Original Research Article

Tropospheric Influence on Low-Band Very High Frequency (VHF) Radio Waves

Abstract

This study is aimed at understudying the effects of temperature and relative humidity on low-band VHF signals, obtaining a path loss propagation model for the Calabar and checking the suitability of the free space propagation model in the study terrain. Results obtained shows that temperature and relative humidity has no effect on VHF signals. The suitability of the free space propagation model for the study terrain failed, as calculated results under-estimated path losses in the study area. Multiple regression analysis was used to obtain a suitable path loss model for the study terrain. However, since the studied meteorological variables has not effect on VHF signals in the study area, the measured path losses could be attributed to the foliage, hills, distance and other components of the study terrain in which the signal is propagated.

Keywords: VHF Signals, Radio Waves, Temperature, Relative Humidity, Path Loss

Introduction

The International Telecommunication Union (ITU) designation for the range of radio frequency electromagnetic waves, from 30 to 300 megahertz (MHz), with corresponding wavelengths of ten meters to one meter is called the Very High Frequency (VHF) radio waves. They propagate mainly by line-of-sight and are blocked by obstacles. However, due to refraction, they travel beyond the visual horizon to about 160 km [1, 2].

VHF radio waves is used for FM radio broadcast, two-way land mobile radio systems, long-range data communication, marine communications, etc. There are two VHF bands, the low-band VHF (49-108 MHz) and high-band VHF (169-216 MHz). Low-band VHF range of 49 MHz is used for transmission of wireless microphones, cordless phones, radio-controlled toys and more. Slightly higher VHF range of 54-72 MHz operates television channels 2-4, as well as wireless systems. VHF range 76-88 MHz operate channels 5 and 6. The highest low band VHF is 88-108 MHz and operates the commercial FM radio broadcast band [3].

The basis of radio communication systems is the electromagnetic wave theory. There are a variety of phenomena that occur when an electromagnetic wave is incident on a surface. These phenomena depend upon the polarization of the wave, the geometry of the surface, the material properties of the surface and the characteristics of the surface relative to the wavelength of the electromagnetic wave. As waves propagate through the earth's atmosphere, they carry information over long distances without wires. Like waves, there are affected by the medium in which there are propagating and as such, results to a reduction in signal power at the receiver's end [2-4].

In communication systems, radio waves radiate from an antenna, travelling outward in all directions. It is affected by the environment depending on its range of frequency and may travel to the receiving antenna by various modes of wave propagation [4, 5]. As they travel, signal strength of radio waves radiating from the transmitter to the receiver are affected by atmospheric conditions even in line-of-sight situations. These atmospheric variables causes the propagated waves to vary from its anticipated range. The higher the frequency, the higher the chances of being disturbed by tropospheric variables [6]. This weakens the received signal, as some of its energies are reflected, refracted, absorbed, depolarized, scattered and diffracted [7-27].

Studies have been carried out by several researchers to explore the effect of atmospheric elements on radio waves [28-36], but the results and conclusions has been contradictory. Some research studies claim that relative humidity is the main factor while others claim that temperature is the dominating factor [37-40].

For instance, in [30], the authors did not state the transmitting frequency, however, they mentioned that the research was investigating signals in the VHF band. Obtained result depicts that path loss increases as a result of increase in temperature while path loss reduces as a result of increase in relative humidity. The authors in [34, 38] investigated signals in the low-band VHF range. The results were contradicting. While [34] concluded that temperature increase reduces path loss, the result was the reverse for the authors in [38]. Also, while [34] concluded that increase in relative humidity led to an increase in path loss, the result was the reverse for the authors in [38]. In [39], the authors investigated high-band VHF radio waves and came with the conclusions with that an increase in temperature reduces path loss and vice versa, while an increase in relative humidity increases path loss and vice versa.

Sequel to the need to understand the effect of temperature and relative humidity on low-band VHF radio waves in order to ease its deployment for signal transmission in any terrain, this paper aims at determining how temperature and relative humidity affects signals in the VHF low-band using signals generated at a frequency of 105.5MHz. The obtained result will be used to develop a propagation model for the study area and make comparison with the existing free space propagation model. This is done to check the suitability of the free space propagation model for transmission of signal in the study area.

