



## FM Signal Coverage Mapping and Path Loss Model Comparison: A Case Study of Search FM (92.3 MHz) Minna, Niger State

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### ABSTRACT

Electric field strength of radio signals decreases with increase in distance from the transmitting antenna. The Electric field strength of Search FM (92.3 MHz) radio signals was measured along four radial routes from the transmitting antenna, using a Digital Signal Level Meter, GE-5499, covering the signal range of 25 – 107dB $\mu$ V. Geographical coordinates and distance from the transmitting antenna were obtained at every location corresponding to each measured Electric field strength using a Global Positioning System (GPS), GPS-72. The study revealed that Search FM (92.3 MHz), the campus community radio of the Federal University of Technology, Minna, provides targeted coverage primarily within its host institution and surrounding areas. While its broadcast does not extend optimally across Niger State, the station achieves effective service delivery to its intended audience in compliance with National Broadcasting Commission (NBC) regulations. Field measurements revealed that the strongest signal quality, Grade A (signal level  $\geq 60$  dB $\mu$ V), is confined to Gidan Kwana, with Grade B (signal level  $> 30$  dB $\mu$ V and  $< 60$  dB $\mu$ V) coverage across most parts of Minna, and Grade C (signal level  $> 0$  dB $\mu$ V and  $\leq 30$  dB $\mu$ V) reception in towns such as Paiko, Gawu, Kacha, Maikunkele, Kuta, and Pawa. Other regions of Niger State fall outside the coverage area. Path loss modelling was conducted to evaluate predictive accuracy of selected established models. Results showed that the Egli model provided the most reliable predictions, with mean RMSE value of 8.34, outperforming both the Hata Urban and Suburban (mean RMSE value of 10.45 and 10.08 respectively) and Ericson Urban and Suburban (mean RMSE value of 28.82dB and 69.43dB respectively) path loss models. These findings underscore the suitability of Egli model for FM signal prediction in Minna's terrain and highlight the importance of model selection in optimizing radio coverage planning for community-based broadcasting services.

**Keywords:** Radio signal, Propagation, Electric field strength, Path loss, Signal Coverage Area

### INTRODUCTION

Propagation of radio waves is a term used to explain how radio waves travel from point A to point B. It involves the events occurring in the transmission path between two stations (transmitting and receiving) that affect the communications between the stations. When the electrons in a conductor (antenna wire) are made to oscillate back and forth, electromagnetic waves are produced. These waves radiate outwards from the source at the speed of light ( $3 \times 10^8$  m/s). The mode of propagation of radio signals depends on the frequency band (such as Very Low Frequency (VLF), Low Frequency (LF), Medium Frequency (MF), High Frequency (HF), Very High Frequency (VHF)) used for the transmission (Ohworho *et al.*, 2026). Frequency Modulated (FM) radio signals are within the VHF band of the radio spectrum.

In the VHF band, wave propagation is mainly by the troposphere and the earth's surface with some influence from the ionosphere on the lower bands. The inhomogeneity of the atmospheric refractive index and precipitations in the troposphere give rise to refraction, reflection, ducting and scatter (Ashidi & Oviangbede, 2026; Oyedum *et al.*, 2011). The three modes of propagation of radio waves through the troposphere are: Surface, direct and ground reflected wave propagation.

The surface wave component of energy radiated from a transmitting antenna, is so rapidly attenuated that its contribution to the total field is usually negligible. Generally, then, it is necessary to consider only the direct and ground-reflected transmission components (Okoko, 2022.; Rappaport, 2002; Kraus, 1988). In the absence of any intervening obstacles, the direct wave, varies inversely with the square of the distance from the transmitter. Waves that are

reflected by buildings, terrain, hills, trees e.tc, take longer paths to get to the receiving antenna, and this creates undesirable poor signal strength. The intensity of the ground-reflected wave, and the total field, varies with the angle of incidence, the frequency and the conductivity and dielectric constant of the earth. The vector sum of the direct wave and the ground reflected wave is called space wave (Hall & Barclay, 1991).

