Validation of Egli Model and Estimation of Pathloss Exponent of a Radio Signal at VHF Band in Hilly Terrain

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Abstract: Pathloss exponent is one of the most important parameter which has been considered widely in wireless communications analysis. It determines the rate at which the signal reduces as the distance (LOS) between the transmitter and the receiver increases and this parameter enhances the effective propagation of radio signal. This paper investigated the radio signal propagation profiles at 88 MHz at various elevation levels. In this work, a Retekess TR501 FM long range instrumentation was used as transmitter. This instrument is capable of transmitting audio signal at VHF band and the signal strength was measured quantitatively across the regions along several routes with the aid of a hand held spectrum analyzer. A global positioning system (GPS) receiver was used to determine the elevation above ground level and the geographic coordinates for four different itinerary in hilly environment. The line of sight (LOS) of the various data points from the transmitter was determined using a digital distance meter. The measured data obtained were compared with existing standard models (Free-space, Egli and Irregular terrain model). The findings revealed that, the average measured values was in good agreement with optimized Egli model having the MAE of 7.10 dB, MAPE of 3.20% and RMSE of 4.80 dB which is within the acceptable international standard range while Free space model underestimated the measured values. The work also shows that the path loss increases with increasing line of sight and the mean path loss exponent obtained in this region is 2.18 which is within the acceptable international standard range for urban environment. Furthermore, it was revealed that, radio signal strength depend directly on elevation regardless of LOS between transmitter and receiver, that is, the signal strength is enhanced at higher elevation point than lower elevation.

Key words: Hilly terrain, LOS, pathloss, signal strength, VHF.

I. INTRODUCTION

Investigation into behaviour of wireless propagation in the hilly environments has received an attention by different scholars due to increase in demand for wireless communication. It was noted that, when a mobile user moves over large distances the attenuation of propagating radio waves is affected by the antenna separation distance and large objects, such as hills, buildings and vegetation. Smaller objects in the radio channel, such as trees, uneven walls, cars and lamp posts, induce more rapid signal variations in the propagating radio waves and leads to pathloss of radio signal [1]. Many effects also leads to pathloss, such as; free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas [2]. Variation of transmitter and receiver height also produces path loss [3]. A fundamental element of wireless communication system planning is predicting the signal strength at same location that results from a transmitter at some other location over the years, a wide variety of approaches have been developed to predict coverage using what are known as propagation models. Propagation modeling is an effort to predict what happens to signals en route from the transmitter to the receiver. Obviously, the signal gets weaker with increase in distance. Prediction and estimation of path loss is an important and significant element of system design in any communication system. The international telecommunications union radio (ITU-R) has encouraged scientists and engineers in their respective Countries to carry out researches leading to the development of signal propagation profile/curve in their localities (CCIR Report 239-6, 1986) [4]. Hence, this work seeks to study and find an innovative solution to overcome the challenges of the effects of hilly terrain on radio signal and validating Egli model for this region.

II. PROPAGATION MODELS

The propagation models selected for comparison with experimental data were chosen as suitable and pertinent for the 88 MHz frequency band. Many propagation models have been derived and studied, however; there no single model can be applied for all the environments. As a result, the Quality of Service (QoS) of the whole cellular network depends on the selection of most suitable of the radio propagation model.

2.1 Free space model

The major assumption in free space propagation is that there is a clear line of sight (LOS) between transmitter and receiver, meaning that no obstructions exist. In other words, waves travel without reflection, diffraction, scattering, or any other mechanisms. This model is used to predict the received signal power at a particular distance [5],

$$L_{FS} = 32.44 + 20log(f) + 20log\ (d) \qquad (1)$$

where f is the operating frequency in MHz and d is the separation distance between TX and RX

2.2 Egli model

Egli is simplified model that assumes gently rolling terrain with average hill heights of approximately 50 feet, Because of this assumption, no terrain elevation data between the transmit and receive facilities is needed. Instead, the free space propagation loss is adjusted for the height of the transmitter and receiver antennas above ground. As with many other propagation models, Egli is based on measured propagation paths and then reduced to mathematical model. In case of Egli, the model consist of a single equation for the propagation loss [6].

$$L = 117 + 40\log(d) + 20\log(f) - 20\log(H_T - H_R) \qquad (2)$$

where L is the attenuation in dB(between dipole), *d* is the path distance in miles, *f* is the frequency in Mega Hertz, H_T is the transmitter antenna height above ground level(AGL)in feet, H_R is the receiver antenna height above ground level in feet.