Free Space Propagation Model

This involves loss in signal strength in decibels (dB), as signals travel from the transmitter to the receiver. It is calculated by discounting hindrances that occur in its transmission path. For a sphere with radius d and surface area A,

$$A = 4\pi d^2 \quad (1)$$

At a distance d, away from the transmitter, the power per unit area

$$P_{Di} = \frac{P_T}{4\pi d^2} \quad (2)$$

Practically, all antennas provide directional propagation, hence, directivity gain

$$G_T = \frac{P_D}{P_{Di}} \quad (3)$$

where P_D = power density along mean axis of radiation antenna radiation and P_{Di} = power density of an isotropic antenna. From (3),

$$P_D = G_T P_{Di} \quad (4)$$

Putting (2) into (4)

$$P_D = \frac{P_T G_T}{4\pi d^2} \quad (5)$$

At the receiving end, let P_R be the power received at the receiving antenna. Under matched conditions and effective aperture of antenna at maximum directivity A_e

$$P_R = P_D A_e \quad (6)$$

But,

$$A_e = \frac{G_R \lambda^2}{4\pi} \quad (7)$$

Where λ is the wavelength of the radiated wave and G_R is the maximum directivity gain of the antenna

Putting (7) into (6)

$$P_R = \frac{P_D G_R \lambda^2}{4\pi} \quad (8)$$

Putting (5) into (8)

$$P_R = \frac{P_T G_T G_R \lambda^2}{16\pi^2 d^2} \quad (9)$$

Therefore,

$$\frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{(4\pi d)^2} \quad (10)$$

But,

$$V = f\lambda \quad (11)$$

Therefore,

$$\lambda = \frac{V}{f} \quad (12)$$

Where V is the speed of light and f is the transmission frequency

putting (12) into (10)

$$\frac{P_R}{P_T} = \frac{G_T G_R V^2}{(4\pi f d)^2} \quad (13)$$

Substituting $V = 3.0 \times 10^8$ m/s and $\pi = \frac{22}{7}$ into (13)

We have,

$$\frac{P_R}{P_T} = 0.0005\,\frac{G_T G_R}{(fd)^2} \quad (14)$$

Converting (14) to decibel (dB), we have

$$\left(\frac{P_R}{P_T}\right)_{(dB)} = G_T + G_R - (32.5 + 20 \log d + 20 \log f) \quad (15)$$

Putting $P_{L\ (dB)}$ for $\left(\frac{P_R}{P_T}\right)_{(dB)}$

$$P_{L\ (dB)} = G_T + G_R - (32.5 + 20 \log d + 20 \log f) \quad (16)$$

Equation 16 is the free space transmission equation in decibel (dB). In a summary,

$$P_{L\ (dB)} = G_T + G_R - L_{FS} \qquad (17)$$

Where,

$$L_{FS} = 32.5 + 20 \log d + 20 \log f \qquad (18)$$

Where f is in megahertz (MHz) while d is in kilometers (Km)

Methodology

Equipment used for data collection

A digital spectrum analyzer (GW-INSTEK) GSP-730 with frequency range of 150 MHz - 3GHz was used in measuring the signal strength while a digital temperature and relative humidity meter (model Htc) was used in measuring temperature and relative humidity. A hand-held GPS (GARMIN 78S) was used for the measurement of latitude and longitude. This work was carried out in the city of Calabar, Cross River State. Measurements of received signal strength, geographical coordinates (elevation, longitude and latitude) and meteorological variables were simultaneously taken. Measurements was taken in twelve locations, based on the peculiarity of the location. Measurement was done in August 2022.

Data Collection

Signals transmitted from the base station of Cross River Broadcasting Corporation at a frequency of 105.5MHz was measured at Line-of-Sight (LOS) distance at 12 different routes with the base station as reference point. The received signal strength were obtained at the receiver antenna at a height of 3.0 m. During the measurement campaign, latitude and longitude at the various points of data collection were measured using the GPS, which equally measured the elevation. Concurrently, the temperature and relative humidity meter measured the temperature and relative humidity.

