LAUTECH Journal of Engineering and Technology 19 (4) 2025: 1-12
10.36108/laujet/5202.91.0410

Performance Evaluation of Hit Frequency Modulation 95.7 Megahertz Radio Signal Strength along Selected Routes in Benin City, Edo State, Nigeria

[1]Adoga C. E., [2]Amhenrior H. E. and [3]Ikharo B.

[1,2,3]*Department of Electronic and Electrical Engineering, Edo State University, Uzauire.*

Article Info

Article history:

Received: June 21, 2025
Revised: July 22, 2025
Accepted: July 24, 2025

Keywords:

Signal Strength Level, radio waves, path loss, received signal strength and propagation model

Corresponding Author: adogakrizo1@gmail.com

ABSTRACT

The paper presents the evaluation of the Performance of Hit FM 95.7MHz Radio Signal Strength along five selected routes in Benin City, Edo State, Nigeria. The methodology involves the use of the Tinysa Spectrum Analyzer to measure the signal strength at intervals of 500 meters across the selected routes in Benin City. A Distance Area Application and Global Positioning Receiver System (GPRS) were also employed to measure the distances from the Base Station Transmitter across the routes in the location. A path loss model was evaluated based on these measurements and compared to standard models of the Hata, Egli, Free Space and Durkin's models. The results obtained showed a path loss increase of 95.44dB per decade in the urban area and the developed model outperforms existing models and the free space model proved closest to the measured data.

INTRODUCTION

Hit FM 95.7 MHz, based in Benin City, is a respected radio station providing premier entertainment and broadcasting services in Edo State, Nigeria. With the mission of becoming the country's top-rated radio station, Hit FM employs state-of-the-art technology, broadcasting with a 12-kilowatt base transmitting power and an antenna height of approximately 680 feet. Understanding signal propagation is essential for effective network design; researchers have long studied how signal strength diminishes with distance from transmission towers (Frattasi *et al*., 2010).

Signal strength directly affects the quality and consistency of radio communication, with path loss or signal degradation occurring as radio waves travel from transmitter to receiver, influenced by factors such as building congestion, antenna height, weather conditions, and terrain (Alonso *et al*., 2020). For radio transmission managers, evaluating signal strength is crucial for assessing losses and optimizing network procedures. As radio stations expand and digitalization increases, continual signal strength assessment at varying distances is necessary to gauge transmitter performance and discover areas for improvement (Imoize *et al*., 2022).

Spectrum analyzers are used to measure signal strength in decibels (dBm or dBv). Robust base transmitter signals are vital for reliable reception, especially in challenging environments affected by industrial interference, topography, and vegetation (Nosike *et al*., 2019). Therefore, designing radio networks to minimize interference and maximize coverage distance is key to optimal performance (Emeruwa *et al*., 2018). Path loss increases with both frequency and distance and is influenced by line-of-sight clearance, antenna height, and multipath fading (Naseem *et al.*, 2021). Overcoming obstacles in the environment and optimizing network design with modern techniques can significantly enhance signal strength and transmission quality (Ekunayo *et al*., 2020).

LITERATURE REVIEW

Propagation models

The evaluation of transmission models reveals that signal strength is affected by various factors, including distance, obstacles, weather conditions, and environmental features. This study focuses on Empirical Path Loss Models due to their benefits, analytical effectiveness, and accuracy in similar locations. Specifically, the Durkin, Hata, Egli, and Free Space Path Loss models were investigated.

a. Durkin's model

Durkin's model is used to assess signal wave performance and path losses over irregular terrain in radio routes. However, this model has limitations, including its inability to accurately account for transmission effects through building walls and vegetation, as well as its lack of support for multipath radio communication networks. Despite these limitations, the model provides reasonable predictions for signal strength when characterizing a base transmitter antenna above rooftop height, with standard deviation errors ranging from +/- 5 dB. The algorithm employed in Durkin's model selects the line-of-sight (LOS) path between the transmitter and receiver (T-R) and calculates the clearance between the (T-R) antenna heights and the ground in free space. The Fresnel-Kirchhoff diffraction parameter (V) is then used to calculate the signal strength of unobstructed waves. The Durkin's model is expressed as:

$$V = h\sqrt{\frac{2(d1+d2)}{\lambda d1d2}} \quad (1)$$

Equation 1 illustrates the relationship between key parameters, where h represents the relative height of the transmitter-receiver (T-R) pair, d1 and d2 denote the distances from the transmitter and receiver, respectively and λ signifies the wavelength of the radio signal. This equation is used to evaluate free space loss and received power, leveraging the two-ray ground model, also known as the plane earth propagation equation

