

RESEARCH

Optimization of AIRTEL GSM signal quality for Adamawa State University, Mubi

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0009-0005-1329-193X**Received:** 07 April 2025; **Accepted:** 09 June 2025; **Published:** 03 July 2025

Path Loss is a gradual attenuation of the Global System for Mobile Telecommunication (GSM) signal when transmitted between the Base Transceiver Station (BTS) and Mobile Unit (MU). Network engineers use Path Loss in the designing and planning of their network signal. Path Loss models also help network engineers in optimizing their network signal for deployment. This research work considers the applicability of the Hata model in the suburban area of Adamawa State University in the Mubi North Local Government Area. The average root mean square error (RMSE) between the predicted and measured was obtained as 1.65 dB, which falls within the 6 dB for good signal propagation. The model of the area was optimized and can be used by the AIRTEL network for deployment in the study area in order to provide quality of service (QoS). The relationships between Path Loss and Temperature, Humidity, and Wind Speed were obtained as 0.044, 0.058, and 0.257, respectively. The results show a linear relationship between Path Loss and the weather parameters; hence, it does not exert any effect.

Keywords: Path Loss, optimization, Hata, RMSE, weather parameters

Introduction

Path Loss is an important tool in determining the network behavior of a signal in a particular area when it propagates between the Base Transceiver Station (BTS) and Mobile Unit (MU). Path Loss models are been used by network engineers in optimizing their network resources for deployment (1, 2). Every BTS is designed to cover a specific distance for effective communication. However, poor network coverage within the designed area results in poor quality of service (QoS), echoes, interconnectivity, and frequent dropped calls (3). Network planning is one of the important tools in the prediction of Path Loss with major concern in the cover area, interference, and frequency assignment (4). Network engineers usually used Path Loss models based on the characteristics of open areas, large city, medium city, and urban and suburban area, which include vegetation, buildings, and the distance

between mobile station (MS) and BTS. These factors have been proven to reduce the QoS received by a subscriber (5). This research work tends to look at the applicability of the Hata model in the study area. The model is adopted because of its suburban characteristics, specifically the Mubi in Adamawa State in Nigeria. This work tends to address the following: to measure the Path Loss of the area and to compare the predicted (output of the model) and determine the root mean square error (RMSE) between the measured and predicted Path Loss in order to optimize the adopted model. However, Path Loss optimization is achieved based on the F1 score, RMSE, and Artificial Neural Network (ANN), which makes predictions more accurate. The results from the optimization clearly outperformed other state-of-the-art methods (6–8). In the research region, additional variables that could impact signal intensity include rainfall, foliage, snow, and geographical features (9, 10). The fuzzy logic technique is employed to predict the Path Loss of

the area considering some selected weather parameters (Temperature, Humidity, and Wind Speed). The relationship between the Path Loss and the weather parameters is determined using the Pearson correlation coefficient.

Propagation model

There are many empirical models available for the prediction of Path Loss which include Erickson, Hata, COST 231, European Communication Committee (ECC-33), Stanford University Interim (SUI), and other modified models.

Hata model

The Hata model is adopted because of its characteristics, which include an operating frequency between 150 Hz and 1,500 MHz, an MS height between 1 and 10 m, a BTS height between 30 and 200 m, and a link distance d between 1 and 20 km (11, 12) as provided by Equation 1.

$$L = 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_b) + a(h_m) + (44.9 - 6.55 \log_{10}(h_b)) \log_{10} d - 2 \left\{ \log_{10} \left(\frac{f_c}{28} \right) \right\}^2 \quad (1)$$

