



Empirical Path-Loss Model for Digital Terrestrial Television Broadcast in UHF Band in Lokoja, Kogi State

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ABSTRACT

Empirical radio propagation models cannot be generalised for all environments and localities because they are based on statistical analysis. Empirical models cannot account for the peculiarities of all environments and their climates, though there are several empirical propagation models. This research work adapted some of these empirical propagation models and determined the most suitable for Lokoja, Kogi State, Nigeria. The following models were modified: Free space, Hata, ITU-R and Ericsson models to suit Lokoja town. A digital terrestrial television signal from StarTimes station, Lokoja was used as the signal source with frequency of 490 MHz. The signal strength of the digitised television signal was taken along three major routes, with the transmitting television station in focus, using a digital signal strength meter and the corresponding line of sight distance to each measurement was taken using a global positioning system (GPS). The results obtained from the data computation and analysis showed that the generalised Free-space model gave a more accurate path-loss prediction in Lokoja with Mean Prediction Error (MPE) of 32.13 dB (used as the correction factor) and Root Mean Square Error (RMSE) of 4.11 dB.

Keywords: *path loss, propagation model, signal attenuation, signal level, radio wave*

1. INTRODUCTION

The global television broadcasting system is undergoing considerable structural and technical changes (Igbonoba & Omoifo, 2021). Consumers now have easier access than ever before to media services such as television communication. For instance, watching television used to need a set time and place for the viewer, thanks to technological advancements, viewers may now watch TV show on a variety of wireless devices and at any time (Lasis *et al.*, 2017). Television regulators and consumers have benefited from increased competition in media markets due to technological advancements in television and the introduction of new products and services; however, certain market developments have given rise to concerns about competition, particularly with regard to signal strength and quality (Asianuba & Enah, 2019). It is possible to mitigate the digital divide and promote development and poverty reduction in addition

to ensuring universal access to television services. As a result of various socioeconomic factors, this is vital for both developed and developing nations (Akinbolati & Ajewole, 2020). This study used digital terrestrial television signal from StarTimes station, Lokoja as the signal source of the UHF signal.

The primary challenge in terrestrial television transmission lies in accurately predicting path loss, which is the attenuation of signal strength along its propagation path. However, signal attenuation due to path loss, caused by factors such as distance, terrain and environmental conditions, significantly affects the signal strength and quality.

Although there are several existing path loss propagation models in use but these models cannot be generalised for all environment, they are environment specific because all environments are not the same (climate, topography, geology, vegetation).

Environmental terrain, structure and climate plays a big role in attenuation. Also, the existing propagation model were developed in countries like Japan, USA, Australia which are temperate regions, so when they are used in a tropical environment like Lokoja in Kogi state the results will be falsified alongside inaccurate signal strength across locations which leads to waste of power or interference.

To overcome this setback, some of the propagation model parameters can be adjusted to suit the study area, in other to reduce the error between the predicted and the measured signal strength. Hence the need to modify the existing paths loss propagation model to minimize the prediction error and ensure a high degree of accuracy. This research work adapted some of these empirical propagation models to determine the one that is most suitable for Lokoja, Kogi State, Nigeria. The following models were modified: Free space, Hata, ITU-R and Ericsson models to suit Lokoja town, using the digital terrestrial television signal from StarTimes Lokoja with transmitting frequency of 490 MHz.

2. Path Loss Model

2.1 Free-space model

Free-space path loss is the loss experienced when electromagnetic wave passes through free-space. The Free-space Model predicts radio wave propagation in an ideal, obstacle-free environment, serving as a fundamental reference for more complex models. The model assumes isotropic antennas and neglects atmospheric effects (Risi *et al.*, 2024).

$$P = 32.4 + 20\log x + 20\log f \quad (1)$$

where,

x = distance (km) and

f = frequency (MHz).

The equation shows that path loss is directly proportional to frequency and distance. Khan *et al.* (2022) verified the accuracy of the model for

short-range wireless transmission and Esteban *et al.* (2024) used the model for a 5G millimeter wave channel.