b. Egli model

The Egli model was introduced by John Egli in 1957. It is a terrain-based model for radio frequency transmission. The model evaluated the path loss of all point-to-point structures for both fixed antenna and mobile antenna in cellular transmission. The model is made from actual data on ultra-high frequency (UHF) and very-high frequency (VHF) television propagation in developed cities. The model evaluates the total path loss of straight routes used for outdoor direct propagation. This transmission model is realistic for frequencies going from 30 MHz to 700 MHz at distances of 40 km. The model is established for capacity statistics of very high frequency television and ultra-high frequency transmissions in cities (Popoola *et al.* 2019). The Egli model is expressed as:

$$\mathrm{PR} = GBGM\left[\frac{hbhm}{d^2}\right]2\left[\frac{40}{f}\right]2\,PT \quad (2)$$

In equation 2, PR is received power (w), PT is the transmitted power (w), GB is the gain of the base station antenna, GM is the gain of the mobile station antenna, hb is the height of the base station antenna (m), hm is the height of the mobile station antenna (m), d is the distance from base station antenna (m) and f is the frequency of transmission. The limitation of the model is that it does not divide the path loss into free space and other losses; rather, it evaluates the path losses as a whole. The Egli path loss model is also expressed as:

$$L = 117 + 40logd + 20logf - 20log(H_T - H_R) \quad (3)$$

Where d is the distance, f, H_T is the height of the transmitter, and H_R is the height of the receiver.

c. Hata path loss model

The Hata path loss model is a consistent research of the graphical signals from the Okumura path loss model. It is a radio transmission model for evaluating the path loss of Cellular Broadcast in peripheral locations for frequencies going from 150MHz - 1500MHz. This model takes into account signal strength for rural, moderate, and large cities. The model exposed rural areas with definite modification factors to ascertain the path loss value for distance coverage. The model also integrates graphical signal waves from the Okumura model and circulates it further to distinguish the effects of reflection, scattering and diffraction caused by city building blockings. The Hata model for rural surroundings applies to the transmission in exposed capabilities where no hitches can obstruct the transmission connection. The Hata model path loss equation is given as:

$$L(Urban)(dB) = 69.5 + 26.16log10f - 13.82log10(hb) - a(hm) + (44.9 - 6.55log10hb)log10d \quad (4)$$

For small to moderate city, the mobile antenna factor is given as:

$$a(hm) = (1.1log10f - 0.7)hm - (1.56logf - 0.8)dB \quad (5)$$

For large city:

$$a(hm) = 3.2(log10(11.75hm)2 - 4.97dB\ for\ \text{f} \geq \text{300MHz}$$

$$a(hm) = 8.29(log10(1.54hm)2 - 1.1dB\ for\ f \leq \text{300MHz} \quad (6)$$

Where f is the carrier frequency (MHz), hb is the base station antenna height (m), hm is the mobile station antenna height (m), d is the base station to mobile station distance (km) and a(hm) is the correction factor (formula varies for urban to large urban).

d. Free space transmission model

The free space propagation model is the elementary path loss model, which possesses a direct route signal between the transmitter and the receiver with no multipath components (Iram *et al*., 2018). The free space transmission loss model evaluates the cellular electromagnetic wave losses anticipated by a radio frequency wave as it passes from the base transmitting station to the receiving station along an unrestricted route (Kitao *et al*., 2016). The free space evaluation model evaluates the decrease in radio signal strength (RSS) as the distance between a stationary station and a moving station increases. The problem with this model is that it does not measure distinct factors that reduce the transmission of signal strength in a mobile transmitter station. Although the logical evaluation shows path loss in the radio signal system. The doubt gives rise to either the total system loss due to the radio signal system plan or the functional effects on the transmitting signal from the permanent station (Nnadi *et al*., 2023). The free space model uses the following formula:

$$PL(dB) = 20log10y(km) + 20log10f(MHz) + 32.44 \quad (7)$$

Where f = frequency in MHz and y = distance in km, PL is path loss in dB.