Where $a(h_m)$ is the antenna correction factor, f_c is the operating frequency, h_b is the BTS height, and h_m is the MS height and is giving by

$$a(h_m) = \{1.1 \log_{10}(f_c) - 0.7\} \quad (2)$$

$$h_m = -\{1.56 \log_{10}(f_c) - 68\} \quad (3)$$

Ericson model

The Ericson model is one of the adjustments of the Hata model that studied patterns according to the behavior of the propagation parameters given by

$$L = a_0 + a_1 \log(d) + a_2 \log(h_b) \log(d) - 3.21 (\log(11.75 h_m))^2 + g(f_c) \quad (4)$$

$$g(f_c) = 44.49 \log(f_c) - 4.78 \log(f_c)^2 \quad (5)$$

$a_0 = 36.2$, $a_1 = 30.2$, $a_2 = -12$, $a_3 = 0.4$ are the propagation constants of suburban cities at specific propagation conditions (12).

Cost 231 model

This is the modification of the Hata model that is used in improving the quality of signal by calculating the Path Loss

of a wireless mobile communication, and it's designed to use a frequency band of 150–200 MHz, with a distance from the BTS up to 20,000 m, MS height of 1–10 m, and a BTS height of 30–200 m. The model of the signal is expressed by Equation 6 as

$$L = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_b) - a(h_m f_c) + [44.9 - 6.55 \log_{10}(h_b) \log d + C] \quad (6)$$

$$a(h_m f) = (1.1 \log(f) - 0.7) h_m - (1.56 \log(f) - 0.8) \quad (7)$$

Where C Is the constant of propagation and $a(h_m f_c)$ is the correction factor of the antenna for the rural and the suburban areas. Ideally, h_m must be in proportional to the coverage areas (13, 14).

ECC 33 model

ECC-33 is another expansion from the optimization of Okumura Hata model. The model is feature by MS height of (2–10 m), with link distance from BTS of (100–800 m) with frequency range up to 3,500 MHz and BTS height of (1–80 m) and is given by Equation 8 as

$$L = A_s + A_m - G_b - G_m \quad (8)$$

where A_s is the attenuation factor of the free space, A_m is the median Path Loss, G_b is the BTS gain, and G_m is the MS gain (15).

$$A_s = 92.4 + 20 \log_{10}(d) + 20 \log_{10}(f_c) \quad (9)$$

$$A_m = 20.41 + 9.38 \log_{10}(d) + 7.894 \log(f_c) + 9.56 [\log_{10}(8)]^2 \quad (10)$$

SUI model

The SUI model was introduced by the Institute of Electrical and Electronics Engineering (IEEE) as Wireless Access Broad Band Group. It is also an expression of the Hata model through the optimization process. The model requires that BTS height should be between 10 and 80 m with a distance of 9,100–8,000 m, and an MS height of 2–10 m. The frequency is expected to be upgraded to 1,900 Hz with a carrier frequency range from 0 to 3,500 MHz, as given by Equation 11.

$$L = A + 108 \log \quad (11)$$

$$\left[\frac{d}{d_0} \right] + X_f + X_n + K \quad (12)$$

$$A = 20 \log_{10}(4\pi d_0) \quad (13)$$

$$K = U - \gamma h_b + \frac{w}{h_b} \quad (14)$$

$$X_f = 6 \log(f/2000) \quad (15)$$

$$X_h = -10.8 \log(h_m/2000) \quad (16)$$

$$X_h = -20.0 \log(h_m/2000) \quad (17)$$

Study area

Adamawa State University Mubi is located in the Northeast geopolitical zone of Nigeria. The university is located between longitudes $13^{\circ} 16'27''\text{E}$ and $13^{\circ} 17'12''\text{E}$ of the prime meridian and latitudes $10^{\circ} 16'46''\text{N}$ and $10^{\circ} 17'12''\text{N}$ of the equator (13). It has a total land area of about 1.04 km. Adamawa State University being located within the Mubi region, falls within the Tropical Wet and Dry climate region of the Koppen's climatic zone; it is characterized by warm and hot temperature conditions with mean annual values greater than 22°C (14, 16, 17). The months of May through October are classified as the wet season, and November through April as the dry season. Common weather variables of this climatic region relevant to the current study include Temperature, Rainfall, Humidity, and Wind Speed. Being an educational land use, the university environment is characterized by predominant exotic and landscaped vegetation cover comprising various tree plant species, which serves as aesthetic beauty and a windbrake to the structures.