The space wave is affected by the shadowing effect of hills or other obstructions in the line of sight between the transmitter and the receiver. Terrain affects wave propagation by reflection, diffraction and the positions of the common volumes in tropospheric scatter propagation. Due to the reflection of signals, field strength along a route shows severe fluctuation (Hall & Barclay, 1991).

Propagation path loss models are useful for the prediction of received signal strength at a given distance from the transmitter and estimation of radio coverage areas (Iwuji, *et al.*, 2023; Eichie *et al.*, 2017). Coverage areas of broadcast stations can be classified into primary, secondary and fringe areas. The size of each of these coverage areas depends on the transmitter power, the directivity of the antenna, the height of antenna above the earth's surface, the ground electrical conductivity and the frequency of propagation (Eichie *et al.*, 2015). The coverage areas decrease with increase in frequency and reduction in the ground conductivity (Hall & Barclay, 1991).

The primary coverage area is defined as a region about a transmitting station. In this region, the signal strength is adequate to override ordinary interference in the locality at all times. The secondary coverage area is a region where the field strength is often sufficient to be useful but is insufficient to overcome interference completely at all times. Within this

area, the signal is a bit weak. The fringe coverage area can be regarded as that in which the field strength can be useful for some period, but its service can neither be guaranteed nor be protected against interference. Within this area, the station's signal will be very weak (Eichie *et al.*, 2017).

Several studies have highlighted the challenges of FM signal coverage due to obstructions on the propagation path. Radio propagation is highly sensitive to topographical variations, with hills, valleys, and vegetation often causing shadowing, diffraction, and multipath effects that reduce reception quality (Hall & Barclay, 1991).

Onu & Adeosin (2020) investigated the propagation characteristics of UHF waves in Akwa Ibom State, Nigeria, and observed that features such as tall trees and clustered high-rise buildings and hills, caused obstruction of the transmitted 2.0 GHz UHF waves. Mardeni & Kwan (2010) carried out research on, optimization of Hata propagation prediction model in suburban area in Malaysia. The study revealed that the optimized Hata model had the best

performance as the relative error was the lowest compared to other models used.

Adeniran *et al.* (2020) studied FM radio signal variation of two major radio stations within Akwa Ibom State. The study presented spatial coverage of two FM radio stations within the state. Ajewole *et al.* (2012) carried out research to determine the coverage area of Power FM and Crystal FM radio signals in Niger State, Nigeria. The research revealed percentages of the Local Government Areas (LGAs) receiving Grades: A (signal level  $\geq 60$  dB $\mu$ V), B (signal level  $> 30$  dB $\mu$ V and  $< 60$  dB $\mu$ V) and C (signal level  $> 0$  dB $\mu$ V and  $\leq 30$  dB $\mu$ V) quality of service from the FM radio stations.

**MATERIALS AND METHODS**

**The Study Area**

The study was carried out at the peak period of the dry season in Minna, Niger State (Figure 1), on Search FM (92.3MHz), a campus radio of the Federal University of Technology, Minna, Niger State. Parameters of the transmitting station are shown in Table 1.



Figure 1: Map of Niger State showing Local Government Areas

**Table 1: Parameters of Search FM (92.3 MHz) Transmitting Station Used In This Study**

Frequency	92.3 MHz
Maximum Transmitter Power	160 W
Operating Transmitter Power	150 W
Transmitting Antenna Height above sea level	150 m
Transmitting Antenna Height above sea level	252 m
Receiving Antenna Height	10 m

**Data Acquisition**

Electric Field strength of Search FM radio signals was measured using a Digital Signal Level meter (GE – 5499) with a signal level range of 30-120 dB $\mu$ V. A Global Positioning System (GPS) Receiver (GARMIN GPS 72) was used to measure line-of-sight distance from the transmitting antenna and determine the elevation/coordinates of each measurement point. The measurements were taken at a distance interval of