Characterization of Radio Transmission

The gradual decrease of the Signal Strength (Power) of the transmitted electromagnetic waves as the Transmitter and Receiver (T-R) distance increases is termed Path Loss.

$$PL(dB) = 10log\frac{Pt}{Pr}\ (dB) \quad (8)$$

The average path loss for a random transmitter to receiver separation is a function of distance given by:

$$PL(dB) = PL\ (do) + 10\eta log\frac{d}{do} \quad (9)$$

It was displayed by (*Otasowie et al*., 2016) for values of d, the path loss PL (dB) is an arbitrary variable with a log-normal distribution, whose mean value is due to shadowing. To reward shadow diminishing, the path loss outside the location distance is given as

$$PL(dB) = PL\ (do) + 10\eta log \frac{d}{do} + A \quad (10)$$

Where A is the shadowing factor of Gaussian arbitrary variables and the standard deviation is given as

$$\sigma_e = \sqrt{\sum_{i=1}^{n} \frac{[\ PL(d1) - PL\ (do)]\ ^2}{N}} \quad (11)$$

Evaluation of Model Substantiation

1. Mean Error (ME). The MSE is the maximum to describe how near the route is to the data facts. It shows the change between the measured path loss (Fr) values and the experimental evaluation path loss model (F_m) at a transmitter-receiver distance (d_0).

$$ME = \frac{1}{n}\sum_{i=1}^{n}(F_r - F_m) \quad (12)$$

2. The commonly agreed root mean square error for a model is about (6-10) dB (Chika *et al*., 2023). The RMSE value is evaluated using the equation below:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(F_r - F_m)^2} \quad (13)$$

Standard deviation error.

This is used to evaluate the difference in signal strength of the considered path loss model for the Hit FM station in the selected routes; the values attained from the established path loss model are related to the ones gotten from field measurements. The mean error (ME), root mean square error (RMSE), and standard deviation error (SDE) are arithmetical methods used to evaluate the enhanced path loss transmission models (Elechi *et al*., 2018).

REVIEW OF RELATED WORKS

Numerous research studies have evaluated the value of path loss models. Researchers collect measurement data from specific locations to assess model performance. For instance, Faruk *et al*. (2018) focused on propagation path loss characterization, evaluating VHF and UHF channels in Ilorin, Kwara State, using a log-normal propagation path loss model. The findings indicated an average path loss value of 2.80 dB, penetration loss of 11.49 dB, and standard deviation of 7.35 dB at 1 km. Similarly, Chika *et al*. (2023) investigated the effects of atmospheric conditions on Ultra High Frequency (UHF) radio waves in Benin, Edo State. Television signal strength and weather conditions were measured to find out the atmospheric factors that significantly influence signal strength. The study's results were shared with the Edo Broadcasting Service for consideration in transmission station design and installation.

Khalid *et al*. (2018) examined UHF radio signal waves in areas with dense vegetation. The findings highlighted the role of trees, their shape, leaves, and height in path loss evaluation. The study also noted that signal strength decreases in hilly areas with dense foliage, emphasizing the need for careful planning in unstable city locations. These studies demonstrated he importance of understanding path loss and signal strength in various environments, ultimately informing the design and optimization of wireless communication systems. Studies have consistently shown that path loss models play a fundamental role in planning radio frequency signal networks. These models enable network agents to optimize signal transmission from cell towers, thereby enhancing customer satisfaction (Hoomod *et al*. 2018; Alnatoor *et al*. 2022). The paper utilized various propagation models, including Hata, Ericson, and European Cooperation in Science and Technology (COST 231), to evaluate measured field data. The findings indicated that the Hata model performed well in rural areas, while the Ericson model showed minimal discrepancies in urban settings.

Similarly, Ajose *et al*. (2017) employed propagation models to predict radio signal strength and mitigate multipath fading effects. Their study used drive tests and root mean square error analysis to evaluate the performance of different models. The results showed that the Ericson model provided a good fit for measured path loss data, with root mean square errors of 5.85 dB and 5.86 dB at antenna heights of 1.5 m and 2.0 m, respectively. Atayero *et al*. (2019) emphasized the importance of realistic transmission models for effective radio network planning in urban environments. They noted that existing models have limitations, which can lead to computational errors. Therefore, further research is needed to develop and validate new methods for predicting path loss propagation in urban settings.

Research on signal strength and transmission models has yielded valuable insights. According to Akanni *et al*. (2020), signal fading occurs due to differences in signal strength over a wavelength. Their study evaluated various transmission models, including Okumura-Hata and Cost 231, to determine the most suitable for network planning at 1800MHz. Also study by Oluyinka *et al*. (2016) found that GSM signal strength depends on factors like transmitter location, traffic demand, and user density. They measured signal strength using spectrum analyzers and smartphones, revealing that network performance varied between operators, with Etilsalat outperforming MTN in their study area.

