), Makurdi. The models are free space, Hata, ITU-R P.529-3 and ERC Report 68 models. NTA, Makurdi transmits at a frequency of 210.25 MHz for video signal. Measurement of the video signal levels was done along four radial routes from the transmitting station. A digital signal level meter and Global Positioning System (GPS) was used to measure the signal level of the transmitted signal from the station along these routes and to measure the corresponding distances away from the base of the transmitting antenna respectively. The results obtained, after processing and computation of the data; show that the free space model gives more accurate prediction for field strength in Makurdi city, after general modification, with the correction factor of -29.85 and Root Mean Square Error of 4.12 dBμV/m.*

Key Words: Signal level, attenuation, field strength, VHF, propagation model

1. INTRODUCTION

In broadcast systems, it is very important to determine a system's propagation characteristic through a medium to make the signal parameters more accurate. Such system should be able to predict the accuracy of the radio propagation behaviour. A network that the behaviour is not accurately predicted will either lead to a too expensive network or a network of bad quality [1].

There are several empirical propagation models but none of these models can be generalised for all environments because 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 localities [2]

Propagation models can either be empirical, deterministic and semi-deterministic [3]. Empirical propagation model for field strength will be considered in this work using television VHF signal of Nigeria Television Authority (NTA), Makurdi channel 10 with transmitting frequency of 210.25 MHz for video signal and 215.25 for audio signal.

2. FIELD STRENGTH MODELS

Field strength models are radio signal propagation models which present the electric field strength as a function of the signal distance from the point of transmission. Among several field strength models, free space model, Hata model, ITU-R P.529-3 and ERC Report 68 models shall be considered because they are widely accepted.

2.1 Free Space Model

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.

If a transmitter in free space radiates isotropically in all direction with power, P_T, and gives a power flux density, S, at a distance d [4],

$$S = \frac{P_T}{4\pi d^2} \tag{1}$$

The equivalent field strength, E is given by:

$$E = \sqrt{S.120\pi} \tag{2}$$

$$= \frac{\sqrt{30 P_T}}{d} \tag{3}$$

or $E(mV/m) = \frac{173\sqrt{P_T(kW)}}{d(km)}$ (4)

$E = P_T - 20\log d + 104.8$ in dBμV/m (5)

2.2 Hata Model

Hata model was given in term of path loss but its corresponding field strength with respect to a 1 kW Effective Radiated Power (ERP) transmitter is given as [5]:

$E = 69.82 - 6.16\log f + 13.82\log h_b + a(h_m) - (44.9 - 6.66\log(h_b)) \times \log d$ (6)

where:

E is field strength at a distance from a 1 kW ERP transmitter in dBμV/m

f is frequency of the transmission in MHz

h_b is height of the base station or transmitter in metres

h_m is height of the mobile or receiver in metres

d is distance between the transmitter and the receiver in kilometres

2.3 ITU-R P.529-3

ITU-R gives analytical expressions that are valid for some frequency ranges and correspond approximately to some of its propagation curves. The equation is [6]:

$E = 69.82 - 6.16\log f + 13.82\log h_1 + a(h_2) - (44.9 - 6.55\log h_1)(\log R)^b$ (7)

where:

E is Field Strength for 1 kW ERP

f is frequency (MHz)

h_1 is base station effective antenna height in the range 30 – 200 m

h_2 is mobile station antenna height in the range 1 – 10 m

R is distance (km)

$a(h_2) = (1.1\log f - 0.7)h_2 - (1.56\log f - 0.8)$ (8)

$b = 1$ for $R \leq 20\ km$ (9)

$b = 1 + (0.14 + 1.87 \times 10^{-4} f + 1.07 \times 10^{-3} \acute{h}_1)\left(\log\frac{R}{20}\right)^{0.8}$ for $20\ km < R < 100\ km$ (10)

where:

$\acute{h}_1 = \frac{h_1}{\sqrt{1 + 7 \times 10^{-6} h_1^2}}$ (11)

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

2.4 ERC REPORT 68

ERC Report 68 gives a number of equations for different frequency ranges but the equation that is within the frequency range of original Hata equation is given as [5]:

$E = 69.75 - 6.16\log(f) + 13.82\log(h_b) + \alpha \times (44.9 - 6.55\log(h_b)) \times (\log(d)) + a(h_m) + b(h_b)$ (12)

where

$\alpha = 1$ if $d <= 20\ km$ (13)

$\alpha = 1 + (0.14 + 1.87 \times 10^{-4} \times f + 1.07 \times 10^{-3} \times h_m) \times (\log(d/20))^{0.8}$ if $d > 20\ km$ (14)

$a(h_m) = (1.1\log(f) - 0.7) \times minimum(10, h_m) - (1.56\log(f) - 0.8) + maximum(0, 20\log(h_m/20))$ (15)

$b(h_b) = minimum(0, 20\log(h_b/30))$ (16)

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

3. STUDY AREA

Makurdi is the capital of Benue State in Nigeria. The city is located in central Nigeria along the Benue River (7.7411°N, 8.5121°E) with estimated population of 292,645 [7] (Fig -1). The town is divided by the River Benue into the north and south banks, which are connected by two bridges: the railway bridge and the new dual carriage bridge.

As a result of the location of the city in the valley of River Benue, it experiences warm temperatures most of the year. However, it is relatively cool during harmattan period from November to January. Makurdi records average maximum of 35°C and minimum of 21°C daily temperatures in dry season while maximum of 37°C and minimum of 16 °C in rainy season. Benue State has vegetation which consists of rain forests that have tall grasses, tall trees and oil palm trees which occupy the state's southern and western fringes while the northern and eastern parts of the state have Guinea Savannah with mixed trees and grasses that are of average height [8].

Fig –1: Location of Makurdi in Nigeria [9]

4. DATA COLLECTION AND ANALYSIS

The local VHF television station signal, NTA Makurdi Channel 10, in Makurdi, Benue State, Nigeria, was used for this work. The transmitting frequency was 210.25 MHz for video signal and the power output of the transmitter was 1.1 kW while the transmitting antenna was mounted on a mast of 150 m high.

Measurement of the video signal levels was done along four radial routes, designated Route A, B, C and D, from the transmitting station as shown in Fig -2. 1.5 m high dipole antenna 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. Also, Global Positioning System (GPS 72 – Personal Navigator) was used to measure the corresponding distances away from the base of the transmitting antenna.

To aid comparison with other models, the field strength values of the measured signal in dBμV/m were calculated for a 1 kW Effective Radiated Power (ERP) transmitter. The field strength for each route was obtained as well as the field strength as predicted by free space, Hata, ITU-R P.529-3 and ERC Report 68 models. The Root Mean Square Error (RMSE) was determined along all the routes for each model together with the Mean Prediction Error (MPE) which was used as the correction factor to modify all the models to get the least possible error. The different routes considered resulted in having a number of correction factors for each model along each route. So, to generalise each model for all the routes in Minna, the average values of the MPE of the four radial routes were calculated and used as the correction factors to generalise the field strength models.

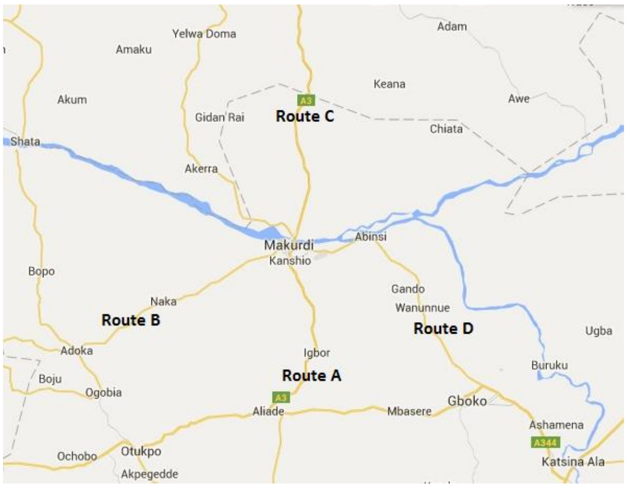

Fig -2: Satellite map of Makurdi showing the routes along which measurements were taken [10]

5. RESULTS

5.1 Field Strength Models

Fig. 3 to Fig. 6 show the field strength models and the measured field strength for all the routes considered. The models have the same trend for all the routes. The free space model has the highest field strength prediction while the ERC Report 68 model has the lowest field strength prediction. The RMSE of the field strength models for each route is shown in Table 1.