Data Analysis

Measured data were grouped according to routes and the average values was used for the analysis. The data for received signal strength, temperature and relative humidity were averaged for each location. Line of sight (LOS) distance of each measurement point were calculated, taking the base station as the reference point. Path loss of the measured signal was calculated as

$$P_L = P_T - P_R \quad (19)$$

Where,

P_T = Transmitted power

P_R = Received power

P_L = Loss in power

Where P_T = 68.451dBm

Various graphs were plotted and correlation were calculated for a proper understanding of the effects of temperature and relative humidity on low-band VHF signals. A path loss model to suit with the terrain of the study area was obtained using multiple regression analysis. Finally, free space path loss was calculated using the free space path loss equation and the calculated values were compared with the measured path loss model. This was done to ascertain its suitability for transmission of low-band VHF signals in the study terrain. Where the free space path loss model does not suit with the terrain, an optimized free space path loss model was developed.

Results and Discussion

Effects of Temperature and Relative Humidity on VHF Radio Waves

The table below contains the average temperature, average relative humidity and the measured path loss obtained from equation (19).

Location	**Temperature (^oC)**	**Relative Humidity (%)**	**Measured Path Loss (dBm)**
A	28.1	69	143.451
B	27.2	68	148.451
C	29.5	61	140.451
D	29.9	61	149.451
E	30.5	60	146.451
F	30.8	59	146.451
G	28.6	66	145.451
H	29.8	58	141.451
I	30.8	70	143.451
J	29.0	60	135.451
K	31.0	61	147.451
L	29.4	59	145.451