2.3 Longley-Rice Model

The Longley-Rice model of radio propagation is also known as Irregular terrain model (ITM). Longley-Rice model for frequencies between 20 MHz and 20 GHz is a general purpose model that can be applied to large variety of engineering problems. The model, which is based on electromagnetic theory and on statistical analyses of both terrain features and radio measurements, predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time [7]. ITM incorporate various additional parameters to increase the accuracy of pathloss predictions like the soil conditions, the climate but most importantly refraction and diffraction due to obstacles and terrains.in the simplest form, the model can be stated as

$$L_{ITM} = L_{FS} + A_{ref} \qquad (3)$$

The component A_{ref} sums up possible attenuation in addition to the FSPL. It is computed using three different distance ranges [8]. For shorter distances, mostly at line-of-sight, the two-ray model is used. For distances where the horizon limits the line-of-sight or in the case there is an obstruction, diffraction is the dominant factor and a double knife edge estimation is applied. For very long distances, scattering becomes the dominant factor for A_{ref}. For a detailed description of A_{ref} [9], [10]. To calculate L_{ITM}, we use an already established software package called SPLAT available at [11].

III. MEASUREMENT CAMPAIGN

The measurement campaign took place in two different environments within Ibadan, Oyo state, South-western Nigeria (7.39639°N, 3.91667°E). The first set of readings were obtained in Isokun, Ojoo route which represent a typical hilly environment as shown in Figure 1. The measurement set consist of four different routes, namely; Odusokun, Ori-oke anu, Ajisafe, Ori-Oke koseunti. Henceforth, the four routes shall be referred to as itinerary A, B, C and D respectively. The purpose of this kind of measurement was to investigate the effects of hilly terrain on signal strength and to determine e the path loss exponent in this environment at 88 MHz.

3.1 Measurement Configuration

The measurement configurations consist of a transmitter (TX) and a receiver (RX). The equipment used for transmitting the audio signal is Retekess TR501 FM transmitter. The transmitter is made stationary and mounted on a tall fence at about 7 m above the ground as shown in figure 2. Audio signal is transmitted using a phone which is connected to the audio port of the transmitter via USB cord. The location of TX is measured using a Global positioning system (GPS) while handheld spectrum analyzer was used as a mobile receiver to capture the audio signal strength (in dBm). The observed signal strength values are then converted into path loss values using received power and gains of the transmitting and receiving antennas. These are referred as observed path loss values. The path loss exponent i.e propagation constant from the observed path loss was deduced using equation (1) [12],

Pathloss exponent was then evaluated from the experimental data obtained using (4).

$$n = \frac{Pl\ (d)(dBm) - Pl(do)}{10LogD} \qquad (4)$$

The pathloss exponent (n) for each route are derived by determined *n* for each of the LOS and their respective pathloss (excluding the reference distance *do*) and the average pathloss exponent for each route is determined. Figure 3 shows the pictorial representation during measurement in hilly environment. Hence, while performing the large scale pathloss measurements, the results are reliable when the transmitter is stationary.

3.2 Model Validation

The experimental pathloss was compared with two outdoor propagation models (Egli and free space) at 88 MHz and the accuracy of the measured pathloss was estimated using the root mean square error (RMSE) and Mean Absolute Percentage Error (MAPE) [13] was calculated to estimate the better model for path loss prediction in this region understudy. The best model for optimization was decided using (5) and (6).

$$RMSE = \sqrt{\frac{\sum\left(P_{m-}P_p\right)^2}{N}} \qquad (5)$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{P_{mt} - P_{pt}}{P_{mt}}\right| \times 100\% \qquad (6)$$

where, P_m is the measured pathloss in dBm, P_p is the predicted pathloss in dBm, N is the number of measured data points., P_{mt} is the mean value of measured data and P_{pt} is the mean value of predicted pathloss.