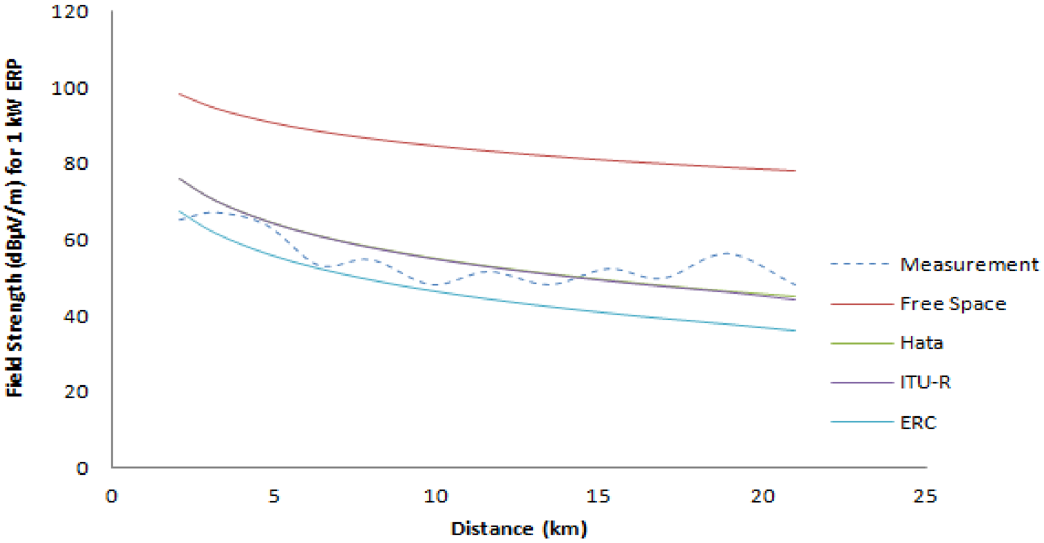

Fig -3: Field strength models for route A

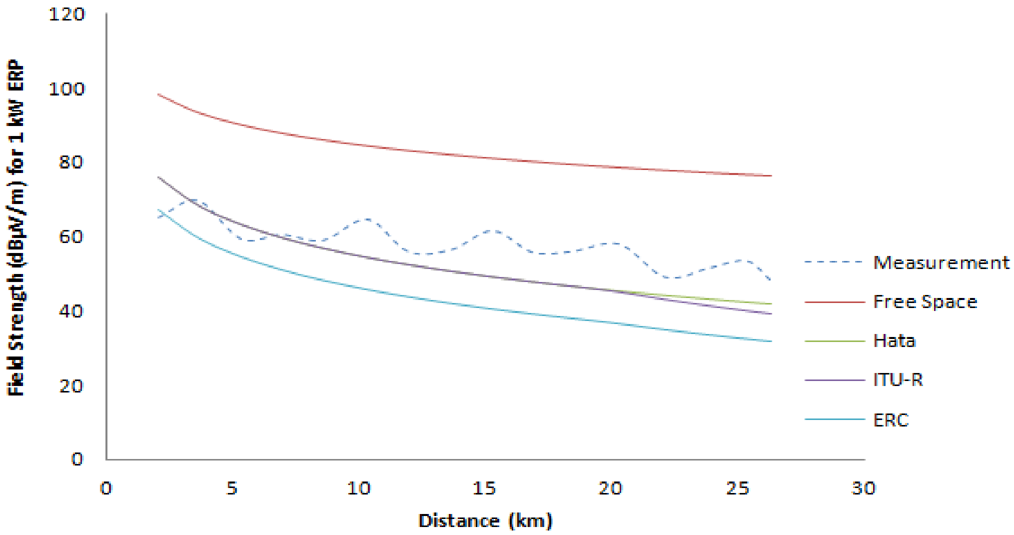

Fig -4: Field strength models for route B

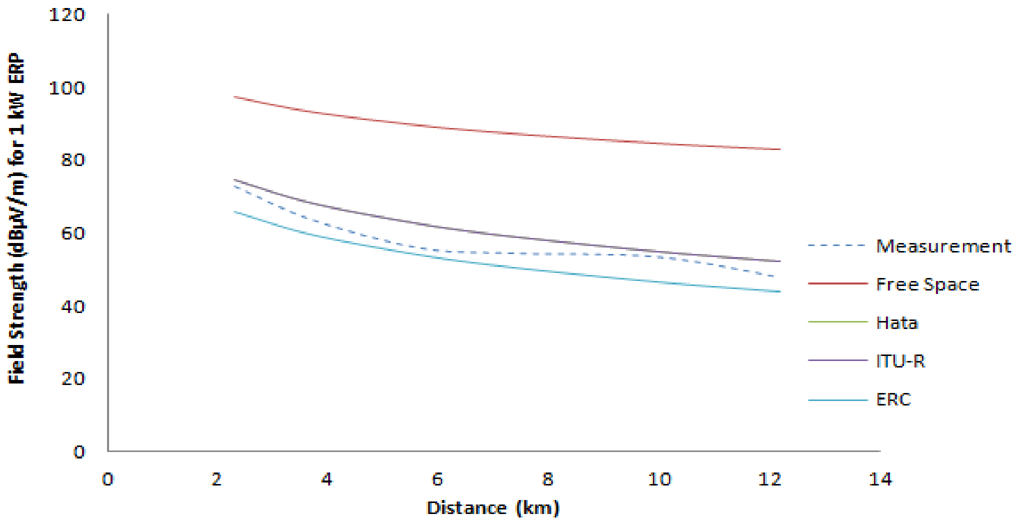

Fig -5: Field strength models for route C

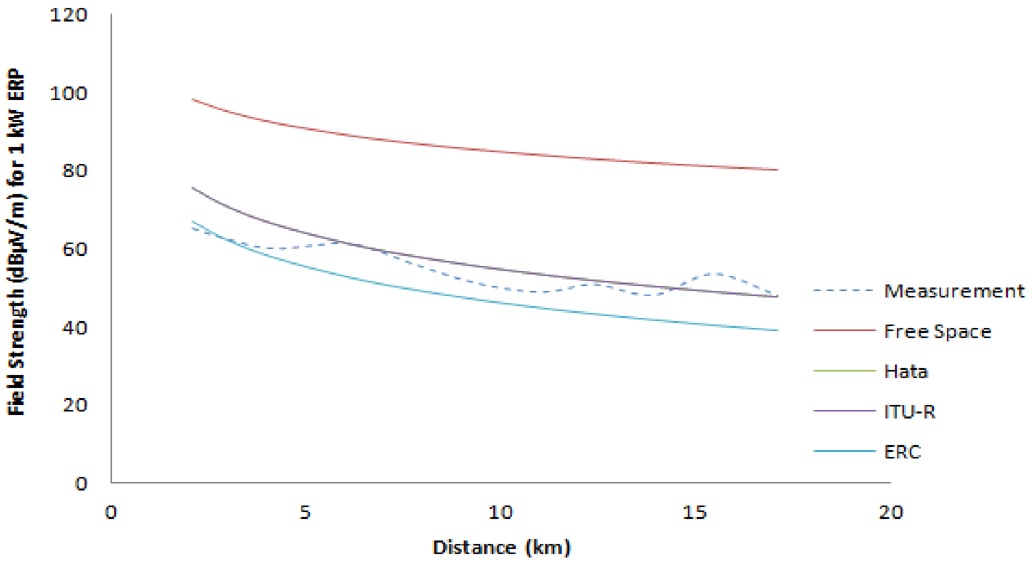

Fig -6: Field strength models for route D

Table -1: Root Mean Square Error of the Field Strength Models

	Free Space	Hata	ITU-R	ERC
ROUTE A	31.12	5.54	5.57	8.84
ROUTE B	25.69	7.93	8.48	15.30
ROUTE C	31.38	4.16	4.16	5.15
ROUTE D	31.97	5.18	5.18	6.74

5.2 Modified Field Strength Models

Fig. 7 to Fig. 10 show the modified field strength models for all the routes and Table 2 shows the correction factors used for the modified field strength. Also, Table 3 gives the RMSE of all the field strength models for each route.