Accordingly, studies have investigated the impact of various factors on signal strength in wireless networks. Joseph *et al*. (2023) examined the effect of radio refractivity on signal strength for two portable networks, 9mobile and MTN, in a city. They measured signal strength hourly using a portable Android software and calculated radio refractivity using the 2015 International Telecommunication Union Radio communication region (ITU-R) model. The results showed no proven link between signal strength and radio refractivity, attributing variations to factors like antenna height, structures, wind, and distance from the base transmitter to the receiver. Another study by Mohammed *et al*. (2021) focused on indoor signal loss and its impact on path loss with distance. They evaluated the influence of building materials on the global system for mobile communication signal strength for MTN, Globacom, and Airtel networks in Rivers State, Nigeria. The findings revealed that buildings with Alucoboard walls had higher penetration signal strength compared to concrete buildings with corrugated iron roofs. Nkordeh *et al*. (2014) compared radio signal propagation models, including Okumura, Hata, and COST 231, based on path loss and signal strength quality. They emphasized the importance of considering factors like signal distance, bit error rate, antenna gain, and data rate when designing wireless networks.

Another study by Zakari *et al*. (2022) highlighted the need to select appropriate factors and telecommunication models to ensure enhanced productivity in television broadcasting. These studies demonstrated the complexity of signal propagation and the need for careful consideration of various factors to optimize wireless network performance. A paper by Olika *et al*. (2021) investigated suitable models for radio transmission path loss in a suburban city. The study measured Radio Signal Strength (RSS) in two European environments - open valleys and channels - using VESNA sensor nodes with radio transceiver modules across three frequency bands: 400 MHz, 868 MHz, and 2400 MHz. Different transmission models, including flat earth, two-slope, and four-slope models, were evaluated. The findings indicated that the flat earth model more accurately predicted path loss values in channels compared to open slope models. Additionally, the study evaluated standard transmission path loss measurements at four positions in Malaysia, comparing results from six empirical path loss models: Standard University Interim (SUI) Model, Hata, Cost 231, log-normal shadowing, Egli, and Error Correction Coding 33. The paper concluded that the SUI and lognormal shadowing models effectively predicted path loss values, providing valuable insights for radio transmission planning.

METHODOLOGY

Research Location

Field measurements were conducted in Benin City, the capital of Edo State, Nigeria. Situated between Latitude 06°20´E to 6°22´N and Longitude 5°35´E to 5°44´E, the city lies at an average elevation of 77.8m above sea level. Strategically located along major highways connecting Lagos to Eastern states. The city serves as a critical hub for commerce and trade. Its extensive road network links Benin City to neighboring towns like Siluko, Sapele, Okene, and Ubiaja. The city is also accessible by air and is proximal to the Niger River Delta ports of Sapele and Koko. Benin City's layout features a dense arrangement of houses and streets. The city is home to various industries, including processing plants, a Crepe rubber factory, and Sawmills.

Description of the broadcast Station

Hit FM 95.7MHz Radio Base Transmitter Stations (BTS) is a digital global radio transmitter owned by Edo State Broadcasting Corporation and located off Benin Auchi Road, Aduwawa, Benin City. It operates on UHF channel 55 with a frequency of 97.5 MHz. The transmitter has a 207.264-meter mast, a 12 kW power output covering a vast radius of 150 kilometers. Its Effective Radiated Power (ERP) is 41.76 dBw. Detailed specifications are provided in Table 1.

Table 1: Hit FM 95.7MHz Parameters.

S/N	Features	Description
1	Base Station Power (kW)	12 kw
2	Base Station Frequency (MHz)	95.7 MHz
3	Height of Transmitting Mast(m)	150 m
4	Elevation of Propagation Aerial (m)	10 m
5	Propagation Aerial Gain (m)	20.7 m
6	Direction of Transmitting Antenna	Omni–directional
7	Power Transmitted (dB)	85.5 dB
8	Transmitting Antenna Height (m)	168.2 m
9	Distance btw the transmitter and Receiver	7 km
10	Spectrum Analyzer antenna height (m)	3 m

Experimental Arrangement for Measurement

The equipment employed to conduct the measurement is a Tiny Spectrum Analyzer connected to a laptop through a mini-Universal Serial Bus (USB) cable to ensure better high-resolution data acquisition. A global positioning system (GPS) receiver set was used to locate base station locations and a map was used to enable the driving route. A distance application in conjunction with a compass was used in ascertaining directions. To augment the path loss model, field data were taken at 0.5 meters (500 m) intervals up to 13000 meters from the base station, with received signal strength (RSS) recorded in Comma Separated values (CSV) format. The mobile device was maintained at a constant height of 1.5 meters. Figure

1 depicts the Map of the study location of the reference measurement location.