3.3 Model Optimization

In this work, the least square optimization technique for Egli model is presented. In order to enhance or ameliorate its performance as observed from the measured data, certain correction was be introduced to Egli model. The most suitable tool for such enhancement was least square method [2]. Egli model for irregular terrain is given in equation (7) contains three basic elements, they are; Initial offset parameter, Eo, the initial system parameter E_{sys}, and slope β of the model curve.

$$L(db) = 117 + 40log_{10}(d) + 20log_{10}(f) - 20log_{10}(H_T H_R) \quad (7)$$

where:

$$E_o = 117 \quad (8)$$

$$E_{sys} = 40log_{10}(d) + 20log_{10}(f) \quad (9)$$

$$\beta_{sys} = -20log_{10}(H_T H_R) \quad (10)$$

The path loss

$$L(p,q,r) = \sum_{i=1}^{N}[y_i - E_R(d_i,p,q,r)]^2 \quad (11)$$

Where p,q = model parameter based on enhancement.

ER(di, p, q, r) = modeling result at the di based on optimization;

N=Number of field data set

y_i=Measured path loss

d_i =Separation distance between TX and RX

The parameters p and q was statistically determined using:

$$p = \frac{\sum {d_i}^2 \sum y_i - \sum d_i \sum d_i y_i}{N \sum d_i^2 - (\sum d_i)^2} \quad (12)$$

$$q = \frac{N \sum d_i y_i - \sum d_i \sum y_i}{N \sum d_i^2 - (\sum d_i)^2} \quad (13)$$

The measured path loss, y, and distance, d, were substituted in equations (10) and (11) to obtain the values of p and q. The values of E_{sys} and β_{sys} were obtained using equations (14) and (15) respectively.

$$E_o = p - E_{syt} \quad (14)$$

$$\beta_{sys} = \frac{q}{20log_{10}(H_T H_R)} \quad (15)$$

Figure 1: Pictorial representation of the overview of Isokun region

Figure 2: Pictorial representation of the transmitter mounted on the fence

Figure 3: Pictorial representation during measurement in hilly environment

IV. RESULTS AND DISCUSSION

The collated results were categorized according to routes of field strength measurement. Figures 4, 5, 6 and 7 depicts the variation of signal strength with LOS and elevation so as to generate the corresponding propagation profiles using contour maps for each routes. Along the routes considered, some points shows higher signal strength than the points closer to the transmitter due to higher elevation. This trend was also observed in all the routes as depicted in some points. In some routes, the elevation falls sharply so also the signal strength was abnormally low, irrespective of the distance. This clearly revealed why it makes it difficult for communities in these areas to receive direct signal. At few points along the route where high elevations were recorded, signal levels were also enhanced. Also, the presence of vegetation produces a constant loss, independent of distance between communication terminals.

