Empirical Measurements and Model Optimization for Path Loss Determination in Dust Haze at VHF Band

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ABSTRACT

The impact of dust haze on radio wave propagation at very high frequency (VHF) band has been a significant challenge for wireless communication systems. In order to mitigate the effects of path loss due to dust haze, accurate models for path loss determination are essential. This study aims to investigate the effects of dust haze on VHF band propagation and optimize path loss models for accurate prediction. Empirical measurements were conducted in a dust haze environment, where received signal strength measurements were taken at different distances from the transmitter. The collected data was used to estimate the path loss exponent, which is a critical parameter in path loss models. Correlation values of (R2) were found to be 0.9618 and 0.9832 for 92.1 MHz and 98.5 MHz respectively. The results indicated that dust haze significantly increases path loss at VHF band, and the path loss exponent is larger in a dust haze environment compared to normal atmospheric conditions. Based on the empirical data, a modified path loss model was proposed and optimized using regression analysis. The findings of this study can be applied in the design and optimization of wireless communication systems operating in dust haze environments.

(Keywords: empirical, optimization, path loss, atmospheric dust haze, Very High Frequency, VHF, radio signal attenuation, wireless communications)

INTRODUCTION

Path loss is an important parameter in wireless communication system design as it determines the attenuation of a radio signal as it propagates through the medium. In dust haze conditions, path loss can be significantly increased, leading to poor signal quality and reduced communication range [1][2].

VHF (Very High Frequency) band is commonly used in wireless communication systems due to its ability to penetrate obstacles and travel long distances. However, in dust haze conditions, VHF band signals can experience significant path loss due to the presence of dust particles in the atmosphere. The measurement of path loss in dust haze conditions is essential for determining the attenuation of VHF signals and optimizing communication system design [3]. Various measurement techniques have been proposed for path loss determination in dust haze conditions. Empirical measurements involve collecting field data by transmitting signals at various frequencies and distances and recording the received signal strength. This data is then used to derive the path loss exponent, which is a measure of the attenuation of the signal with distance.

The importance of wireless communication systems in modern society cannot be overstated, as they provide a means for people and devices to communicate and exchange information wirelessly over long distances. However, these communication systems are subject to various challenges, such as path loss, which occurs when the transmitted signal experiences attenuation as it propagates through the medium.

Path loss can be caused by a variety of factors, including atmospheric conditions such as dust haze. Dust haze is a weather phenomenon that occurs when airborne dust particles are suspended in the atmosphere, resulting in reduced visibility, and increased atmospheric attenuation [4]. This can have a significant impact on wireless communication systems, particularly those that operate in the VHF (Very High Frequency) band. VHF signals are commonly used in wireless communication systems due to their ability to penetrate obstacles and travel long distances, but in dust haze conditions, the signal can experience significant path loss, leading to poor signal quality and reduced communication range. To design effective communication systems that can operate in dust haze conditions, it is essential to measure and optimize the path loss. There are two main approaches to this problem: empirical measurements and model optimization [5].

Empirical Measurements

Empirical measurements involve collecting field data by transmitting signals at various frequencies and distances and recording the received signal strength. This data is then used to derive the path loss exponent, which is a measure of the attenuation of the signal with distance. Empirical measurements can be performed using various techniques, such as drive test measurements and field strength measurements.

Drive test measurements involve driving a vehicle with a transmitter and receiver along a predetermined route while recording the received signal strength at various points. This data can be used to create a signal strength map of the area, which can be used to optimize the placement of communication infrastructure.

Field strength measurements involve deploying stationary transmitters and receivers at various locations and recording the received signal strength. This data can be used to determine the path loss exponent, which can then be used to predict the signal strength at different distances from the transmitter.

Empirical measurements are straightforward to perform and provide accurate results, but they can be time-consuming and expensive []. In addition, they do not take into account the specific atmospheric conditions that may be present, such as the size and density of the dust particles, which can have a significant impact on path loss.

Model Optimization

To overcome the limitations of empirical measurements, more sophisticated models for path loss determination in dust haze conditions have been developed. These models use atmospheric scattering theory to model the interaction of radio waves with dust particles in the atmosphere. They take into account parameters such as dust particle size, density, and refractive index, as well as the frequency and distance of the signal [6].