2.2 Ericsson model

Ericsson model is based on the software developed by Ericson Company using updated Hata model to accommodate the varying parameters in different environment. The model is given as (Milanovic *et al.*, 2007):

$$P = y_o + y_1 \log_{10} x + y_2 \log_{10} t_b + y_3 \log_{10} (t_b) \log_{10} x - 3.2 [\log_{10} (11.75 t_r)]^2 + s(f) \quad (2)$$

where:

P = path loss in dB

x = transmitter – receiver distance (km)

t_b = base-station antenna height (m)

t_r = receiver antenna height (m)

f = frequency (MHz)

$s(f)$ = frequency correction factor, given as:

$$s(f) = 44.5(f) - 4.8(\log_{10} (f))^2$$

y_o, y_1, y_2, y_3 - empirical constants (model parameters set by tuning)

2.3 ITU-R P.529-3 Model

The ITU-R P.529-3 model is a radio propagation model applicable to frequencies between 30 MHz and 3 GHz. It was developed by the International Telecommunication Union - Radio (ITU-R). This model accounts for terrain-related losses, including hill obstruction and diffraction. The path loss (L) equation is (Moses *et al.*, 2018):

$$P = 69.6 + 26.2\log f(\text{MHz}) - 13.8 \log \log t_b - b(t_r) + [44.9 - 6.6t_b] \log x - A \quad (3)$$

where:

$$[b(t_r) = [1.1\log f - 0.7]t_m - [1.6\log f - 0.8]$$

A
 = 30
 – 25log (% of areas covered by the buildings)

f = frequency (MHz)
 t_b = base-station antenna height (m)
 t_r = mobile-antenna height (m)
 x = transmitter – receiver distance (km)
 $b(t_r)$ = correction factor (mobile-antenna height)

2.4 Hata Models

Hata Models are empirical models used to predict path-loss in urban, suburban, and open areas. They are extension of Okumura model. The models were developed by Masaharu Hata in 1980 and they calculate path loss (L) in decibels (dB) (Mardeni & Kwan, 2010):

a. Urban Area Path Loss

$$P_{urban} = 69.6 + 26.2\log_{10}f - 13.8\log_{10}t_b - b(t_r) + [44.9 - 6.6\log_{10}t_b] \log_{10}x \quad (4)$$

where:

f = frequency (MHz)
 t_b = base-station antenna height (m)
 t_r = mobile-antenna height (m)
 x = transmitter – receiver distance (km)
 $b(t_r)$ = correction factor (mobile-antenna height), which differs for small and large cities

i. Small/medium cities:

$$b(t_r) = (1.1\log_{10}f - 0.7)t_r - (1.56\log_{10}f - 0.8) \quad (5)$$

ii. Large cities:

if $f \leq 200$ MHz

$$b(t_r) = 8.3(\log_{10}1.5t_r)^2 - 1.1 \quad (6)$$

if $f \geq 400$ MHz

$$b(t_r) = 3.2(\log_{10}11.6t_r)^2 - 5 \quad (7)$$

b. Suburban region

$$P_{suburban} = P_{urban} - 2[\log_{10}(\frac{f}{28})]^2 - 5.4 \quad (8)$$

c. Rural/open Area

$$P_{rural} = P_{urban} - 4.8(\log_{10}f)^2 + 18.33\log_{10}f - 40.9 \quad (9)$$

3. Data Collection and Analysis

Terrestrial television digital signal from StarTime Lokoja was used as the signal source for this study. The frequency of the signal is 490 MHz with transmitting power of 3.2 kW and the transmitting antenna height is 150 m.