Method of data collection

The Received Signal Strength Indicator (RSSI) of Global System for Mobile Telecommunication (GSM) operators (AIRTEL, Globacom Limited [GLO], and Mobile Telecommunications Network [MTN]) was measured using Network Signal Information Software (NSIS) installed on Mobile Equipment (ME). The measurement was performed in two sections: the rainy and dry seasons for the period of 6 months. In the rainy season, the RSSI was measured for the period of 3 months from July to September and the dry season. The RSSI was taken for the period of 3 months starting from December to February. The selected weather parameters data (Temperature, Humidity, and Wind Speed) were collected from the Metrological Unit of the Geography Department, Adamawa State University, Mubi, for the corresponding months mentioned above.

Methods of data analysis

Root mean square error

The average RMSE of the measured Path Loss and the predicted Path Loss from the adopted model is computed using Equation 18.

$$\text{RMSE} = \sqrt{\sum_{i=1}^n \left(\frac{PL_m - PL_c}{N} \right)^2} \quad (18)$$

Where PL_m is the measured Path Loss, PL_c is the calculated Model Path Loss, and N is the number of measured data

points. The adopted model shall be optimized for good signal propagation.

Error analysis

The evaluation of the precision of the relationship was evaluated through the utilization of the coefficient of correlation as giving by

$$(r) = \frac{n \sum TP - (\sum T)(P)}{\sqrt{[n \sum T^2 - (\sum T)^2] [n \sum P^2 - (\sum P)^2]}} \quad (19)$$

$$(r) = \frac{n \sum HP - (\sum H)(P)}{\sqrt{[n \sum H^2 - (\sum H)^2] [n \sum P^2 - (\sum P)^2]}} \quad (20)$$

$$(r) = \frac{n \sum WP - (\sum W)(P)}{\sqrt{[n \sum W^2 - (\sum W)^2] [n \sum P^2 - (\sum P)^2]}} \quad (21)$$

Where n represents days in the months of July, August, September, December, January and February. T is the Temperature, H is the Humidity, w is the Wind Speed, and P is the measured Path Loss.

Optimization equation

The optimization equation of the adopted model is given by Equation 22.

$$\begin{aligned} PL = & 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_b) \\ & + a(h_m) + (44.9 - 6.55 \log_{10}(h_b)) \log_{10} \\ & - 2 \left\{ \log_{10} \left(\frac{f_c}{28} \right) \right\}^2 - \text{RMSE} \end{aligned} \quad (22)$$

Fuzzy logic development

The Path Loss in the study area has been built to predict using a fuzzy logic simulation model and the RMSE derived from the estimated Path Loss values. Fuzzy logic serves as a sophisticated modeling and computational instrument, typically founded upon the concept of "degree of truth" (18) as opposed to conventional Boolean logic (0 or 1) that is predominantly employed in contemporary computing systems. The values of 0 or 1 are regarded within fuzzy logic as the "extreme cases of truth," implying that values can exist within the continuum between these extremes. For instance, the measured Path Loss can be categorized into classifications such as poor, good, and excellent. Fuzzy logic can be used to study present and future events through prediction of occurrences. To actualize the implementation, **Figure 1** will be utilized.

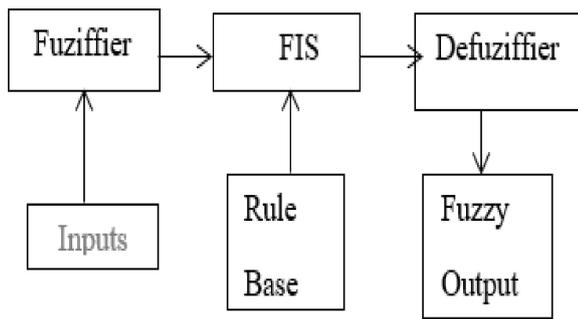


FIGURE 1 | Fuzzy logic procedure block diagram.