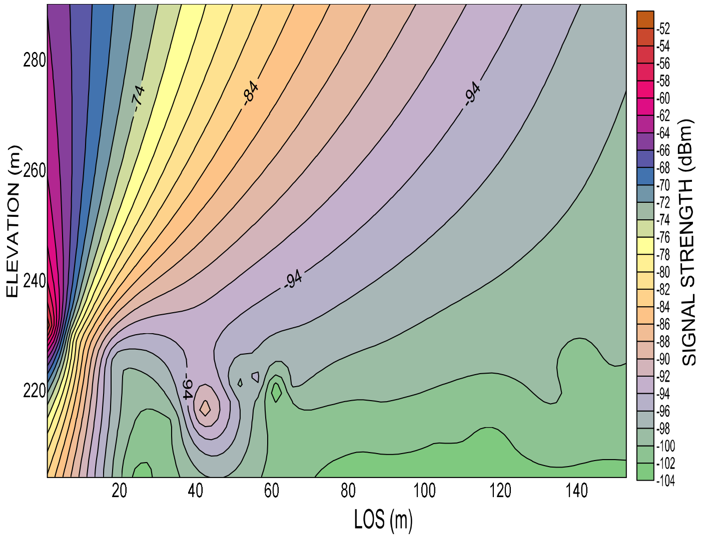

Figure 4: Variation of signal strength and elevation with LOS in itinerary A

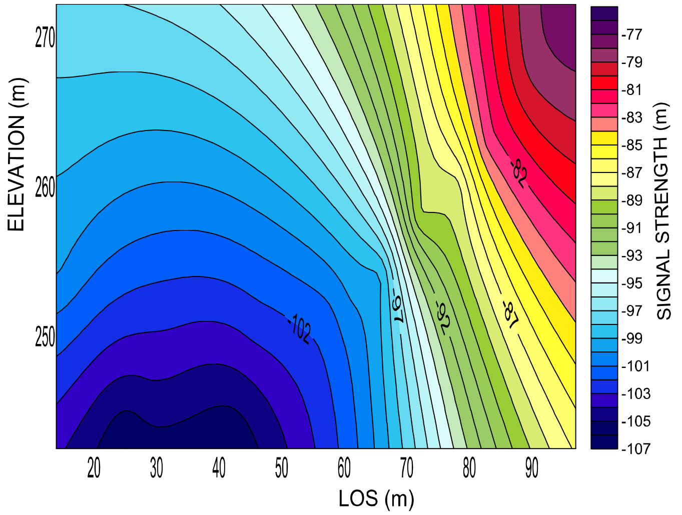

Figure 5: Variation of signal strength and elevation with LOS in itinerary B

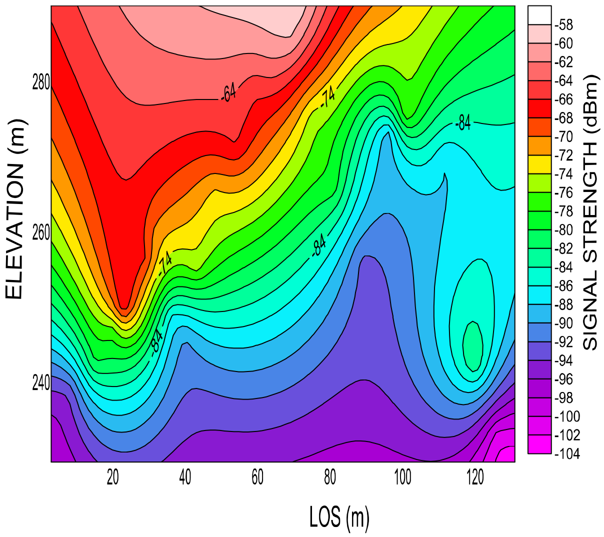

Figure 6: Variation of signal strength and elevation with LOS in itinerary C

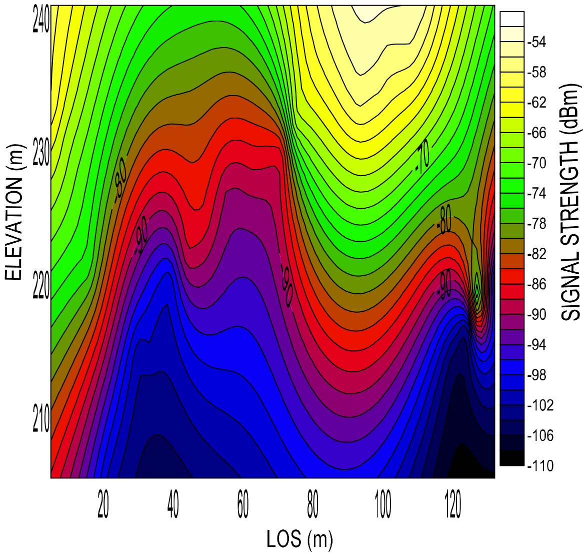

Figure 7: Variation of signal strength and elevation with LOS in itinerary D

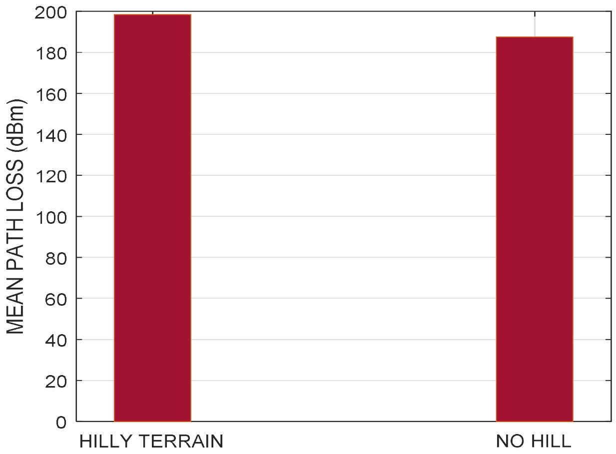

Figure 8: Mean pathloss for hilly terrain and when there is no hill

4.2 Variation of pathloss with LOS and Selection of best model

Figures 9, 10, 11 and 12 shows the variation of the measured pathloss obtained with respect to distance. It also shows the comparison of measured pathloss with an existing model (Freespace, Egli and Longely-Rice models). These models were used to compare the pathloss obtained because of the frequency used (88 MHz). Generally, in the four routes considered (A, B, C and D) the measured pathloss increases as distance increases from the reference point. It was also noted that the average measured pathloss in the four itineraries are in good agreement with Irregular terrain model and Egli model with root mean square error of 10.2891, 8.2686, 2.0132 and 4.0315 respectively. Free space pathloss (FSPL) prediction of the hilly environment falls below standard (underestimated the measured pathloss) with RMSE 97.58 dB, this is attributed to the fact that the FSPL does not take into consideration, correction factors for base station height h_b and receiver station height hr. The rate at which the signal strength attenuates as the LOS increases (pathloss exponent) were obtained for the four routes using equation (4) , the values were found to be; 2.20, 2.19, 2.17 and 2.16 respectively while the average value obtained for the region is 2.18

