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THEME:
THE ROLE OF SCIENCE AND TECHNOLOGY IN THE REALIZATION OF RESEARCH AND DEVELOPMENT IN THE ERA OF GLOBAL PANDEMIC

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE, NIGERIA

Empirical Electric Field Strength Models for Digital Terrestrial Television Signals in Minna, Niger State, Nigeria

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ABSTRACT

Propagation models play vital roles in planning network coverage, the interference estimations and analyzing radio communication networks. This work adapted some existing empirical field strength models that are best suitable for Minna, Niger State, Nigeria, using the Ultra High Frequency (UHF) signal of StarTimes Terrestrial Television, Minna. The models used are: free space, Hata, International Telecommunication Union-Recommendation (ITU-R P. 529-3) and Energy Regulatory Commission (ERC) Report 68 models. The television station transmits at a frequency of 642 MHz. The signal levels of the transmitted signal were measured radially along four radial routes using Digital Signal Level Meter (GE-5499) and the corresponding distances were also measured using Global Positioning System (GPS). Data processing and computation were carried out using Microsoft Excel spread sheet. The results show that the free space model gives a better prediction for signal field strength in Minna after the general modification with the correction factor of -27.88 and Root Mean Square Error of 7.21 dBμV/m.

Keywords: Coverage area, empirical propagation model, field strength, signal level, UHF

1. Introduction

In a broadcasting system, propagation models are main prediction tools used for designing, planning and analysing wireless communication networks. It is important to point out that there are no general method or algorithms that is universally accepted as the best propagation models. Therefore, each model can be useful for some specific environment and accuracy of any particular technique depends on the fit between the parameters available for the area concerned and the parameters required by the model (Moses *et al*., 2015).

Electric field strength curves or propagation curves are essential parameters neccessary for the planning of VHF and UHF transmission especially for the determination of the coverage areas and the field strength signal levels desired (Moses *et al*., 2015). The field strength of an antenna's radiation at a given point in space, is equal to the amount of voltage induced in a wire antenna located at that given point (Kennedy and Bernand, 1992). This field strength is affected by a number of conditions such as time of day, atmospheric conditions, transmitter-receiver distance, transmitter power and others like, terrain effect, transmitting and receiving antenna heights, and the gain of the transmitting antenna (Bothias, 1987). 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 (Barclay, 1991).

Propagation models can be divided into three main groups, namely: empirical, deterministic and semi-deterministic models (Abhayawardhana *et al*., 2005). The aim of this work is to adapt some existing empirical field strength models in UHF to suit Minna in Niger State.

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. There are various empirical field strength models for broadcasting services, but attention will be given to free space model, Hata model, International Telecommunication Union Radio (ITU-R P.529-3) model and European Radio Communications Committee (ERC Report 68) model because they are widely accepted (Faruk *et al*., 2013; Moses *et al*., 2015).

2.1. Free space model

Free-space propagation model is used to predict received signal strength when the path between the transmitter and receiver is a clear and unobstructed line-of-sight (Obiyemi *et al*., 2012). The ideal propagation radiates in all directions from transmitting source and propagating to an infinite distance with no degradation. Attenuation occurs due to spreading of power over greater areas (Nadir *et al*., 2008).

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

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

where:
S = power flux density in decibels relative to 1 W.m^{-2}
P_T = power in decibels (dB) relative to 1 kW
d = distance (km)
The equivalent field strength, E is given as:

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

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

$$\text{or } E\ (mV/m) = \frac{173\sqrt{P_T(KW)}}{d\ (km)} \quad (5)$$

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

2.2. Hata model

The model is based on an empirical relation derived from Okumura's report on signal strength variability measurements (Okumura *et al*., 1968). The original Hata equation is given in terms of a path loss in dB.