Model optimization involves tuning the parameters of the model to fit the empirical data and improve the accuracy of the predicted path loss. This can be achieved using various optimization techniques, such as genetic algorithms and particle swarm optimization. Model optimization provides a more accurate prediction of path loss in dust haze conditions than empirical measurements, as it takes into account the specific atmospheric conditions that may be present [7]. However, it requires a significant amount of computational resources and expertise to develop and optimize the model.

The effects of obstacles such as mountains, ridges, vegetation, and structures and environmental conditions on VHF Radio propagation is an important factor for system planners involved in broadcasting. Environmental conditions involved rainfall, fog, humidity, temperature, and wind. Less effort has been put on the effect of dust haze in this tropical region [8] [9].

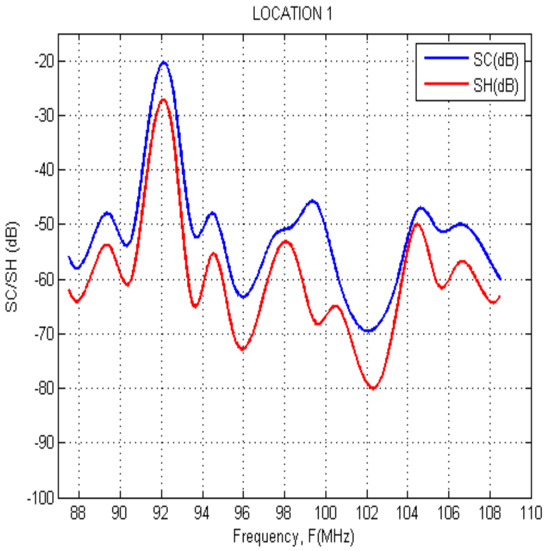
The successful design and deployment of a wireless system requires a good knowledge of the characteristics of the propagation channel. To this end, therefore, channel modeling for many scenarios has been topics of path loss modeling for many years. To analyze the wireless medium path loss prediction is considered to be one of the most important characteristics [10][11].

METHODOLOGY

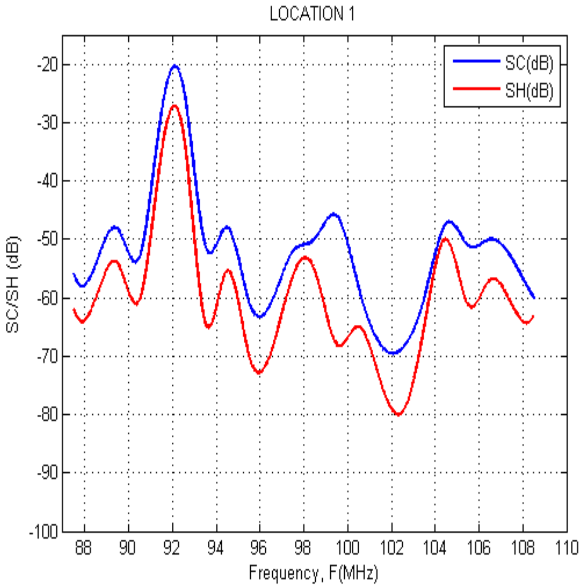
The research was carried out along four (4) test sites selected that have the characteristics of dust haze. The sites have a clear line-of-sight between the transmitter and receiver. The receiving equipment was set up in accordance with the manufacturer instructions. Spectrum analyzer GSP 730 with frequency range of 150 KHz – 3.5 GHz was set to a frequency 100 MHz at a sampling rate of RBW: 300 KHz Span: 10 MHz and Sweep: 500ms to receive signal strength from the two transmitting stations considered - 92.1 MHz and 98.5 MHz respectively. Spectrum analyzer was connected to antenna – century UHF.VHF.FM, TV WA-3010TG, the connection was made with a coaxial cable of 50 ohms for impedance matching. Furthermore, the spectrum analyzer was connected to a laptop loaded with Aaronica test software for data logging via a USB cable.

A Drive test measurement was employed for proper reception of the signal strength from the two transmitting stations at various points within a test site. The same process was repeated across the remaining three (3) test sites selected. The collected data was analyzed using MATLAB Rs2021a for the curve fitting.to determine the path loss exponent, which is a measure of the signal with distance.