100 m along the 4 radial routes shown in Table 2. Each route took off from the base of the transmitting antenna at the main campus of the Federal University of Technology, Minna. The sensitivity distance was determined as the distance at which the received signal strength fell to the minimum detectable level (0 dB $\mu$ V) of the receiving system. The four routes and their sensitivity distances are:

**Table 2: Details of the Four Radial Routes from the Transmitting Antenna**

S/No.	Route	Sensitivity Distance (km)
1	Gidan Kwanu - Bida	44.63
2	Gidan Kwanu - Suleja	34.15
3	Gidan Kwanu-Lapai	40.98
4	Gidan Kwanu-Sarkin Pawa	39.63

**RESULTS AND DISCUSSION**

The coordinates (Longitude and Latitude) of the measurement points, with the measured signal levels, were used in Surfer,

to draw a contour map of Search FM (92.3 MHz) radio signal coverage in Niger State (Figure 2).

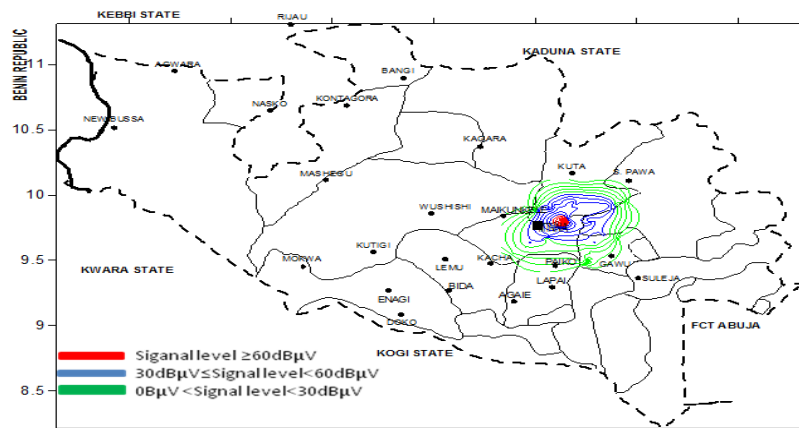


Figure 2: Coverage Area of Search FM (92.3 MHz) within Niger State

Figure 2 revealed that Search FM (92.3 MHz) campus radio does not provide optimum coverage in Niger State, which is acceptable, due to NBC regulation for campus radios. However, both campuses of the university, Bosso and Gidan Kwanu campuses which are about 15 km line-of-sight distance apart, receive adequate signal strength from the campus radio.

The measured Path Loss for each route was computed from the measured electric field strength using Equation 1, a relationship derived from standard field-strength and transmission-loss conversion formulas (ITU, 2019). Figure 3

shows path loss variation along the radial routes. Path loss increased with distance from the transmitting antenna.

$$L (dB) = P_t G_t (dBm) + 75.06 - E (dB\mu V/m) + 20\log_{10} f_c \quad (1)$$

Where:

$P_t$  = Transmitting power

$G_t$  = Transmitting Antenna Gain

$E (dB\mu V/m)$  = Electric Field Strength

$f_c$  = Carrier frequency (MHz)