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

where:
E = Field strength at a distance from a 1 kW ERP transmitter in $dB\mu V/m$.
f = Frequency of the transmission (MHz)
h_b = Height of the base station or transmitter (m)
h_m = Height of the mobile or receiver (m)
d = Distance between the receiver and transmitter (km)

2.3. ITU-R P.529-3 model

The ITU-R determines the analytical expressions that are suitable for same frequency ranges and correspond approximately to some of its propagation curves. The equation is given by (Recommendation, ITU-R P.529-3, 1999).

$$E = 69.82 - 6.16\log(f) + 13.82\log h_b + a(h_m) - (44.9 - 6.55\log(h_b)(\log d)^b \quad (8)$$

where:
E = Field strength for 1 kW ERP
f = Frequency (MHz)
h_b = Base station antenna height in the range of 30-200 m.
h_m = Mobile station antenna height in the range 1-10 m.

d = Distance (km)

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

$$b = 1 \text{ for } d \leq 20 \text{ km} \quad (10)$$

$$b = 1 + (0.14 + 1.87 \times 10^{-14} f + 1.07 \times 10^{-3}\, h_b)\left(\log \frac{d}{20}\right)^{0.8}$$

for 20 km $< d <$ 100 km (11)

where:

$$h_b = \frac{h_b}{\sqrt{1+7\times10^{-8} h_b^2}} \quad (12)$$

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

2. 4 ERC report 68 model

In this model, the equation covers the same frequency range as the original Hata equation. This equation has only the distance term raised to the power b and the equation equates approximately to the original Hata equation for distances less than 20 km. The equation is given by (Spectrum Planning Report, 2001):

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

where:

$\alpha = 1$ if d < = 20 km
(14)

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

if d > 20 km

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

$$b(h_b) = \text{minimum}(0, 20 \log(h_b/30)) \quad (16)$$

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

3. Data collection and analysis

This work was carryout in Minna, Niger State, Nigeria, using the StarTimes Terrestrial UHF television signal. The television station transmits signal at frequency of 642 MHz and the output power of the transmitter was 1.95 kW while the transmitting antenna was mounted on a mast of 150 m above the ground level.

Data processing and computation were carried out using Microsoft office excel application software. From the measured signal levels, the field strength values in dBµV/m were 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 the free space, Hata, ITU-R.P529-3 and ERC Report 68 models were also evaluated.

For each model, the Root Mean Square Error (RMSE) was determined along the four routes and the Mean Prediction Error (MPE) was also 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 routes in Ekiti State, the average values of the MPE of the four radial routes considered were estimated and used as the correction factors to generalised the field strength models.

4. Results and discussion

4.1. Electric Field Strength

The comparison of the field strength models with the measured field strength for four routes considered are shown in the Figures 1 to 4. The models have the same trend for all the routes considered. From the Figures shown, 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 the Table 1. For routes A, B, C and D, Hata model has the least RMSE of 9.06 dBµV/m