RESULTS AND DISCUSSION

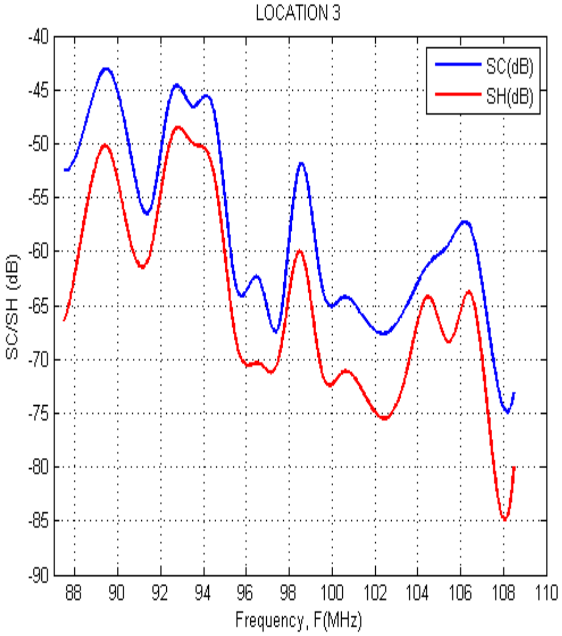


(1-i)

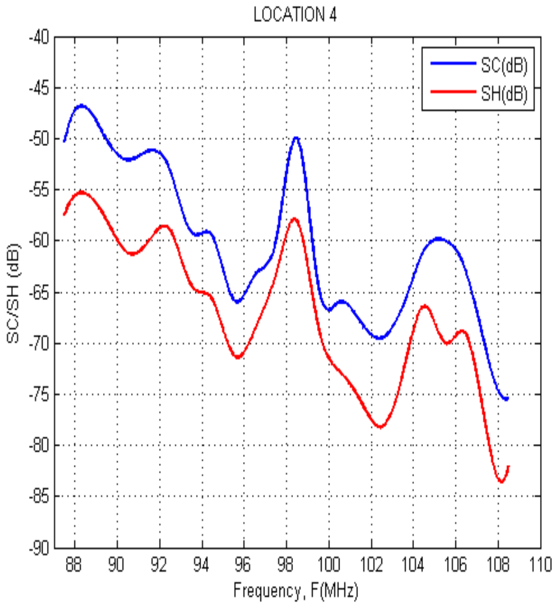


(1-ii)

Figure 1: Received Signal Strength for Test Site One, During Clear and Haze Weather Conditions at (i) 92.1 MHz (ii) 98.5 MHz.

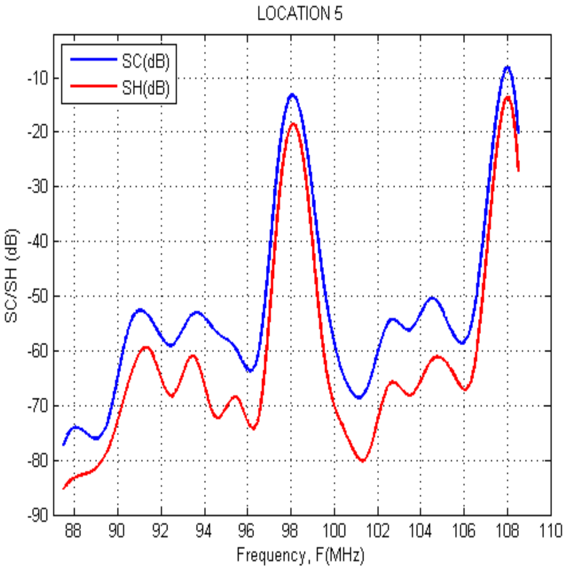


(2-i)