Table 1: Averages of temperature, relative humidity and measured Path loss

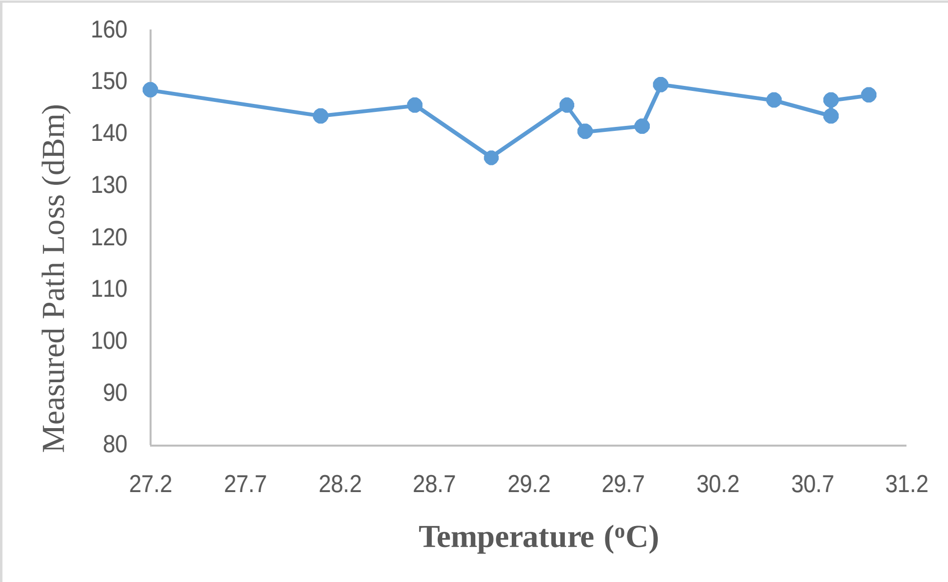

Figure 1: Graph of Measured Path loss against Temperature

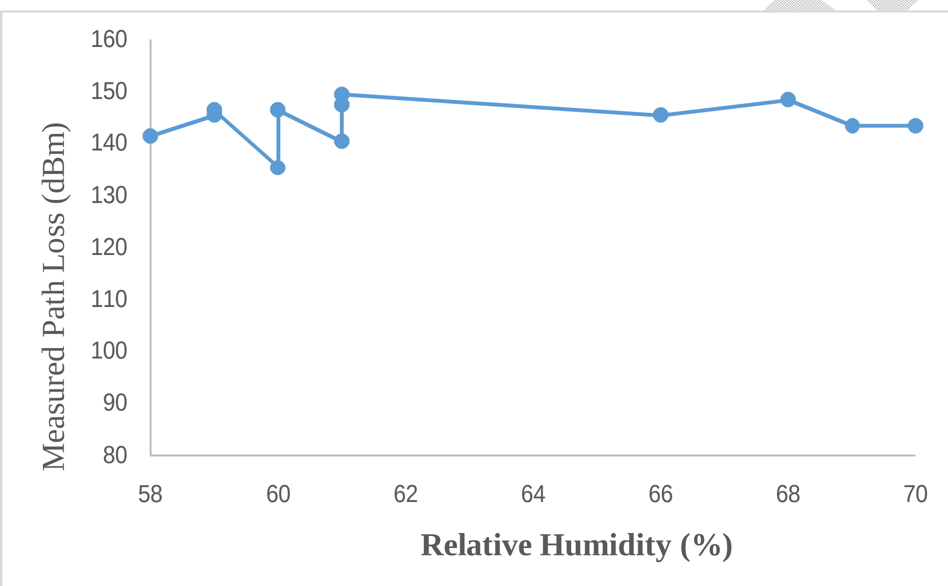

Figure 2: Graph of Measured Path loss against Relative Humidity

From the data in table 1, graphs of measured path loss against temperature and relative humidity were been plotted as shown in figure 1 and figure 2, with correlation coefficients of 0.09 and 0.14 obtained for measured path loss against temperature and measured path loss against relative humidity, respectively. The value of the correlation coefficients means that temperature and relative humidity has insignificant effects on low-band VHF signals. Also, this result does agree with earlier results obtained [30][34][38, 39].

Path Loss Model for Study Area using Multiple Regression Analysis

Multiple regression analysis was used in developing a path loss model for the study area. In this model, path loss was considered the dependent variable while temperature and relative humidity were the independent variable. This was done based on the assumption that temperature and relative humidity influenced radio waves transmission from the transmitter to the receiver. In multiple regression analysis,