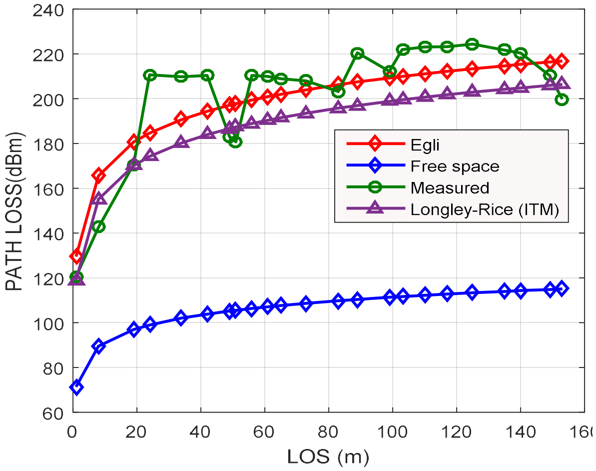

Figure 9: graphical representation of pathloss against LOS for Itinerary A

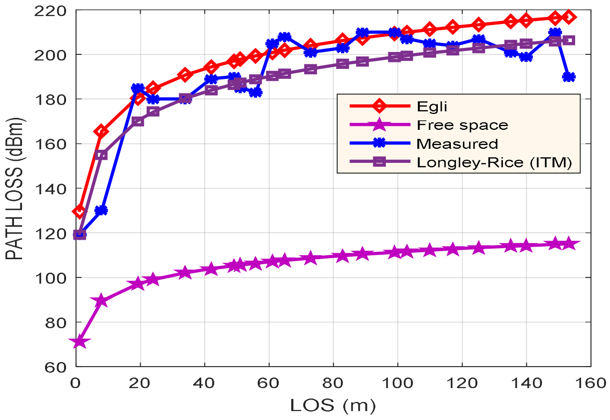

Figure 10: graphical representation of pathloss against LOS for Itinerary B

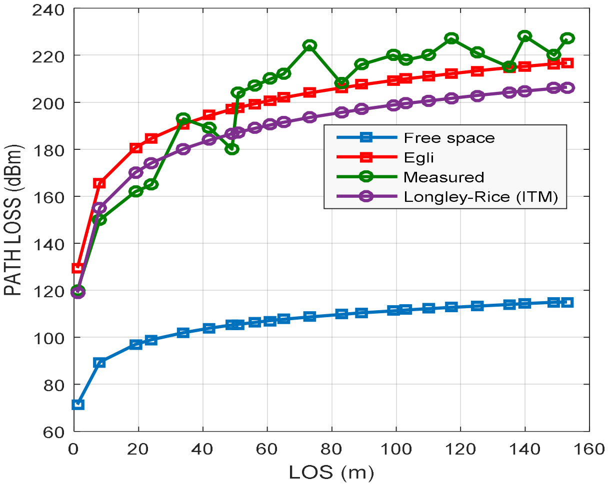

Figure 11: graphical representation of pathloss against LOS for Itinerary C

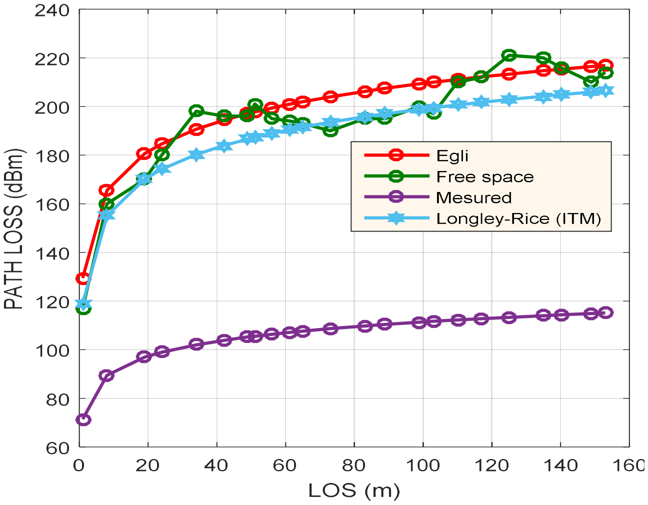

Figure 12: graphical representation of pathloss against LOS for Itinerary D

The optimized model has been validated and the values of p and q were obtained by substituting measured data into equations (12) and (13) while the values of initial offset parameter (Eo), the initial system parameter (E_{sys}), and slope parameter (βsys) were obtained using equations (14) and (15). The values are; p = 165.429 and q = 0.4116, Eo = 126.549 and $\beta_{syt} = 0.01556$. The tuned value Eo was introduced into Egli model. Hence, the optimized Egli model is presented as shown in equation (16).

$$L = 165.429 + 40\log(d) + 20\log(f) - 20\log(H_T - H_R) \quad (16)$$

The average pathloss from the measured data for all the itineraries were determined and compared with the empirical models as well as optimized Egli model as. Figure 13 depicts the comparison between the measured pathloss and the existing models together with optimized model.

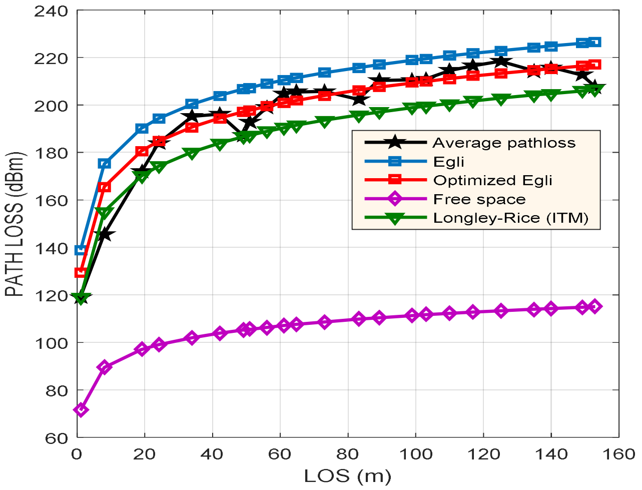

Figure 13: comparison of measured path loss and empirical models

From these results, it is evidently revealed that the optimized Egli model shows a good agreement for all the routes covered compared with all empirical models considered. The performance of the optimized Egli model was study using statistical error analysis shown in Table 