Measurements were taken radially from the transmitting station along three major routes, as shown in Figure 3.1, with a digital signal level meter (GE-5499 DSL Meter). The signals were received by an antenna connected to the signal meter. The antenna was mounted on a pole of height 2 m for easy movement around the town when taking measurement. The GPS receiver was used as a personal navigator to measure the line-of-sight distance of the different points between where data were collected and the base station alongside the elevation, longitude and latitude. Measurements were taken at interval of 1 km along the routes considered from the base station until the signal faded off.

Data analysis and computation were done using a computer spreadsheet program (Microsoft Excel) running on a personal computer. The path loss for each route were evaluated from the measured signal, also the predicted path loss from the considered models were also calculated. The obtained results were compared using RMSE while the MPE was used as a correction factor to modify the models.

Due to the different routes considered, the number of correction factors will be the same with the number of routes considered, resulting in several correction factors for an area. Therefore, to generalise each model to have a single correction factor, in respective of the number of routes considered, the average values of the MPE of the three routes used were taken as the correction factors to generalise the Path-loss models.

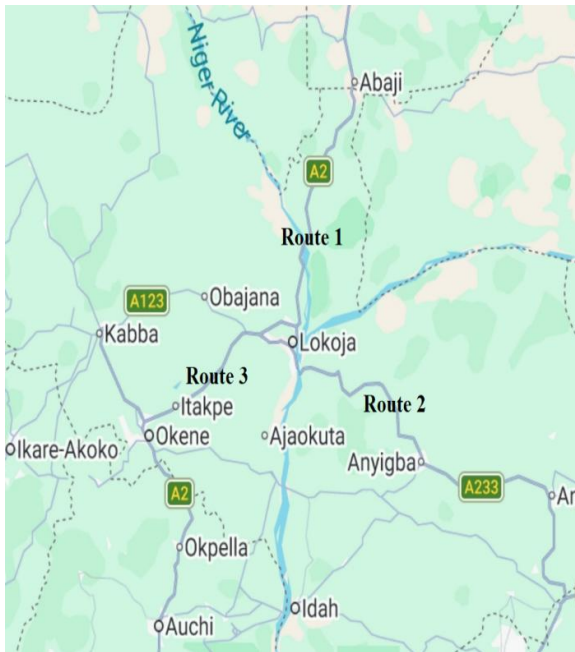


Figure 3.1: Satellite map showing Lokoja and the routes of measurements
Source: (Satellite World Map, 2025)

4. Results and Discussion

4.1 Comparison of the path loss model

The measured path loss along all the routes and the considered path loss models are shown in Figure 4.1 - 4.3 and the RMSE is given in Table 4.1. The signal strength generally tends to decrease with increasing distance from the base station, consequently, increasing the path-loss with distance. This observation aligns with the fundamental principle of electromagnetic wave propagation, where signal strength attenuates as it spreads out from its source. However, this attenuation is not uniform or linear; instead, the

graphs show significant fluctuations, characterized by sharp peaks and troughs at various distances as a result of environmental factors such as buildings, trees, and other obstructions

All the results have the same trend. The Free-space model has the least path-loss prediction values with 32.31dB RMSE while Ericsons model has the highest prediction value with 28.87 dB RMSE. Hata models (large city) has the least average RMSE of 5.69 dB, thus having the most accurate prediction for path loss in Lokoja, Kogi state.