$$Y = \beta_o + \beta_1 T + \beta_2 R + \mu \qquad (20)$$

Where

$Y = P$ = calculated path loss

β_o = constant

β_1= predictor variable for temperature

β_2= predictor variable for relative humidity

μ = prediction error

T = temperature

R= relative humidity

Here,

$\beta_o = 112.720$

$\beta_1 = 0.639$

$\beta_2 = 0.205$

μ = 3.648

Therefore, regression model becomes

$$P = 112.720 + 0.639T + 0.205R + 3.648 \quad (21)$$

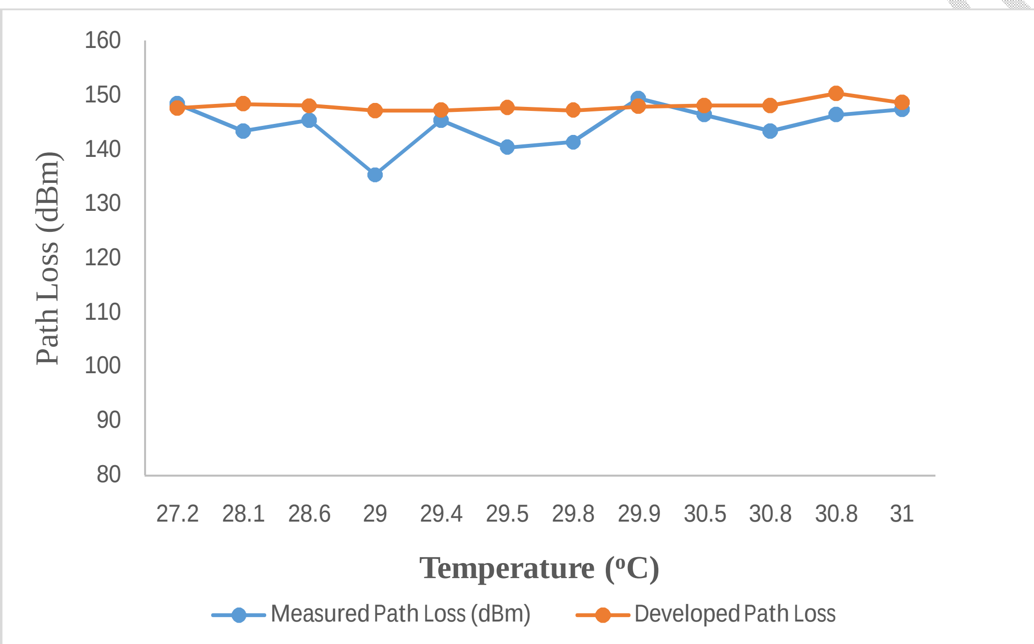

Figure 3: Graph of Measured Path loss/Developed Path Loss against Temperature

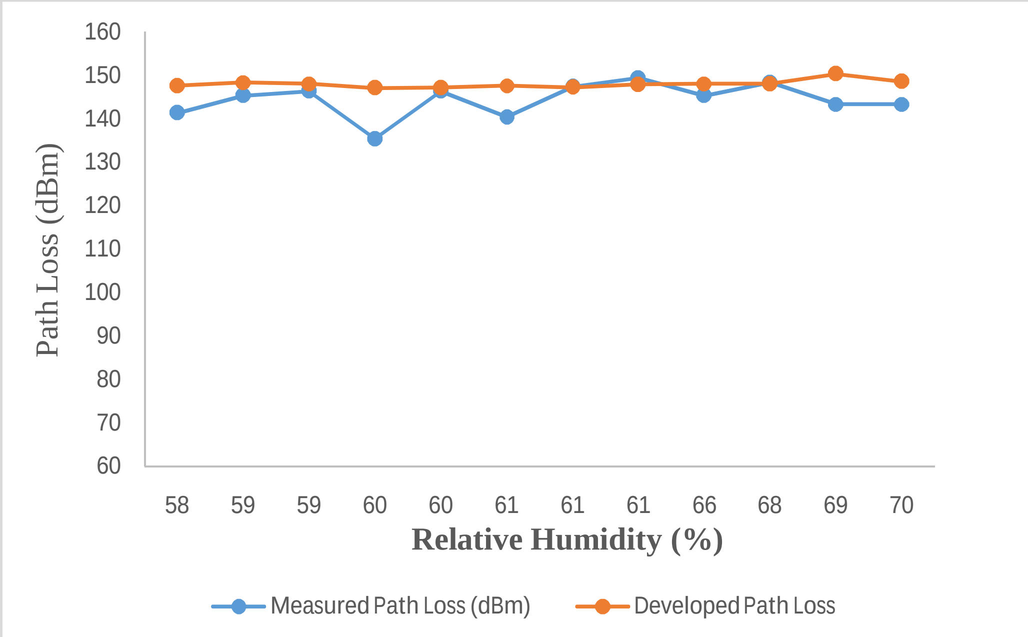

Figure 4: Graph of Measured Path loss/Developed Path Loss against Relative Humidity

Equation (21) becomes the path loss model in the study area. This means that a unit increase in temperature results to 0.639dB increase in path loss and a unit increase in relative humidity results to 0.205dB increase in path loss. The low prediction error of 3.648dBm indicates a better fit for the model. The average values of temperature and relative humidity were inserted into equation (21) and the values plotted against temperature/relative humidity, as shown in figure 3 and figure 4.

Analysis of Free Space Propagation Model

From the longitudes and latitudes of the measured routes and that of the base station as the reference point, the LOS distance of each location from the base station was obtained. This is presented in the below table.

Location	**LOS Distance (Km)**
A	14.700
B	18.219

C	16.919
D	14.548
E	12.679
F	7.902
G	0.394
H	5.172
I	6.895
J	11.227
K	12.359
L	11.865

Table 2: Calculated LOS distance of measurement location from base station

From table 2, loss in signal propagation for the free space model is determined. Recall, loss in signal strength for free space propagation is given in equation (18) as