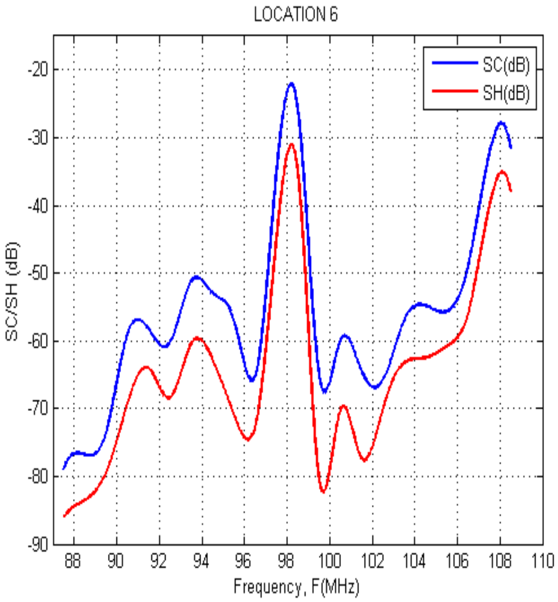


(2-ii)

Figure 2: Received Signal Strength for Test Site Two, During Clear and Haze Weather Conditions at (i) 92.1 MHz (ii) 98.5 MHz.

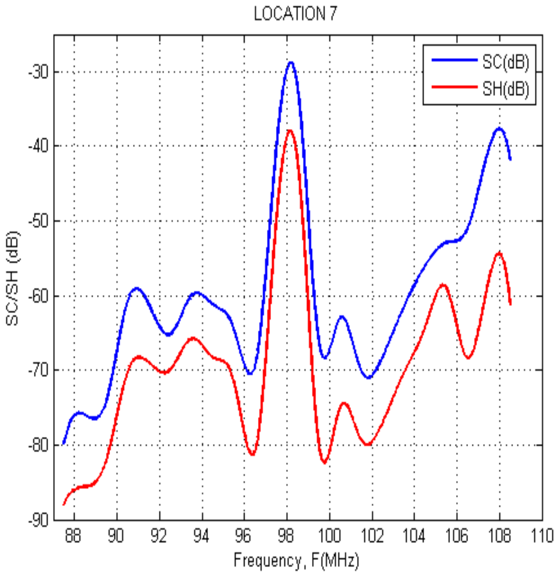


(3-i)

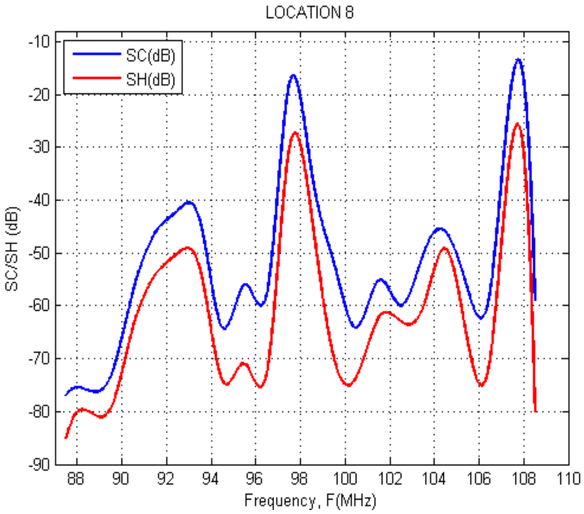


(3-ii)

Figure 3: Received Signal Strength for Test Site Three, During Clear and Haze Weather Conditions at (i) 92.1 MHz (ii) 98.5 MHz.