As revealed in **Figure 1**, first of all, the input parameters (Temperature, Humidity, and Wind Speed) were fed through the method of multiplexing and fuzzified and sent to Fuzzy Inference System (FIS) together with the expert rules developed. Secondly, the rules developed by an expert have been fuzzified in the FIS to give an output. Thirdly, defuzzification of FIS output is carried out to produce the predicted output.

Fuzzification of input and output data

The step to take into consideration when using fuzzy logic is to fuzzify the input and output data. Basically, the input/output are fuzzified based on the data range (maximum and minimum) for defuzzification to be realized.

Classification of input and output data

The input parameters (Humidity and Wind Speed) are classified as Low, Medium and High, and Temperature as Low and High. The output is also classified as Poor, Good, or Excellent.

Membership function

The membership function constitutes the graphical representation that defines the relationship between the inputs and output of a fuzzy set, thereby ensuring their correlation within the interval of 0–1. Basically, two

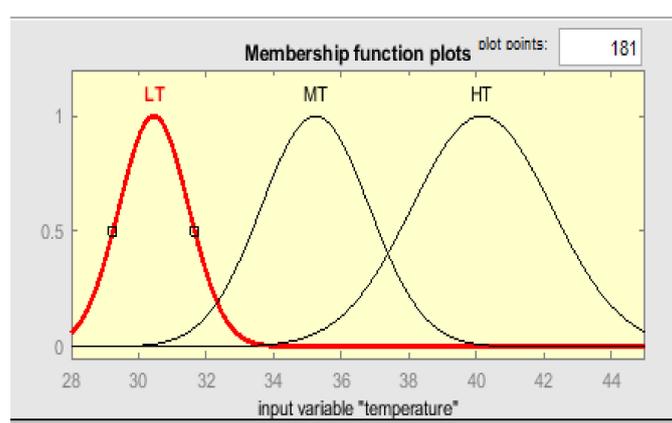


FIGURE 2 | Membership Function (MF) of input variable (Temperature).

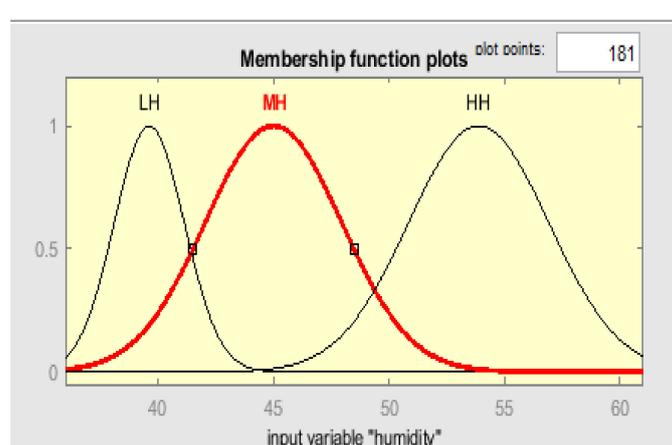


FIGURE 3 | MF of input variable (Humidity).

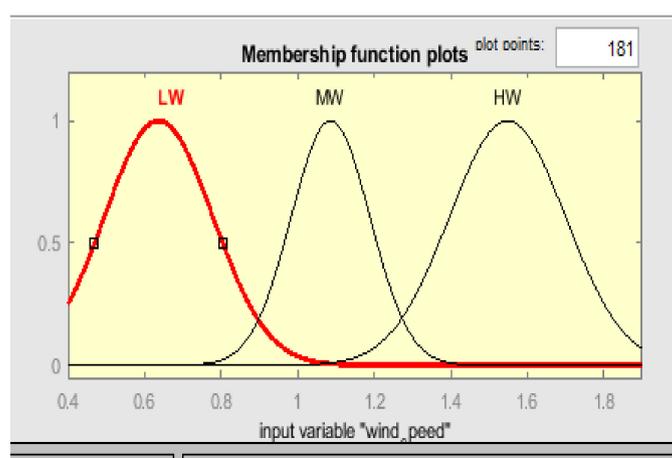


FIGURE 4 | MF of input variable (Wind Speed).