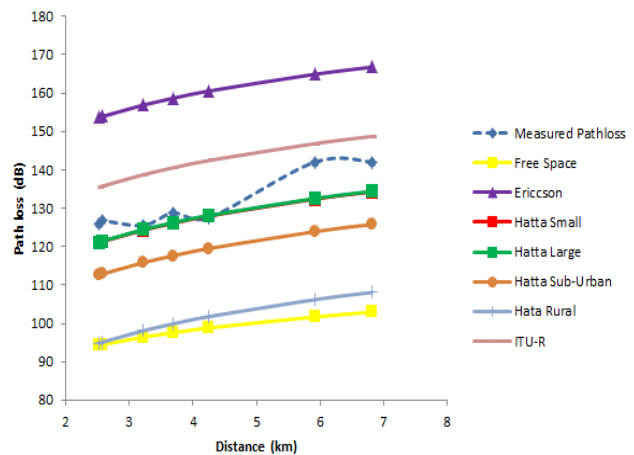


Figure 4.1: Path-loss models along route 1

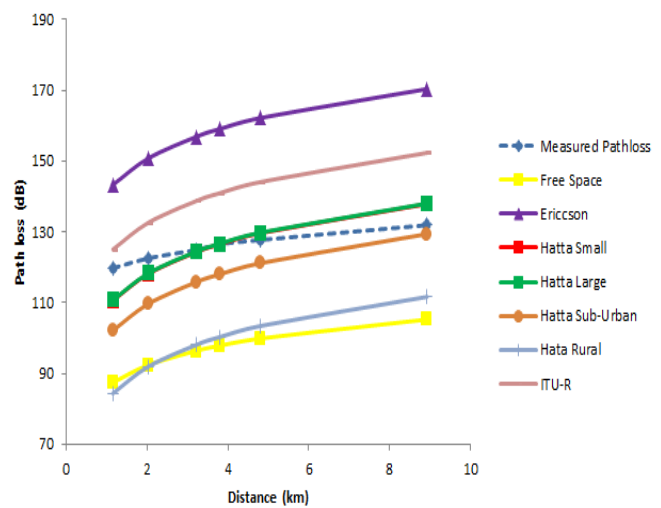


Figure 4.2: Path-loss models along route 2

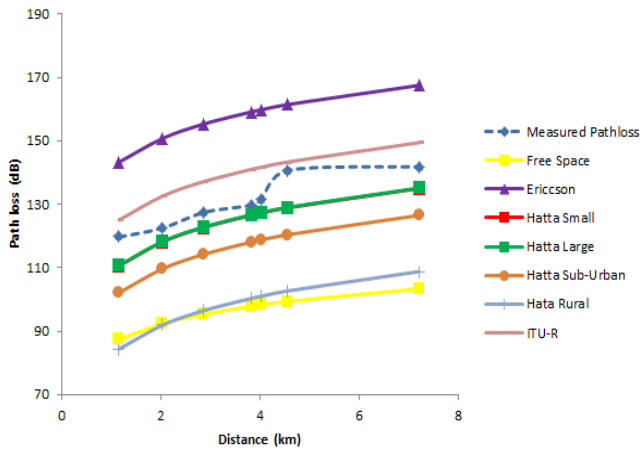


Figure 4.3: Path-loss models along route 3

Table 4.1: Root mean square error (RMSE) of the path loss models

Route	Free-space (dB)	Ericsson (dB)	Hata (Small) (dB)	Hata (Large) (dB)	Hata (Sub-Urban) (dB)	Hata (Rural) (dB)	ITU-R (dB)
1	33.445	28.349	5.499	5.396	13.304	30.796	10.570
2	29.070	31.875	4.861	4.835	10.648	27.672	14.215
3	34.410	26.385	6.968	6.849	15.112	32.693	8.590
Average	32.308	28.870	5.776	5.693	13.022	30.387	11.125

Table 4.2: Mean prediction error (MPE) used as the correction factor

Route	Free-space (dB)	Ericsson (dB)	Hata (Small) (dB)	Hata (Large) (dB)	Hata (Sub-Urban) (dB)	Hata (Rural) (dB)	ITU-R (dB)
1	33.165	-28.154	4.398	4.268	12.888	30.618	-10.042
2	29.016	-31.530	1.041	0.911	9.531	27.261	-13.399
3	34.203	-26.228	6.346	6.216	14.836	32.566	-8.0941
Average	32.128	-28.638	3.928	3.798	12.418	30.148	-10.512