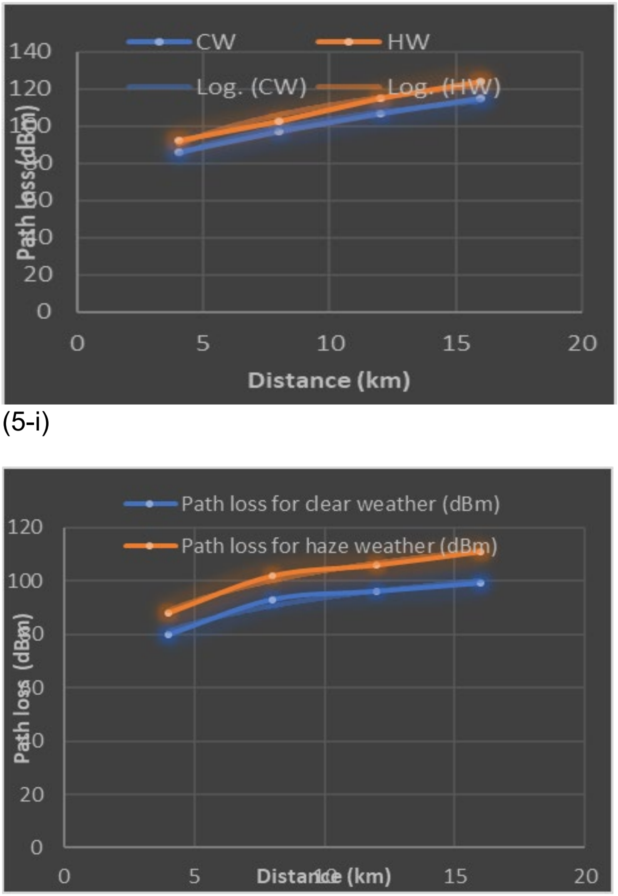


(4-i)



(4-ii)

Figure 4: Received Signal Strength for Test Site Four, During Clear and Haze Weather Conditions at (i) 92.1 MHz (ii) 98.5 MHz.



(5-i)

(5-ii)

Figure 5: The Path Loss Model for (i) 92.1 MHz (ii) 98.5 MHz.

ITU-R gives the equations to be used in the determination of path loss:

$$PL = 20 \log \frac{4\pi d}{\lambda} \quad \textbf{(1)}$$

Where:

PL: Path loss
d : distance
λ: wavelength

Expressing the equation (dB) and using frequency instead of wavelength:

$$\text{PL (dB)} = 32.4 + 20\log f + 20 \log d \quad \textbf{(2)}$$

Where:

f: frequency

Also the attenuation is given as:

$$A_a = \gamma_a \, d \text{ (dB)} \quad \textbf{(3)}$$

The expressions in equation (4) and (5) are the obtained Path loss models for Clear Weather PL_{cw}, and Haze Weather, PL_{Hw}, respectively, for a frequency of 92.1 MHz, with equation (9) depicting the expression for the attenuation due to Haze at the same frequency.

$$PL_{cw} = 20.692 \ln(d) + 56.108 \quad \textbf{(4)}$$

$$PL_{Hw} = 22.934 \ln(d) + 58.346 \quad \textbf{(5)}$$

$$A_H = 5.099 e^{0.035d} \quad \textbf{(6)}$$

The obtained Path loss model due to haze at a frequency of 92.1 MHz has a coefficient of 22.934 which is greater than 20.692 obtained during clear weather, with a correlation value (R^2) of 0.961 which shows that, the correlation is highly significant and justifies the accuracy of the logarithm model obtained.

The expressions in equation (7) and (8) denotes the obtained Path loss models for Clear Weather PL_{cw}, and Haze Weather, PL_{Hw} respectively at a frequency of 98.5 MHz, with equation (9) depicting the expression for the attenuation due (A_H) to Haze at the same frequency.

$$PL_{cw} = 13.643 \ln(d) + 62.258 \quad \textbf{(7)}$$

$$PL_{Hw} = 16.294 \ln(d) + 66.227 \quad (8)$$

$$A_H = 6.9282e^{0.033d} \quad (9)$$

The obtained Path loss model due to haze at a frequency of 98.5 MHz has a coefficient of 16.294 which is greater than 13.643 obtained during clear weather, with a correlation value (R^2) of 0.983 which shows also that, the correlation is highly significant and justifies the accuracy of the logarithm model obtained.

CONCLUSION

Path loss in dust haze conditions is an important factor to consider when designing wireless communication systems that operate in the VHF band. Ultimately, a combination of empirical measurements and model optimization provide accurate prediction of path loss in dust haze conditions across the test site selected in southwest Nigeria. Correlation value of (R^2) were found to be 0.962 and 0.983 for 92.1 MHz and 98.5 MHz respectively. Furthermore, the attenuation coefficients of 5.099 with exponent of $0.035d$ were obtained at 92.1 MHz, while for 98.5 MHz the attenuation coefficients of 6.9282 with exponent of 0.033d were obtained respectively.

The result obtained validate that dust haze attenuates VHF radio wave signals. The model optimization prediction provides good help in designing an effective communication system that can operate in challenging environments.

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