Table -2: Correction Factors used for the Modified and the Generalised Field Strength Models

	Free Space	Hata	ITU-R	ERC
ROUTE A	-30.89	-1.57	-1.52	7.05
ROUTE B	-25.42	5.21	5.71	14.07
ROUTE C	-31.19	-3.76	-3.76	4.83
ROUTE D	-31.88	-3.22	-3.22	5.37
AVERAGE	-29.85	-0.84	-0.70	7.83

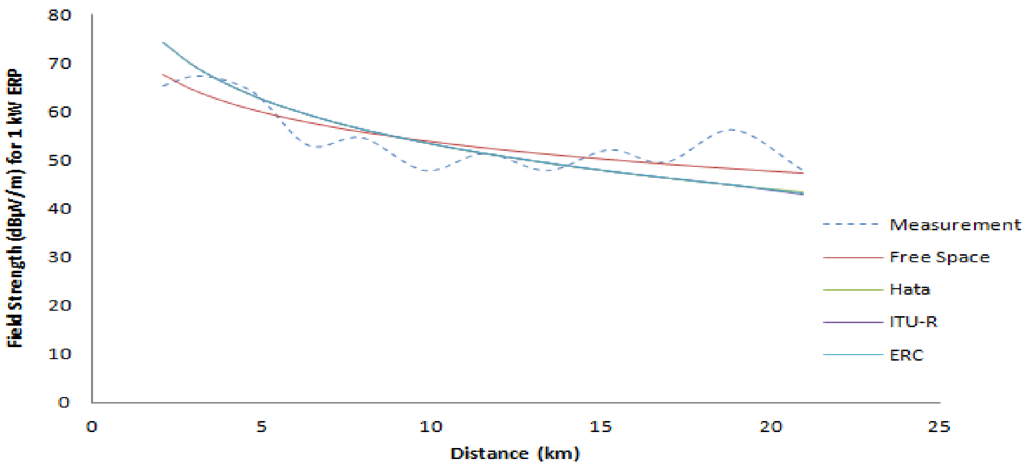

Fig -7: Modified field strength models for route A

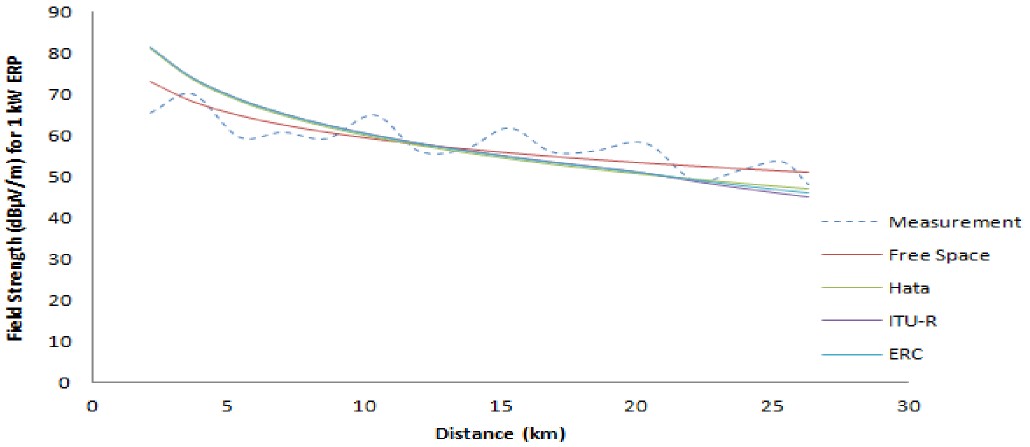

Fig -8: Modified field strength models for route B

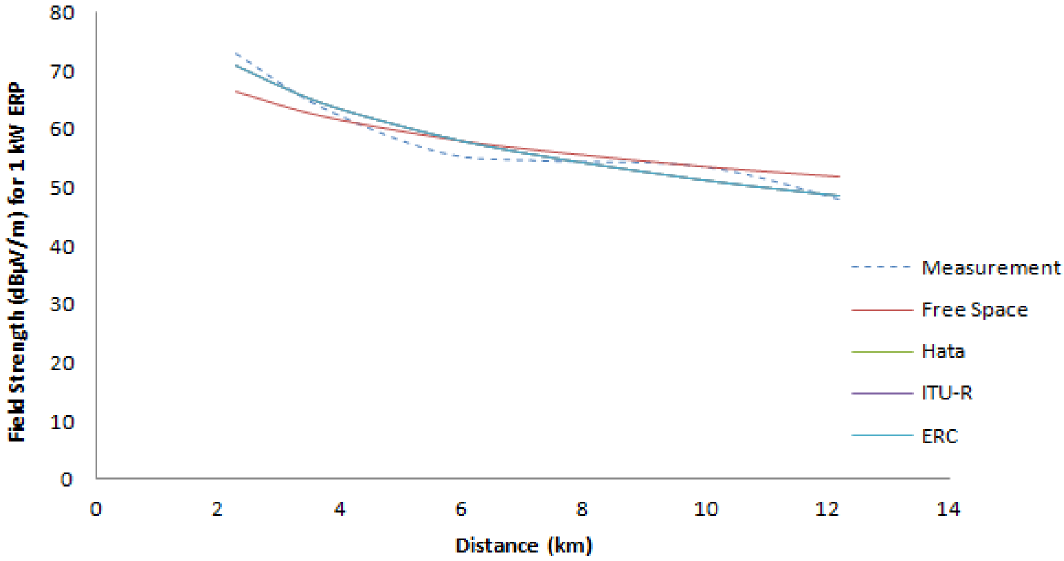

Fig -9: Modified field strength models for route C

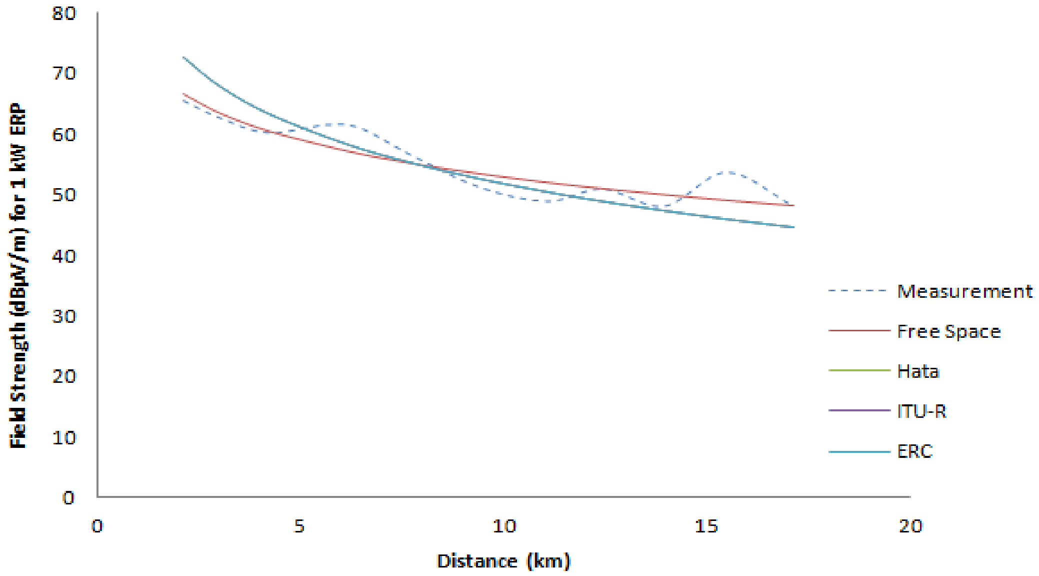

Fig -10: Modified field strength models for route D

Table -3: Root Mean Square Error Values of the Modified Field Strength Models

	Free Space	Hata	ITU-R	ERC
ROUTE A	3.78	5.31	5.36	5.34
ROUTE B	3.74	5.98	6.27	6.13
ROUTE C	3.39	1.78	1.78	1.78
ROUTE D	2.37	4.06	4.06	4.06

5.3 Generalised Field Strength Models

The generalised field strength model for Makurdi city is shown in Fig. 11 to Fig. 14. The correction factors used to generalise the model for the city are the average values of the mean prediction error of all the four routes. Table 4 shows the RMSE values of the field strength models for each route and the RMSE values for Minna city are the average values of the RMSE of the generalized field strength models for all the routes.