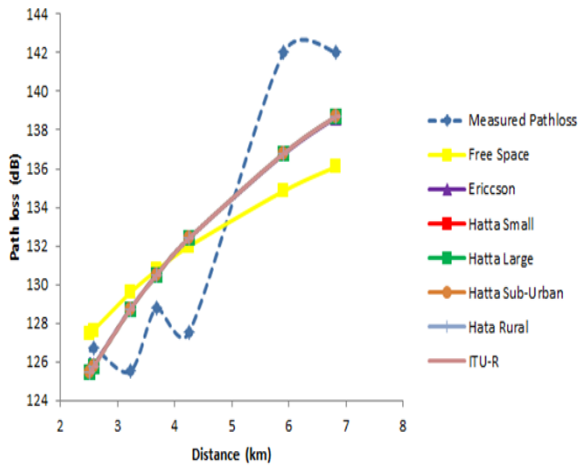


Figure 4.4: Modified path-loss models (Route 1)

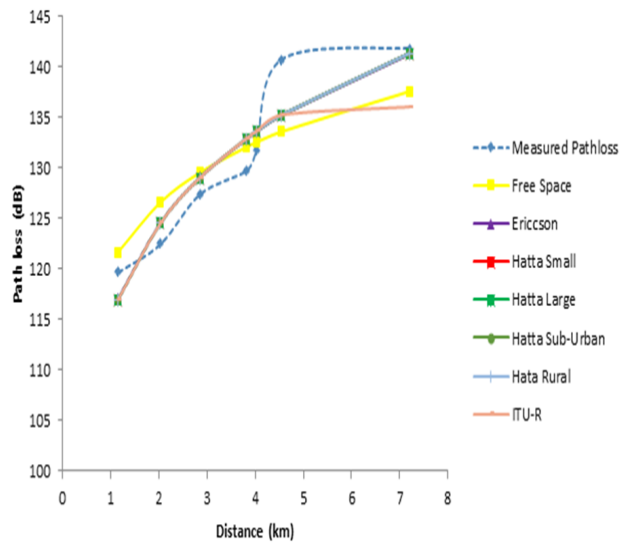


Figure 4.6: Modified path-loss models (Route 3)

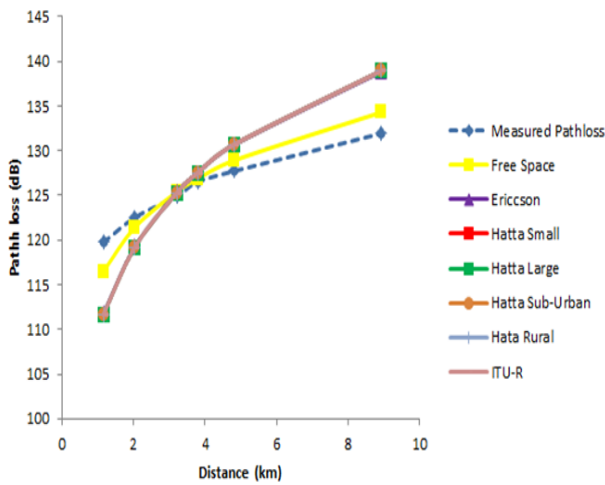


Figure 4.5: Modified path-loss models (Route 2)

4.3 Generalised Path-Loss Models

The generalised path-loss models for Lokoja are given in Figure 4.8 - 4.10 and the RMSE in Table 4.4. The average values of the MPE were used as the correction factors. The generalised Free-space model gives the most accurate path loss prediction with RMSE of 4.11 dB and correction factor of 32.128

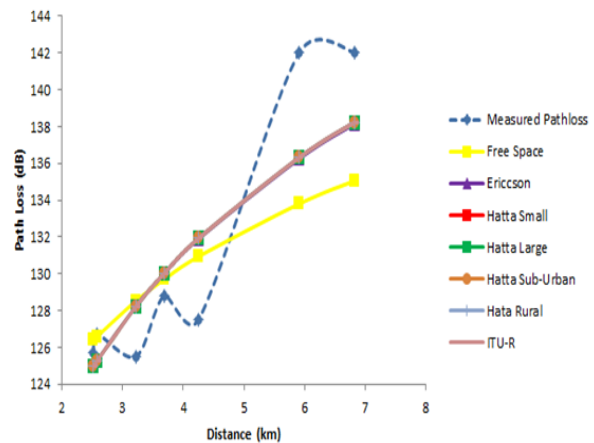


Figure 4.7: Generalised path-loss (Route 1)