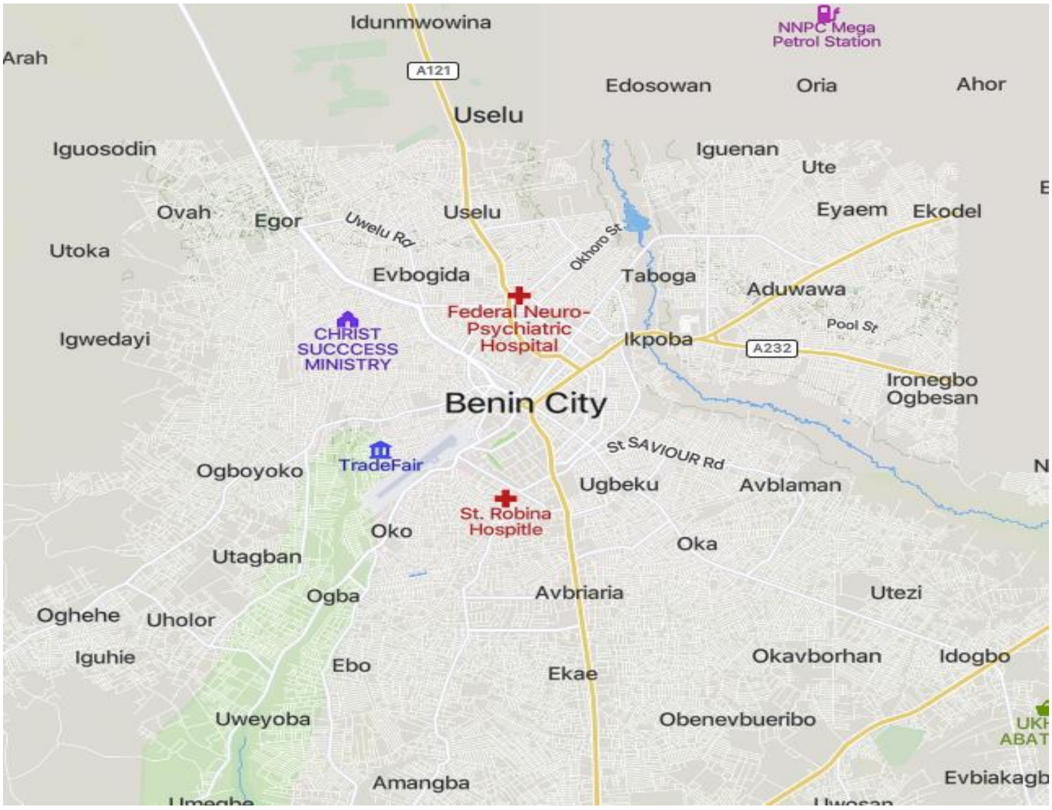

Figure 1: Map of the study area

Characterization of Radio Transmission and Path Loss Modeling

The substantial signal strength decreases from the transmitter to the receiver as the distance increases is termed path loss, given in equation (7) as $PL(dB) = 10log\frac{Pt}{Pr}\,(dB)$ is evaluated by employing measured data at a distance, d_0 of 0.5km, average power given as:

$$PL(dB) = 10\log\frac{40.7918}{1.167 \times 10^{-8}}$$

$$PL(dB) = 10log40.7918 - 10\log 1.167 \times 10^{-8}$$

$$= 95.44dB \qquad (14)$$

The evaluation was physically computed simultaneously to attain the path loss exponent (η) given as:

$$\sigma(\eta) = \sum_{i=1}^{n}[Pl\,(d1) - PL\,(do)]^2$$

$$\sigma(\eta) = [1687.68 - 2080.50\eta + 745.83]^2$$

$$= 2[745.83] - 2080.50$$

$$= 1491.60 - 2080.50$$

$$\eta = 1.40 \qquad (15)$$

$$\sigma_e = \sqrt{\sum_{i=1}^{n}\frac{[\,PL(d1) - PL\,(do)]2}{N}}$$

$$\sigma_e = \sqrt{\frac{[\,1687.69 - 2080.50\eta + 745.83\eta]2}{12}}$$

$$\sigma_e = \sqrt{\sum_{i=1}^{n}\frac{[\,1687.69 - 2080.50(1.40) + 745.83(1.40)]2}{12}}$$

$$\sigma_e = \frac{236.8168}{12}$$

$\sigma_e = 4.4$ dB (16)