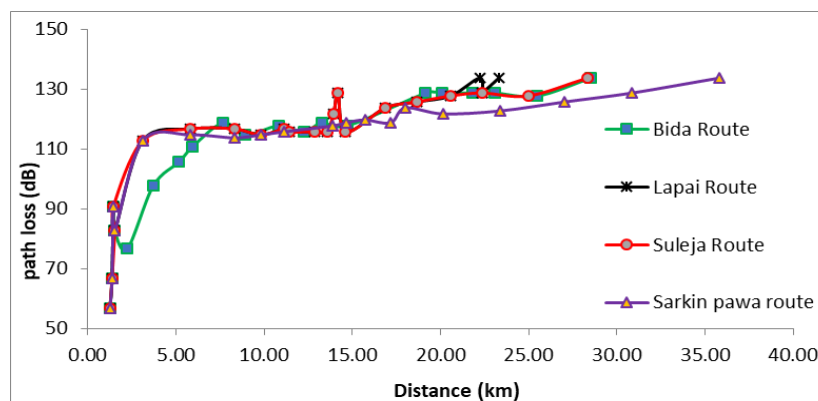


Figure 3: Comparison of Measured Path Loss for the four Routes

To evaluate radio-wave propagation in the study area, the Hata (frequency range of 150 – 1500 MHz), Egli (frequency range of approximately 40 – 900 MHz), and Ericsson (frequency range of 150 – 1900 MHz) models were employed. These models were selected because they are well-established empirical propagation models developed from extensive field measurements. The measurement campaign was conducted at 92.3 MHz within the FM broadcast band. The Egli model was selected because its recommended operating range encompasses VHF frequencies and it has been widely applied to broadcast propagation studies. The Hata and Ericsson models were additionally employed as benchmark empirical models to facilitate comparative analysis with measured path-loss data. Although the operating frequency lies below the original validity ranges of the Hata and Ericsson models, their inclusion enables an assessment of their predictive capability under local propagation conditions and provides a basis for model performance comparison.

The corresponding path loss for each route as predicted by Hata, Egli and Ericson Models were estimated using the following equations:

**Hata Model for Urban Areas**

$$L(dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} + (44.9 - 6.55 \log h_{te}) \log R - [1.11 \log(f_c) - 0.7] h_m - [1.56 \log f_c - 0.8] \quad (2)$$

where  $f_c = 92.3\text{MHz}$ ,  $h_{te} = 150\text{ m}$ ,  $h_m = 10\text{ m}$ . Hence,

$$L (dB) = 78.534 + 30.647\log_{10} R \quad (3)$$

**Hata Model for Suburban Areas**

$$L (dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} + (44.9 - 6.55 \log h_{te}) \log R - 2\{[\log \frac{f_c}{28}]^2 + 5.4\} \quad (4)$$

$$L (dB) = 79.549 + 30.467\log_{10} R \quad (5)$$

**Egli Model**

$$L_t (dB) = 20\log_{10} f_c + 40 \log_{10} R - 20\log_{10} h_b + 85.9 - 10\log_{10} h_m \quad (6)$$

Where  $f_c = 92.3\text{ MHz}$ ,  $h_b = 150\text{ m}$ ,  $h_m = 10\text{ m}$  hence;

$$L_t (dB) = 71.682 + 40\log_{10} R \quad (7)$$

**Ericson Model For Suburban Areas**

$$PL (dB) = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(h_r) - \log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f) \quad (8)$$

Where;  $a_0= 36.2, a_1 = 30.2, a_2 = 12.0, a_3= 0.1, h_b = 150$  m,  
 $h_r = 10$  m

$$g(f) = 44.49 \log_{10}(f) - 4.78(\log_{10}(f))^2 \quad \text{where } f = 92.3 \text{ MHz}$$

$$PL (dB) = 118.255 + 20.2 \log_{10}(d) \quad (9)$$

**Ericson Model For Suburban Area**

$$PL (dB) = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(h_r) - \log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f) \quad (4.9)$$

Where;  $a_0= 43.20, a_1 = 68.93, a_2 = 12.00, a_3= 0.1$

$$PL (dB) = 125.255 + 58.93 \log_{10}(d) \quad (10)$$

Figures 4 to 7 show plots of measured path loss and predicted path loss against distance for each of the four routes