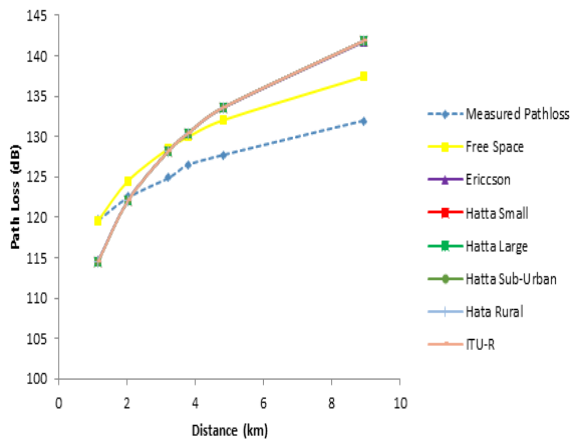


Figure 4.8: Generalised path-loss (Route 2)

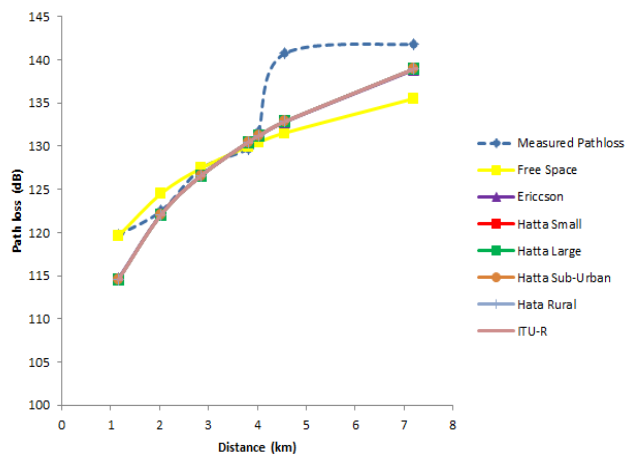


Figure 4.9: Generalised path-loss (Route 3)

Table 4.4: Generalised RMSE of the path loss models

Route	Free-space (dB)	Ericsson (dB)	Hata (Small) (dB)	Hata (Large) (dB)	Hata (Sub-Urban) (dB)	Hata (Rural) (dB)	ITU-R (dB)
1	4.440	3.3542	3.334	3.334	3.334	3.334	3.334
2	3.588	5.499	5.558	5.558	5.558	5.558	5.558
3	4.303	3.753	3.757	3.757	3.757	3.757	3.757
Average	4.110	4.202	4.216	4.216	4.216	4.216	4.216

5. Conclusion

The generalised empirical path-loss model with the least root means square error for Lokoja, Kogi State was obtained using the average of the mean prediction error of all the routes as the correction factors. The correction factors used to generalize the path-loss models are: Free Space (32.128 dB), Ericson (-28.638 dB), Hata Small (3.929 dB), Hata Large (3.798 dB), Hata Sub-Urban (12.418 dB), Hata Rural (30.148 dB) and ITU-R (-10.512 dB) with the following average RMSE of: 4.11 dB, 4.202 dB, 4.216 dB, 4.216 dB, 4.216 dB, 4.216 dB and 4.216 dB respectively.

Thus, the generalised Free space model gave the most accurate path loss prediction in Lokoja, Kogi State in comparison to other models considered. It has the least average RMSE of 4.11 dB and correction factor of 32.12 dB. The generalised models for Lokoja in order to their prediction accuracy are: Free Space, Ericson, Hata-Small, Hata-Large, Hata-Sub-Urban, Hata-Rural and ITU-R models.

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