The measured path loss exponent along selected routes in Benin City was discovered to be 1.40 with a shadow factor of 4.4 dB and PL (d0) is the path loss at station distance known to be 85.5 dB. Putting PL (d0), η, and count A to cover the error, which results loss model for the Benin City area by using equation (9) given as: $PL(dB) = PL\ (do) + 10\eta log\frac{d}{do} + A$

$$PL(dB) = 85.5 + 10\eta log\frac{d}{do} + 4.4$$

$$PL(dB) = 89.9 + 10\ (1.40) log\frac{d}{do}$$

The Empirical path loss model along selected routes in the Benin City area is given as:

$$PL(dB) = 89.9 + 14\log(d\ /\ d0) \quad (17)$$

The field measurements are evaluated to ascertain the values of PL (d0), η, and A for the Benin City area. The field measured values were evaluated along selected routes distance is shown in equation (11) as:

$$PL(dB) = 85.5 + 14 log\frac{d}{do} + 4.4\ (dB) \quad (18)$$

RESULTS AND DISCUSSION

Analytical results

Table 2 shows the mean values of the measured RSS at varying distances along selected routes A to F, for distances (0.5 km ≤ di ≤ 6.0 km).

Table 2: Signal Strength Values of Hit FM 95.7MHz across Selected Routes in Benin City.

Distance (km)	**Signal Strength (dB)**					
	A	B	C	D	E	F
0.5	95	84.5	65	98	79	91
1	93	88.5	77.6	87.4	90	84
1.5	88	97	103	112.1	98	95
2	87	105	100	96	110.9	89
2.5	104	106	96	90	120.8	87
3	78	87	109.8	105.8	134.6	93
3.5	71	102	104	107	132.9	89
4	91.9	113.4	93	103	135	92.7
4.5	89	92	81	106.9	84.5	94
5	94.9	83.9	91.4	111.2	97.7	103.5
5.5	83.9	87.4	87	99	104	90
6	106	94.7	90.3	97.7	111.6	88

Table 3 shows a comprehensive comparison of the measured and predicted path loss signal strength values of Hit FM 95.7MHz along various routes in Benin City and Table 4 presents the Path loss Exponent, Standard Deviation, and Reference path loss values. A path loss exponent of 1.4 and a shadow factor of 4.4 dB suggest that the location is reasonably clogged, causing obvious signal reduction and substantial inconsistency due to shadowing effects. This evidence is essential for planning and improving wireless communication systems in such a location to guarantee consistent signal coverage and quality. Figure 2 shows the path loss values plotted in a 3D format, showing that path loss increases with the line-of-sight distance between the base station and the radio receiving station, with moderate scattering. After the breakpoint distance, the decrease becomes more obvious and irregular. However, the reduction supports the environmental characteristics of the transmitter base stations.

Table 3: Measured and Predicted Path Loss Signal Strength Values of Hit FM 95.7 MHz along Selected Routes in Benin City.

SN	Distance (km)	Measured path loss [Pl (d 0)]	Predicted Path loss [Pl (d1)]	[LP($\mathbf{d0}$) $-\boldsymbol{LP}(\mathbf{d1})$]	[LP($\mathbf{d0}$) $-\boldsymbol{LP}(\mathbf{d1})]^2$
1	0.5	85.5	85.5	0	16 – 24.08η +9.06η2
2	1	88.95	85.5 + 3.01η	4 – 3.01η	144 – 114.48η + 22.75η2
3	1.5	97.43	85.5 + 4.77η	12 – 4.77η	124 – 134η + 36.24η2
4	2	96.65	85.5 + 6.02η	11.2 – 6.02η	225 – 209.4η +48.72η2
5	2.5	100.46	85.5 + 6.98η	15 – 6.98η	289 – 264.52η + 60.53η2
6	3	102.23	85.5 + 7.78η	17 - 7.78η	169 – 219.7η +71.40 η2
7	3.5	98.48	85.5 + 8.45η	13 – 8.45η	301.72 – 313.7η + 81.54η2
8	4	102.8	85.5 + 9.03η	17.4 – 9.03η	83.4 – 174.20η + 91.01η2
9	4.5	94.63	85.5 + 9.54η	9.13 -9.54η	166.41 – 258 η + 100η2
10	5	98.44	85.5 + 10η	12.9 – 10η	29.92 – 113.78 η+ 108.16η2
11	5.5	90.97	85.5 + 10.40η	5.47 – 10.40η	139.24- 254.64η+ 116.42 η2
12	6	97.33	85.5 + 10.79η	11.8 – 10.79η	