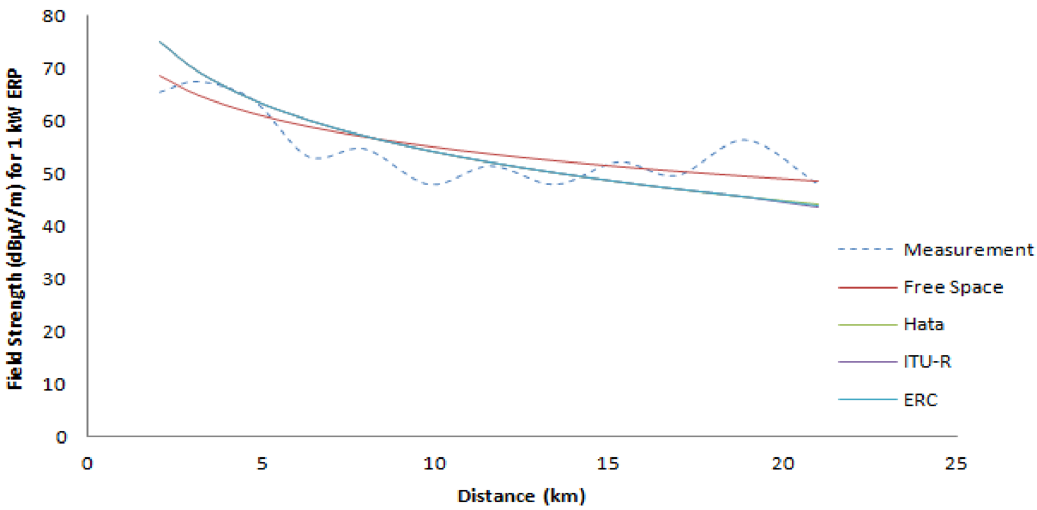

Fig -11: Generalized field strength models for route A

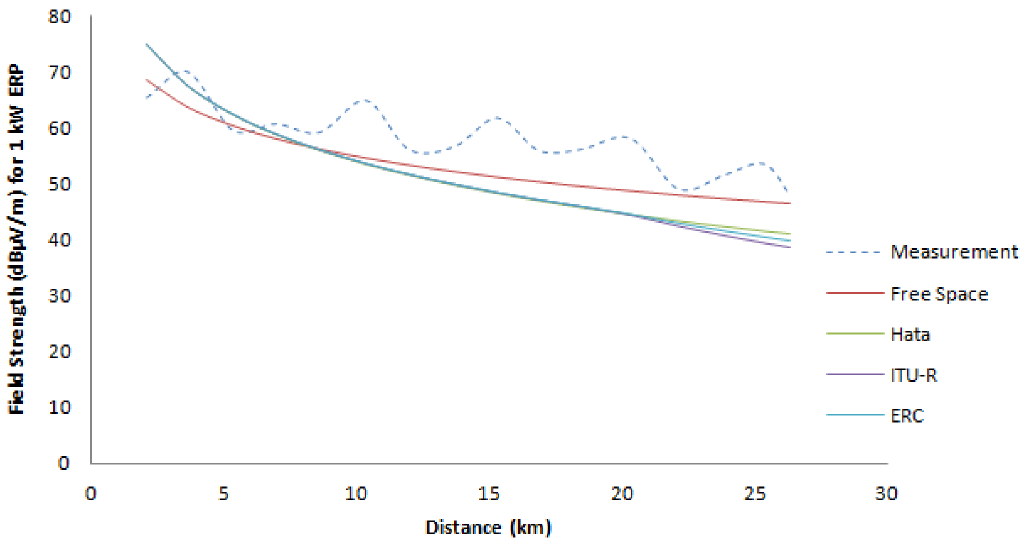

Fig -12: Generalized field strength models for route B

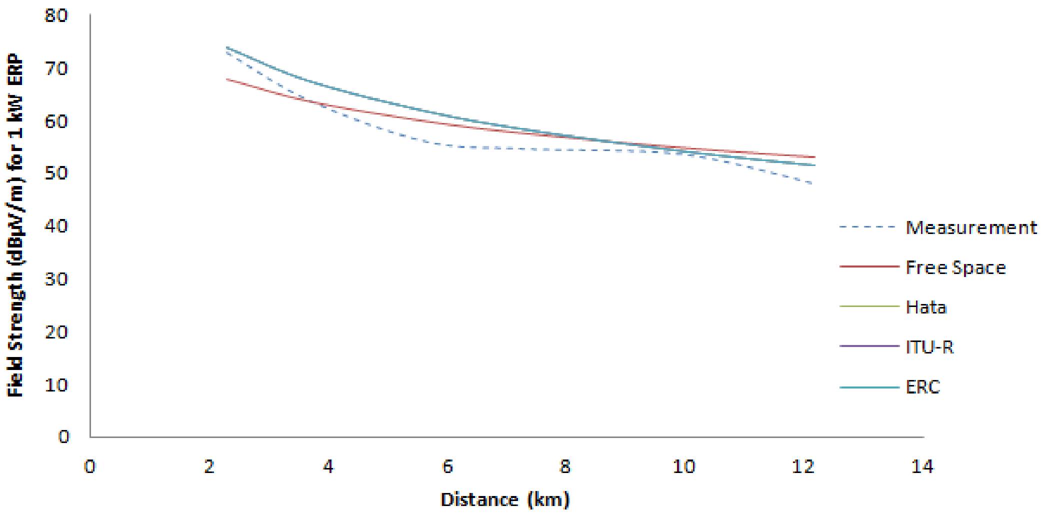

Fig -13: Generalized field strength models for route C

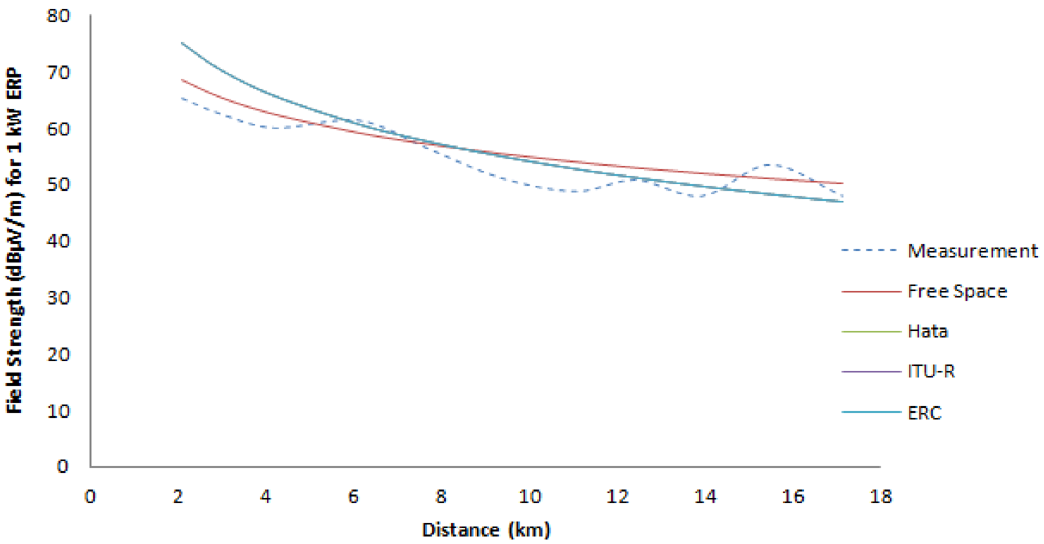

Fig -14: Generalized field strength models for route D

Table -4: Root Mean Square Error Values of the Generalised Field Strength Models

	Free Space	Hata	ITU-R	ERC
ROUTE A	3.92	5.36	5.42	5.40
ROUTE B	5.79	8.50	8.96	8.75
ROUTE C	3.64	3.43	3.54	3.49
ROUTE D	3.12	4.71	4.78	4.75
AVERAGE	4.12	5.50	5.68	5.59

6. SUMMARY AND CONCLUSIONS

By using the average of the mean prediction error of the four routes as the correction factors for each model, field strength models with least RMSE values for Minna city are obtained. More also, the RMSE values used for Minna city are the average values of the RMSE of the generalized field strength models of all the routes.

The correction factors used for all the field strength models consider are: -29.85 for Free space, -0.84 for Hata, -0.70 for ITU-R P.529-3 and 7.83 for ERC Report 68 models with average RMSE of 4.12 dBµV/m for Free space, 5.50 dBµV/m for Hata, 5.68 dBµV/m for ITU-R P.529-3 and 5.59 dBµV/m for ERC Report 68 models.

Thus, the generalized Free-space field strength model gives more accurate prediction for field strength in Makurdi city compared to other models considered.

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BIOGRAPHIES

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