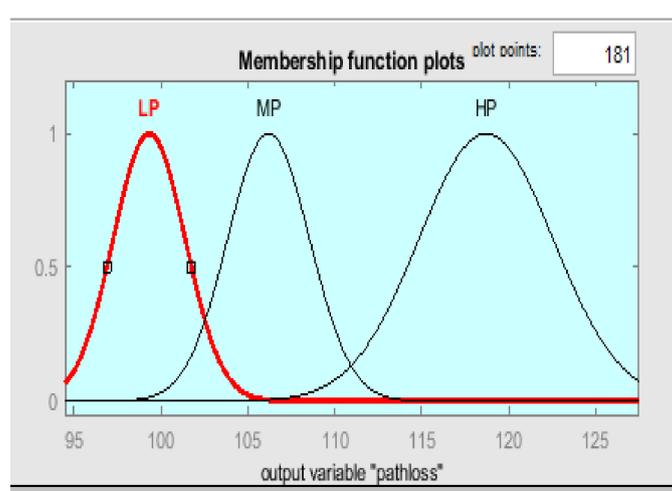


FIGURE 5 | MF of output variable (Path Loss).

subclasses of the membership function can be categorized: discrete (which includes generic singleton and singleton) and continuous (which includes triangular, generalized bell, trapezoidal, Gaussian, and piecewise). A major setback of the membership function is that the input and output of the system need to be predefined for better results (19). However, due to its ability to handle a wide variety of data, this work would adopt the Gaussian membership function. The Gaussian membership functions for Temperature, Humidity, Wind Speed, and Path Loss are presented in Figures 2–5.

Fuzzy rule based formulation

Fuzzy rules are important in decision-making in different applications of fuzzy sets (19). Rule formation is another significant aspect of fuzzy logic. Rules developed by an expert determine the accuracy of the prediction of the model. These are also achieved using the IF and THEN statement in

conjunction with AND, OR, and NOT logical connectors. Using set theory, the relationship between Temperature, Humidity, Wind Speed, and Path Loss may be written as

$$T \cap H \cap W = \{R : R \in T \cap R \cap H \cap H \in W\} \quad (23)$$

Similarly, the sets union is expressed as

$$T \cup H \cup W = \{R : R \in T \text{ or } R \in H \text{ or } R \in W\} \quad (24)$$

While in fuzzy logic

$R \in T \cap H \cap W$ if, $R \in A$, and A represent the universal set for T , H and W .

Fuzzy operators are used to transform Equations 23, 24 as shown in Equations 25, 26.

$$\mu_T \cap \mu_H \cap \mu_W (A) = \text{Min} \{ \mu_T (A), \mu_H (H), \mu_W (W) \} \quad (25)$$

$$\mu_T \cup \mu_H \cup \mu_W (A) = \text{Max} \{ \mu_T (A), \mu_H (H), \mu_W (W) \} \quad (26)$$

Based on the expression of Equation 23, 24, some the fuzzy rules for this model were developed as:

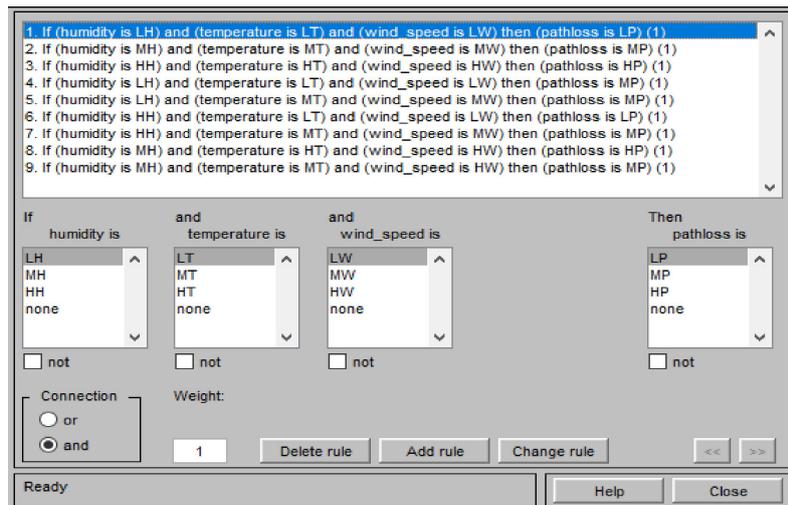


FIGURE 6 | Fuzzy rules developed.

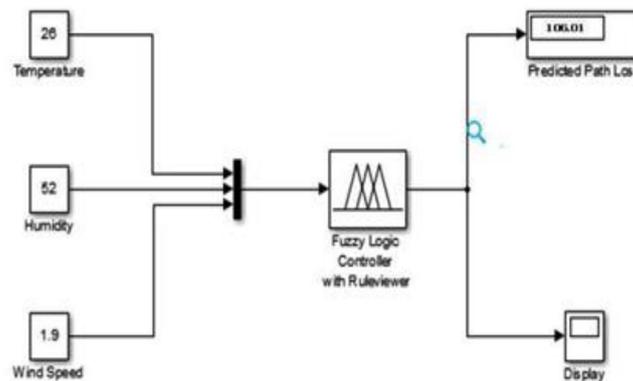


FIGURE 7 | Fuzzy logic simulation model.

1. If (H is LH) AND (T is LT) AND (WS is LW) THEN (PL is LP).
2. If (H is HH) AND (T is HT) AND (WS is HW) THEN (PL is HP).
3. If (H is MH) AND (T is MT) AND (WS is MW) THEN (PL is MP).
4. If (H is LH) AND (T is MT) AND (WS is MW) THEN (PL is MP).
5. If (H is HH) AND (T is LT) AND (WS is LW) THEN (PL is LP).
6. If (H is HH) AND (T is MT) AND (WS is MW) THEN (PL is MP).
7. If (H is MH) AND (T is HT) AND (WS is HW) THEN (PL is HP).
8. If (H is MH) AND (T is MT) AND (WS is HW) THEN (PL is MP)

Figure 6 shows the rules developed in the fuzzy rule based

Fuzzy logic simulation model

As shown in Figure 7, the block diagram in Figure 1 was transformed into a fuzzy logic simulation. The input parameters were randomly selected from the sample data. For example, $T = 26^{\circ}\text{C}$, $H = 52\%$, and $WS = 1.9\text{ km/h}$. After the simulation process, the predicted Path Loss is shown on the display as $PL = 106.01\text{ dB}$, as shown in Figure 7.

Results and discussions

The average predicted Path Loss and the measured Path Loss from the Hata model are presented in Figure 8. Path Loss forecasted for the month of August shoots high due to the impact of the weather parameters on the prediction. The following months were seen to follow the same pattern. Table 1 presents the average monthly RMSE obtained using Equation 2 between the Path Loss predicted and the measured Path Loss.