Table 4: Path loss Exponent, Standard Deviation, and Reference path loss values

Serial	Parameter	Benin Area
1	PL (d0)	85.5
2	A (dB)	4.4
3	η	1.4

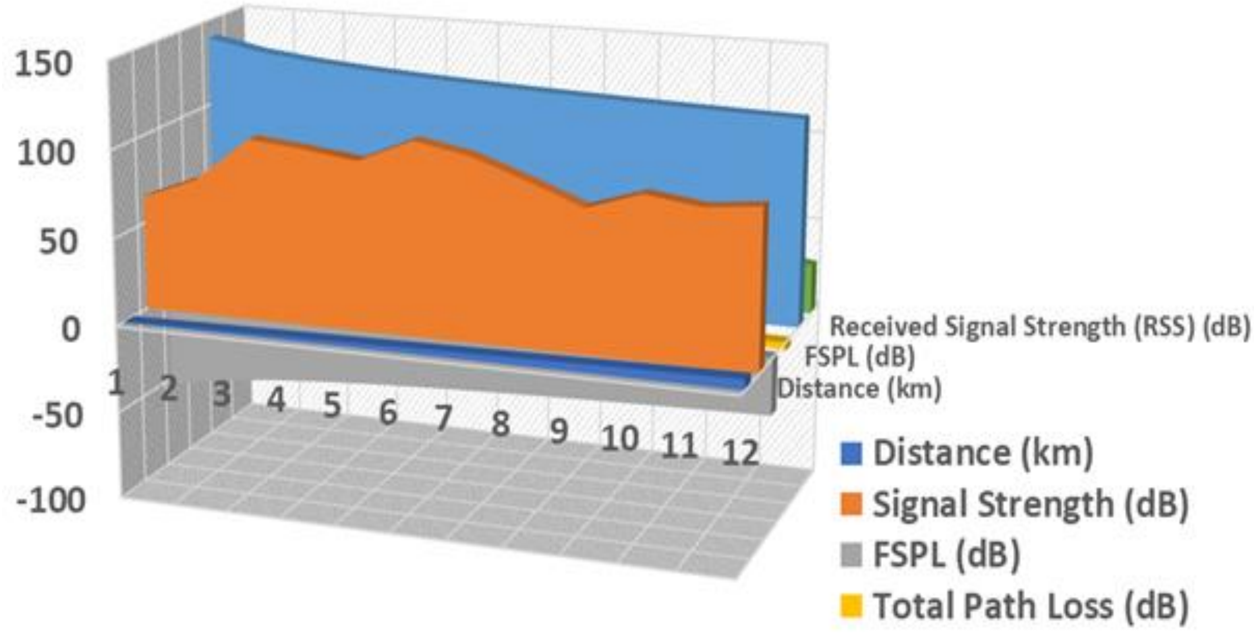

Figure 2: Graph Plot displaying the average measured Path loss distance.

To validate the reliability of the suggested path loss model, this study related the statistically anticipated received signal strength (RSS) results and other existing models with the measured results. The RSS was considered under similar propagation situation parameters. Using equation (2) for the Urban path loss determination of the free space model, equation (3) for the Hata model, and equation (5) for the Egli model, the parameters were replaced (f = 95.7 MHz, h = 1.5m and h = 150m) into these equations. The resulting plots are depicted in Figure.3