$L_{FS} = 32.5 + 20 \log d + 20 \log f$

Hence, in location A, LOS distance = 14.700km

$L_{FS} = 32.5 + 20 \log 14.700 + 20 \log 105.5 = 96.311 dBm$

In location B, LOS distance = 18.219km,

$L_{FS} = 32.5 + 20 \log 18.219 + 20 \log 105.5 = 98.176 dBm$

In location C, LOS distance = 16.919km,

$L_{FS} = 32.5 + 20 \log 16.919 + 20 \log 105.5 = 97.553 dBm$

In location D, LOS distance = 14.548km,

$L_{FS} = 32.5 + 20 \log 14.548 + 20 \log 105.5 = 96.221 dBm$

In location E, LOS distance = 12.679km,

$L_{FS} = 32.5 + 20 \log 12.679 + 20 \log 105.5 = 95.027 dBm$

In location F, LOS distance = 7.902km,

$L_{FS} = 32.5 + 20 \log 7.902 + 20 \log 105.5 = 90.920 dBm$

In location G, LOS distance = 0.394km,

$L_{FS} = 32.5 + 20 \log 0.394 + 20 \log 105.5 = 64.875 dBm$

In location H, LOS distance = 5.172km,

$L_{FS} = 32.5 + 20 \log 5.172 + 20 \log 105.5 = 87.238 dBm$

In location I, LOS distance = 6.895km,

$L_{FS} = 32.5 + 20 \log 6.895 + 20 \log 105.5 = 89.736 dBm$

In location J, LOS distance = 11.227km,

$L_{FS} = 32.5 + 20 \log 11.227 + 20 \log 105.5 = 93.970 dBm$

In location K, LOS distance = 12.359km,

L_{FS} = 32.5 + 20 log 12.359 + 20 log 105.5 = 94.805dBm

In location L, LOS distance = 11.865km,

L_{FS} = 32.5 + 20 log 11.865 + 20 log 105.5 = 94.450dBm

Location	Temperature (^oC)	Relative Humidity (%)	Measured Path Loss (dBm)	Free Space Loss (dBm)
A	28.1	69	143.451	96.311
B	27.2	68	148.451	98.176
C	29.5	61	140.451	97.533
D	29.9	61	149.451	96.221
E	30.5	60	146.451	95.027
F	30.8	59	146.451	90.920
G	28.6	66	145.451	64.875
H	29.8	58	141.451	87.238
I	30.8	70	143.451	89.736
J	29.0	60	135.451	93.970
K	31.0	61	147.451	94.805
L	29.4	59	145.451	94.450

Table 3: Average Temperature and Relative Humidity/Measured and Free Space Path Losses