As shown in Table 1, the months of January and February have the lowest RMSE, followed by December, August, July,

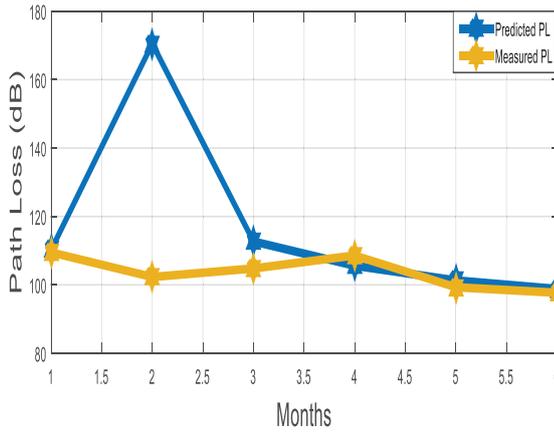


FIGURE 8 | Graphical relationship between predicted PL and measured PL.

TABLE 1 | Average monthly RMSE obtained between the Path Loss predicted and the measured Path Loss.

Months	RMSE
July	1.9
August	1.7
September	2.1
December	1.6
January	1.3
February	1.3
Average	1.65

and September, respectively. The average RMSE of 1.65, which falls within the 6 dB for good signal propagation, was used to optimize the adopted Hata Model given by Equation 1, which shows that the Path Loss of the study area has been minimized. The optimized model of the study area is given by

$$\begin{aligned}
 PL = & 67.92 + 27.81\log_{10}(f_c) - 13.82\log_{10}(h_b) \\
 & + a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10} \\
 & - 2\left\{\log_{10}\left(\frac{f_c}{28}\right)\right\}^2 \quad (27)
 \end{aligned}$$

The graphical presentation between the measured, predicted, and optimized Path Loss is further presented in **Figure 9**.

Figure 9 shows a comparison of the optimized Path Loss of the adopted model equation, the predicted Path Loss (fuzzy logic output), and the measured Path Loss (Hata model output).

The relationship between weather parameters and Path Loss

Table 2 presents the results obtained from Equations 3–5 for the relationship between Path Loss and Temperature, Humidity, and Wind Speed.

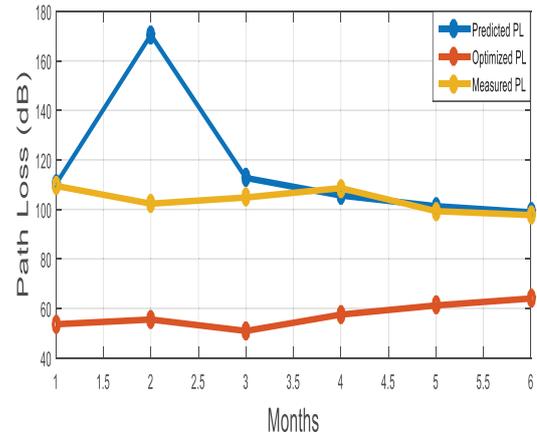


FIGURE 9 | Comparison of measured, predicted, and optimized PL.

TABLE 2 | Correlation relationship results between PL with T, H and WS.

Months	T	H	WS
July	0.049	−0.370	0.302
August	0.178	−0.007	0.008
September	−0.104	−0.109	0.263
December	−0.125	0.282	0.221
January	−0.135	0.237	0.298
February	0.398	0.312	0.451
Average	0.044	0.058	0.257

As shown in **Table 2**, the average correlation relationship was determined, and the results show that Temperature, Humidity, and Wind Speed have no linear relationship with Path Loss and do not exert any impact on the prediction.

Conclusion

In as much as the Global System for Mobile communication has been of great importance in the field of communication, the problem in gradual reduction in power density (Path Loss) has been of great concern. This work measured Path Loss and optimized the adopted Hata model, and it is recommended for network resource deployment. The fuzzy logic model was also utilized to predict the Path Loss of the area. However, the relationship between Path Loss and Temperature, Humidity, and Wind Speed shows a linear relationship; hence, it does not have any effect on the Path Loss.

Funding

The authors wish to declare that no funding is attached to the research work.

Acknowledgments

The authors wish to acknowledge the effort of Mr. David T. Ogbaka in downloading relevant material for the work.

Conflict of interest

Authors wish to declared that no competing interests is associated to this research.

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