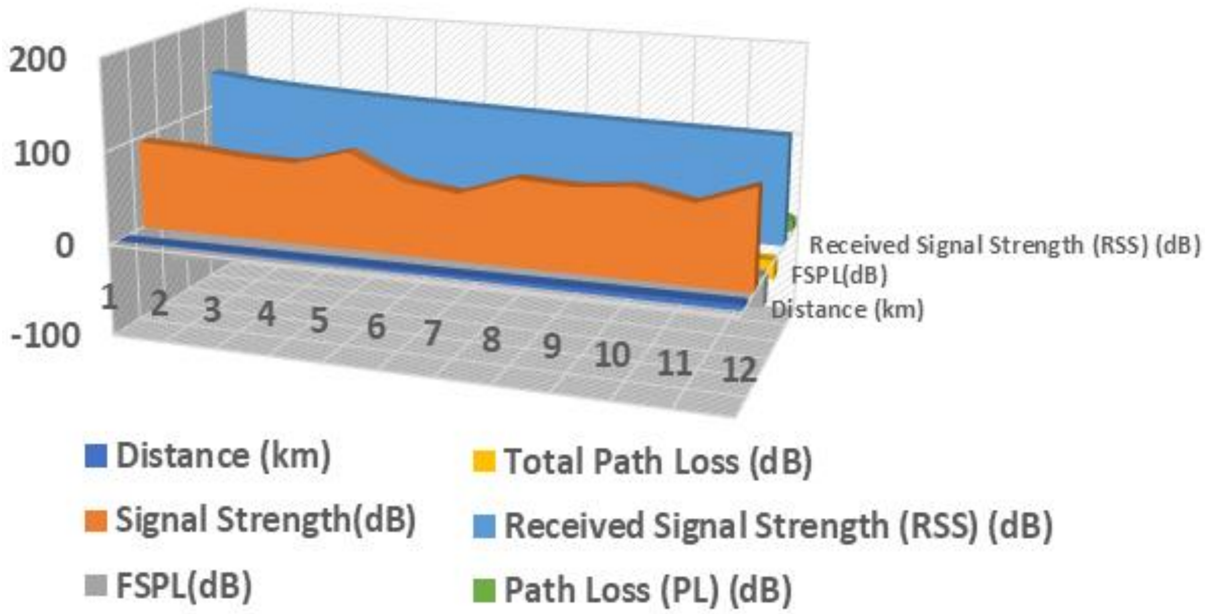

Figure 3: Comparison of the Empirical Model with Existing Models across Selected Routes

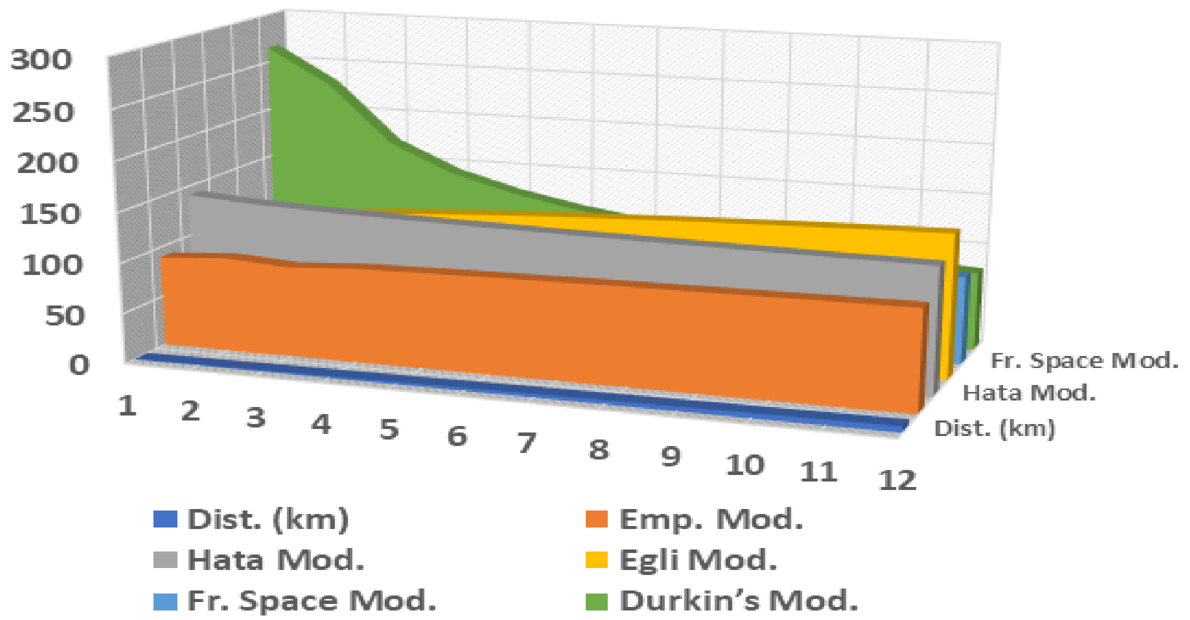

Figure 4 shows the validation of the Empirical model with Egli, Hata and Free Space Path Loss Models in Benin City

From the plotted graph of the path losses in Figure 3, the Free Space model is the closest model to the measurement due to the location in which the measurement was conducted. The next model after that measurement was obtained from the Egli and Hata path loss model. Evaluations between the models have displayed some disparities. These disparities confirm that the FSPL model or any existing model cannot properly fit into a location other than that for which it was established. To make such models suitable for different locations, they must be improved.

CONCLUSION

This study enhances a statistical path loss model for the Hit FM 95.7 MHz network in Benin City, Edo State, Nigeria. By comparing measured data with existing models (Free Space, Egli, Hata and Durkin), making necessary adjustments to improve a location-specific model. Our findings demonstrate the effectiveness of the urbanized model in predicting path loss in the study area. Future research will focus on improving radio signal strength and reliability in the region.

ACKNOWLEDGEMENT(S)

The authors wish to acknowledge and recognize Hit FM 95.7 MHz, on Benin Auchi Road, Aduwawa, Benin City, Edo State, for the release of their transmitting parameters used for this study.

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