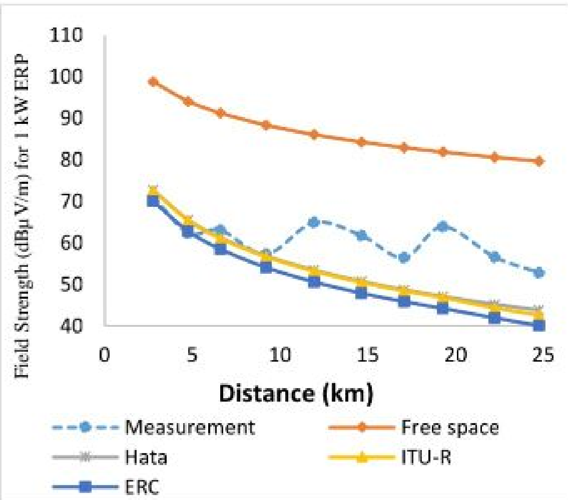

Figure 1: Field strength models for route A

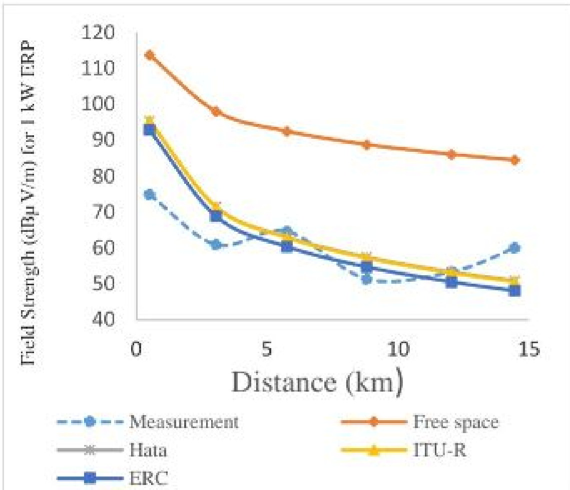

Figure 2: Field strength models for route B

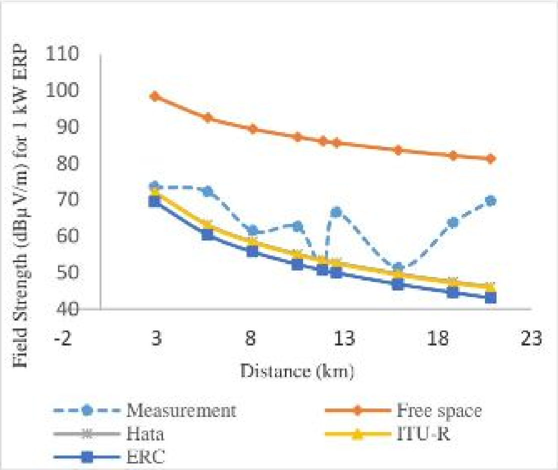

Figure 3: Field strength models for route C

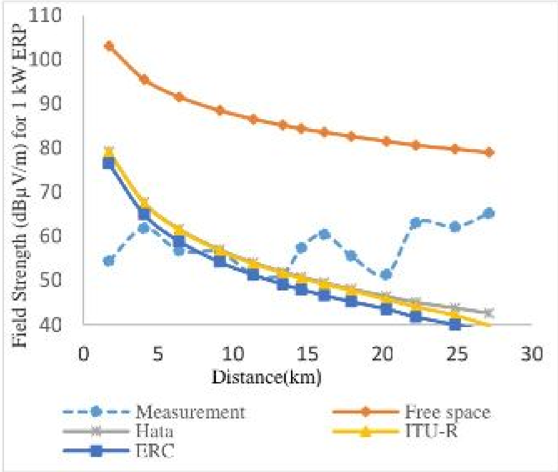

Figure 4: Field strength models for route D

Table 1: Root mean square error of the field strength models

ROUTE	Free Space	Hata	ITU-R	ERC
A	26.10	9.06	9.45	11.43
B	33.48	10.43	10.47	9.70
C	24.75	11.39	11.64	13.62
D	30.14	12.58	13.58	14.19

4.2. Modified field strength models

Figure 5 to 8 show the modified field strength models for all the routes taken. Table 2 shows the correction factors used for modified field strength models, while Table 3 gives the RMSE of the modified field strength models for each route. From the Figures shown, free space model has the lowest field strength prediction with all the models following the same trend.