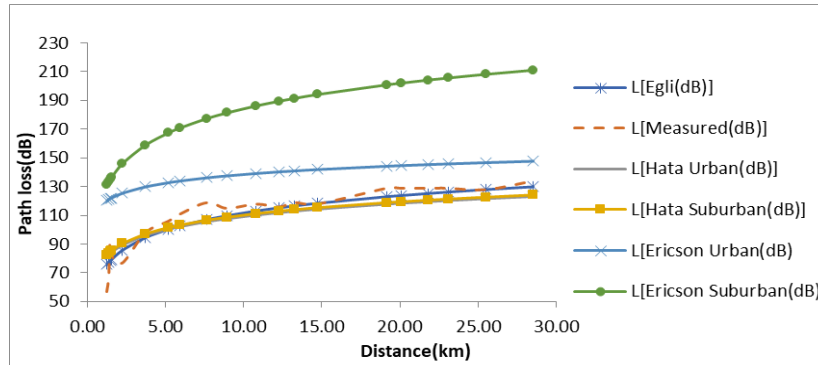


Figure 4: Measured and Models Path Loss Comparison for Bida Route

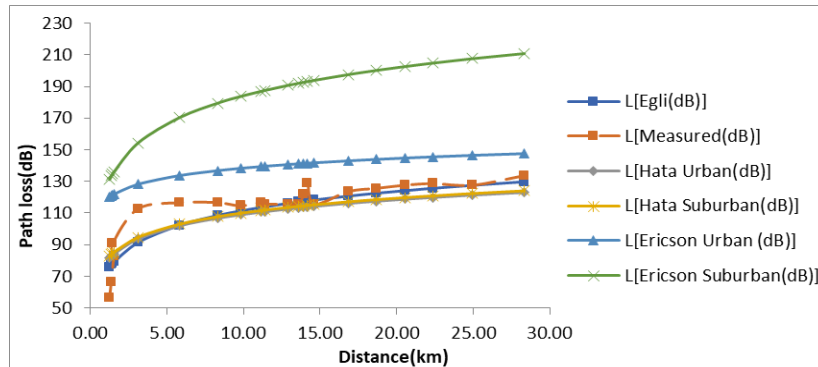


Figure 5: Measured and Models Path Loss Comparison for Suleja Route

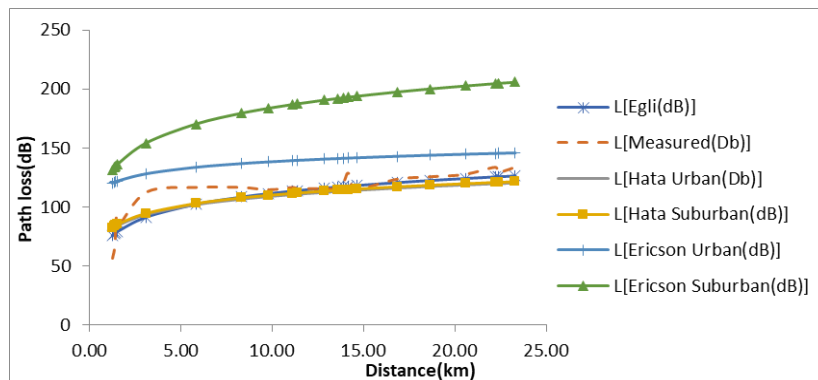


Figure 6: Measured and Models Path Loss Comparison for Lapai Route

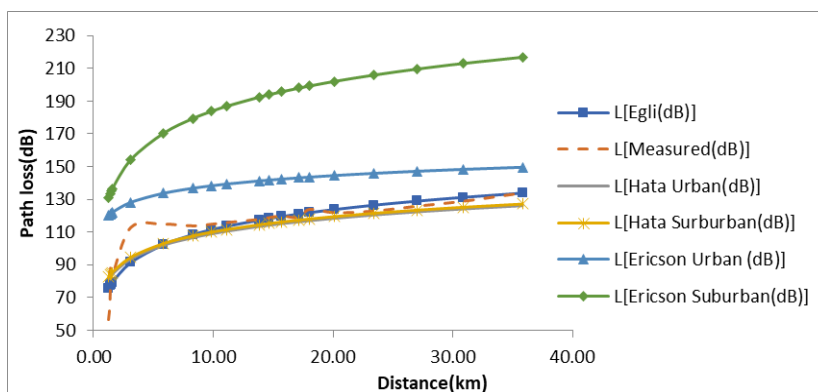


Figure 7: Measured and Models Path Loss Comparison for Sarkin Pawa Route

As seen in the path loss comparison in Figures 4 to 8, Ericson Urban/Suburban path loss models overestimated the path loss on the four routes. Hata urban/suburban path loss models underestimated the path loss for the routes, as compared to Eogli path loss model. Eogli path loss model has estimated values that are close to the measured path loss of Search FM radio signals in Niger State.

The Root Mean Square Error (RMSE) or Deviation of each model from the measured path loss along the four routes was also computed using equations 11.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (X_{obs} - X_{model})^2}{n}} \tag{11}$$

Where  $X_{obs}$  is observed or measured values and  $X_{model}$  is modelled values at time/place  $i$ .

The RMSE of the path loss models for each route is shown in Table 2.

Table 2: Comparison of RMSE for the Four Routes

Models	Bida Route	Suleja Route	Lapai Route	Sarkin Pawa Route
Ericson Suburban	68.74	68.89	68.54	71.55
Ericson Urban	30.59	27.93	27.31	29.47
Egli	7.43	8.72	8.82	8.39
Hata Urban	10.14	10.80	11.18	9.68
Hata Suburban	9.87	10.37	10.69	9.40