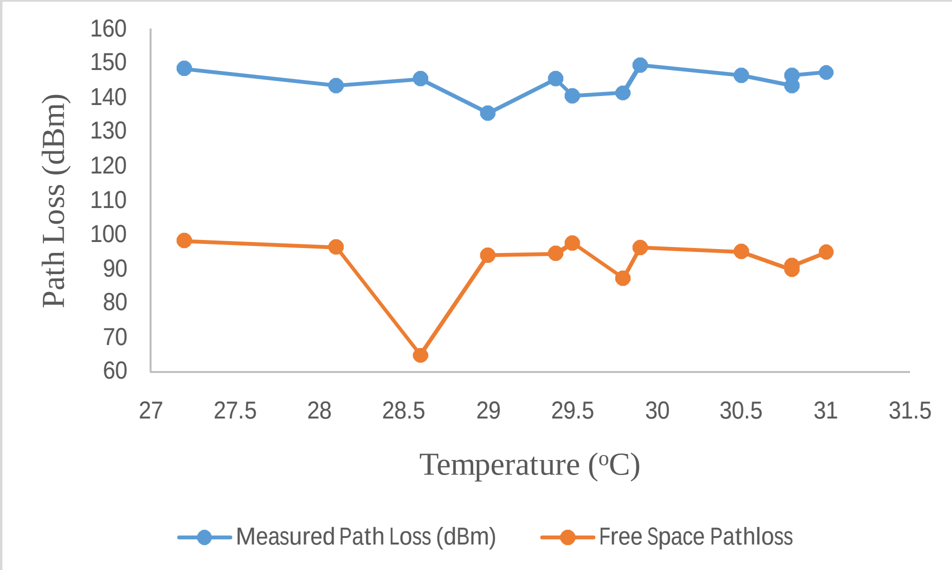

Figure 5: Graph of Measured/Free Space Path Loss against Temperature

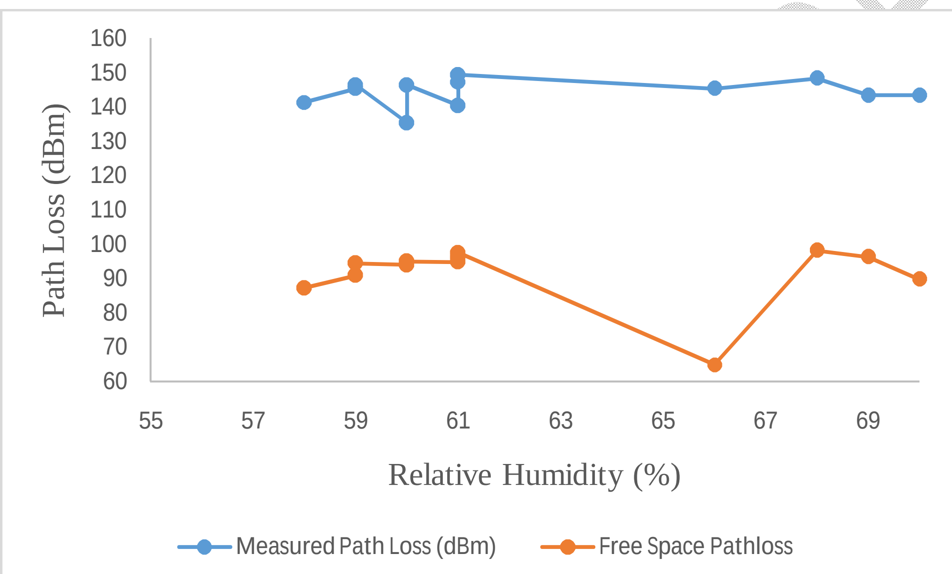

Figure 6: Graph of Measured/Free Space Path Loss against Relative Humidity

From table 3, figure 5 and figure 6, a wide difference in the measured and calculated path losses is observed. This shows that the free path loss model is not a suitable propagation model for the study area. Hence, an adjustment of the free space propagation model for its suitability for signal transmission in the study area must be implemented.

Optimization of Free Space Propagation Model

Recall, in equation (18), free space path loss model is given as

$$L_{FS} = 32.5 + 20\log d + 20\log f$$

To optimize the model for its suitability in the study area, we introduce a prediction error C. Therefore,

$$L_{FS} = 32.5 + 20\log d + 20\log f + C \quad (22)$$

And

$$C = \sqrt[2]{\frac{(P_m - P_{FS})^2}{N}} \quad (23)$$

Where C = 53.7dBm

Therefore,

$$L_{FS} = 32.5 + 20\log d + 20\log f + 53.7 \quad (24)$$

From equation (24), the optimized free space path losses for each location which is obtained as shown in table 4 below. Also, graphs of measured path loss and optimized free space path loss against temperature/relative humidity are plotted in figure 7 and figure 8.

Location	**Temperature (^oC)**	**Relative Humidity (%)**	**Measured Path Loss (dBm)**	**Optimized Free Space Loss (dBm)**
A	28.1	69	143.451	150.011
B	27.2	68	148.451	151.876
C	29.5	61	140.451	151.233

D	29.9	61	149.451	149.921
E	30.5	60	146.451	148.727
F	30.8	59	146.451	144.620
G	28.6	66	145.451	118.875
H	29.8	58	141.451	140.938
I	30.8	70	143.451	143.436
J	29.0	60	135.451	147.670
K	31.0	61	147.451	148.505
L	29.4	59	145.451	148.150

Table 4: Average temperature and relative humidity/ measured and free space path losses