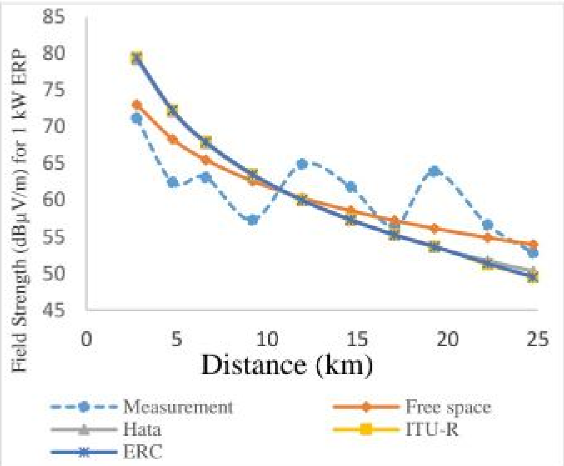

Figure 5: Modified field strength models for route A

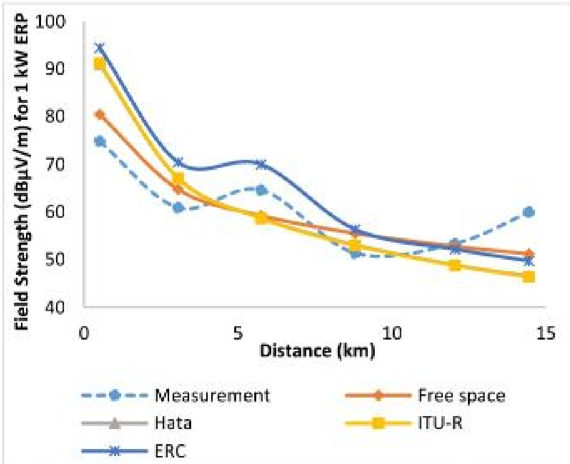

Figure 6: Modified field strength models for route B

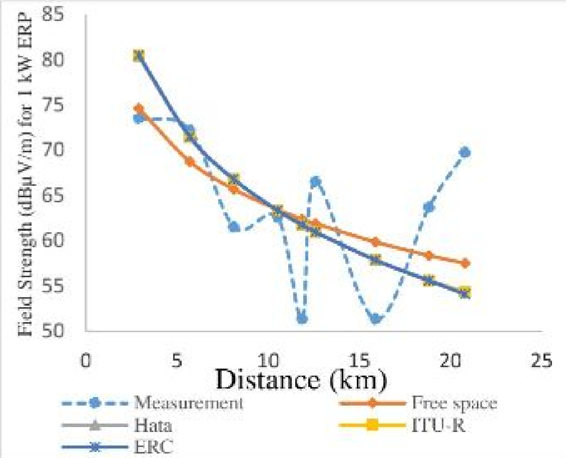

Figure 7: Modified field strength models for route C

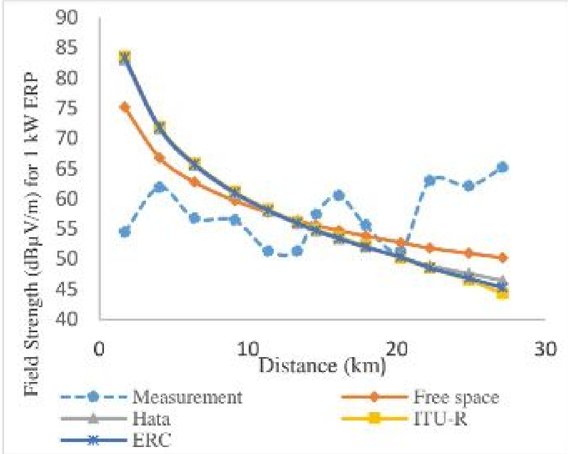

Figure 8: Modified field strength models for route D

Table 2: Correction factors used for the modified and Generalised field strength models

ROUTE	Free Space	Hata	ITU-R	ERC
A	-25.78	6.50	6.89	9.43
B	-33.22	-4.34	-4.26	1.68
C	23.78	8.23	8.46	11.06
D	28.77	3.87	4.43	6.83
Average	**-27.88**	**3.56**	**3.88**	**7.25**

Table 3: Root mean square error of the modified field strength models

ROUTE	Free Space	Hata	ITU-R	ERC
A	4.08	6.32	6.46	6.44
B	5.32	9.46	9.56	10.31
C	6.87	7.88	7.90	7.95
D	9.12	12.10	12.65	12.44
Average	**6.34**	**8.94**	**9.14**	**9.28**

4.3. Generalised field strength models

The generalised field strength models are shown in Figures 9 to 12. The free space has the lowest field strength prediction. The correction factors used to generalise the field strength models for Minna are the average values of the Mean Prediction Error (MPE) of all the four routes. Table 4 show the RMSE values of the generalised field strength models for each route and the RMSE values for Minna are the average values of the RMSE of the generalised field strength models for all the routes. It is observed from the results that, free space model has the average least RMSE of 7.21 dBμV/m for all the routes considered.