Egli model had the least error of 7.43 dB, 8.72 dB, 8.82 dB and 8.38 dB. While Ericson Model for suburban area had the greatest RMSE of 68.73 dB, 68.89 dB, 68.54 dB and 71.55 dB.

Figure 8 shows comparison of the average RMSE for the various models. Eogli Model had the least average RMSE of 8.34 dB while Ericson Model had the greatest average RMSE of 69.43 dB.

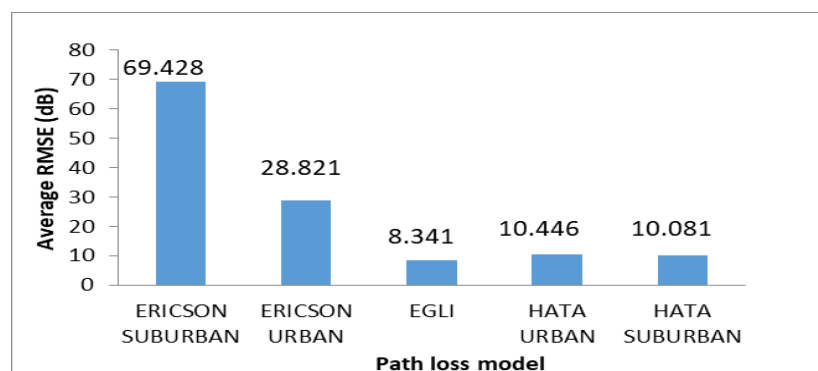


Figure 8: Average Root Mean Square Error for the Path Loss Models

**CONCLUSION**

Search FM (92.3 MHz) Campus Radio of the Federal University of Technology, Minna, Niger State does not provide optimum coverage in Niger State. However, as a campus community radio, it can be said that it gives optimum coverage to its target community, Federal University of Technology, Minna.

The radio signals cover mainly the State capital (Minna) with some few communities receiving Grade A quality of service (that is, the residents of Gidan Kwanu) while the rest part of Minna receive Grade B quality of service. Some towns like Paiko, Gawu, Kacha, Maikunkele, Kuta and Pawa receive

Grade C quality of service and all other parts of Niger State are completely out of the coverage area of Search FM radio signal. Search FM therefore, is in compliance with NBC regulations.

The path loss comparison showed that Eogli model is the most suitable for predicting path loss of FM radio signals in Minna followed by Hata model for urban area and then, Hata model for suburban area. The performance of Eogli model was the best as its mean RMSE value of 8.34 dB, was the lowest compared to the other models.

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