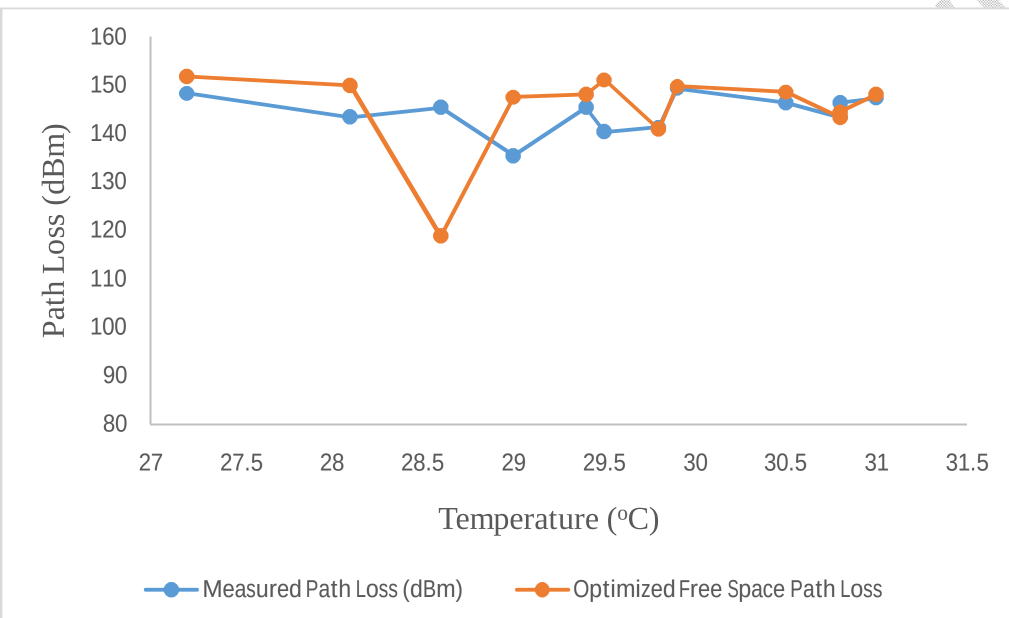

Figure 7: Graph of Measured/Optimized Free Space Path Loss against Temperature

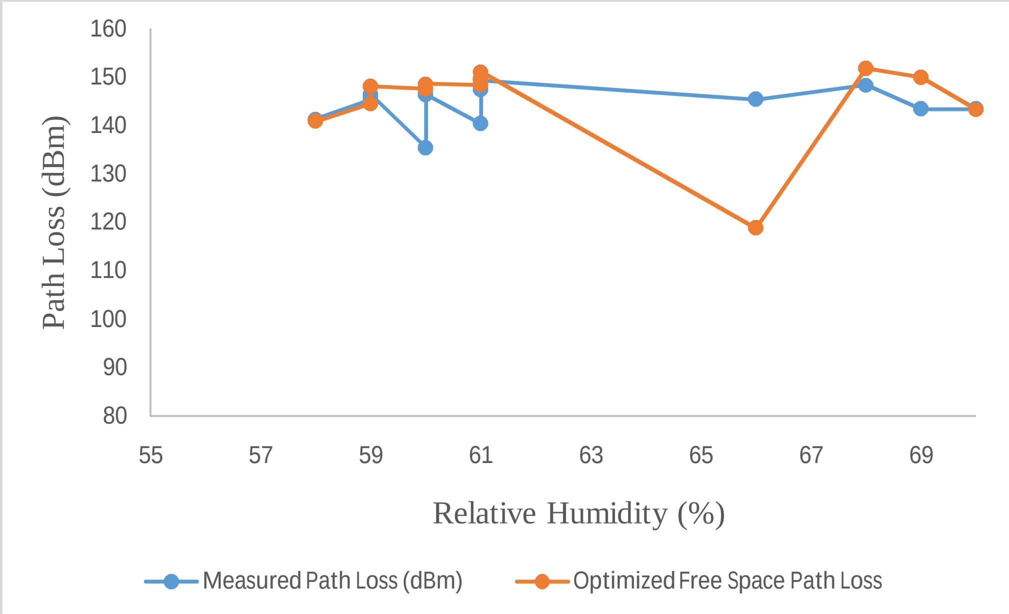

Figure 8: Graph of Measured/Optimized Free Space Path Loss against Relative Humidity

Since the prediction error was above the recommended threshold of at most 6dBm [41], it is justifiable to say that the optimized free space path loss will not be fit for signal propagation in the area under investigation. This is not unconnected to the over-estimation and under-estimation of path losses, as observed in figures 7 and 8 above.

Conclusion

The effects of meteorological variables on low-band VHF signals have been studied, taking temperature and relative humidity as the meteorological variables of importance. Results obtained shows that temperature and relative humidity has no effect on VHF signals. The suitability of the free space propagation model for the study terrain failed, as calculated results showed that this model under-estimated path losses in the study area. Multiple regression analysis has been used to obtain a suitable path loss model for the study terrain.

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