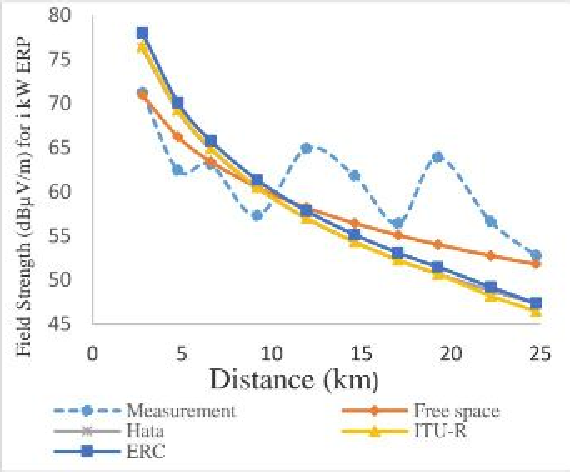

Figure 9: Generalised field strength models for route A

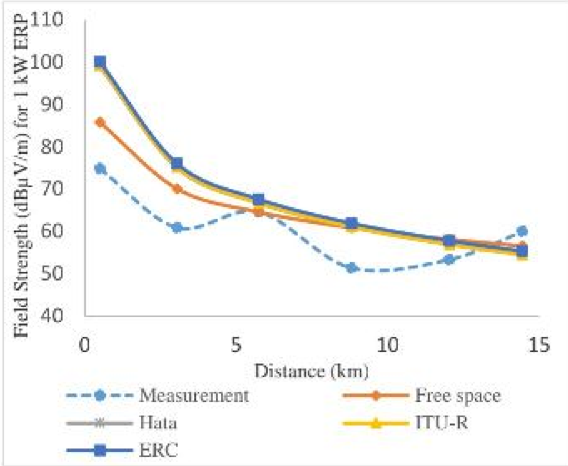

Figure 10: Generalised field strength models for route B

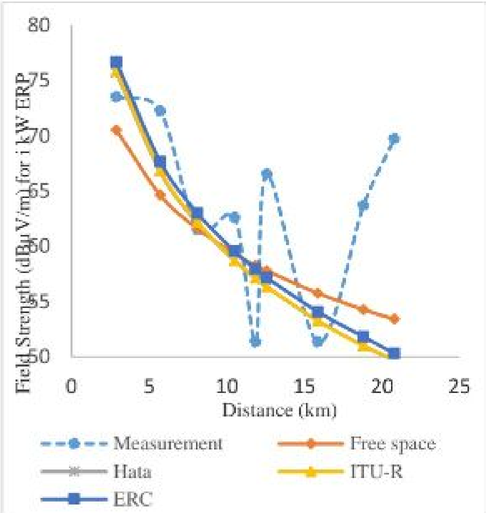

Figure 11: Generalised field strength models for route C

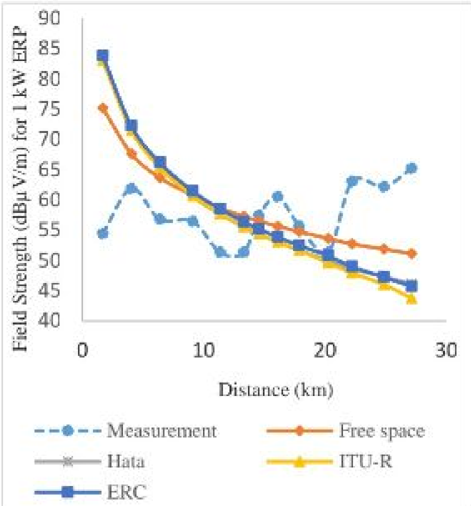

Figure 12: Generalised field strength models for route D

Table 4: Root mean square error of the generalised field strength models

ROUTE	Free Space	Hata	ITU-R	ERC
A	4.51	6.97	7.13	6.87
B	7.32	12.37	12.56	13.08
C	8.01	9.16	9.13	8.82
D	9.02	12.20	12.66	12.46
Average	**7.21**	**10.17**	**10.37**	**10.30**

5. Conclusion

The generalised field strength models for the StarTimes Terrestrial Television, Minna were obtained by using the average of the RMSE of the four routes as the correction factor for each models. The average values of RMSE of the generalised field strength models for the four routes are taken as the RMSE value for Minna. The correction factors used for all the field strength models are as follows: -27.88 for free space, 3.56 for Hata, 3.88 for ITU-R P and 7.25 for ERC Report 68 models with average RMSE of 7.21dBμV/m for free space, 10.17 dBμV/m for Hata, 10.37 dBμV/m for ITU-R and 10.30 dBμV/m for ERC Report 68 models respectively. Hence, the generalised free space field strength model gives more accurate prediction for field strength in Minna as compared to other models used.

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