1. The results as rendered in figure 13 shows that optimized Egli model gave a better performance among the models considered due to lowest predictive error. The value of MAE, MAPE and RMSE are 7.10 dB, 3.20% and 5.80 dB respectively. The lowest RMSE of the optimized Egli obtained is within the acceptable international standard since it is less than the minimum RMSE value of 6dB for good signal propagation. Therefore, optimized Egli model can be used for path loss prediction in this hilly environment

Table 1: Performance of Egli optimized model

Statistics parameters	Optimized Egli	Free space	Egli	ITM
MAE	7.10	97.22	7.19	7.46
MAPE (%)	3.20	46.23	5.85	3.94
RMSE	4.80	97.58	5.34	5.76

V. CONCLUSION

In this paper, pathloss exponent in a hilly environment at VHF band (88 MHz) has been explored and presented. The field measurement has been compared with three existing empirical propagation models, (free space, Longley-Rice and Egli). The findings shows that the measured values was in good agreement with optimized Egli model having the MAE of 7.10 dB, MAPE of 3.20% and RMSE of 4.80 dB which is within the acceptable international standard range while Free space model underestimated the measured values. The work also shows that the path loss increases with increasing line of sight and the mean path loss exponent obtained in this region is 2.18 which is within the acceptable international standard range for urban environment. Furthermore, it was revealed that, radio signal strength depend directly on elevation regardless of LOS between transmitter and receiver, that is, the signal strength is enhanced at higher elevation point than lower elevation.

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