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PATHLOSS PREDICTION MODEL IN WLAN PROPAGATION

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ABSTRACT

Pathloss propagation in urban, suburban, and rural environments has a significant impact on wireless communication networks. Different propagation models have been developed for network locations. The different terrains are unique in their topological features and environmental factors. Therefore, a propagation model suitable for one terrain may not be suitable for another propagation environment for pathloss prediction. This paper proposes a signal prediction model with an 802.11 b/g wireless local area network (WLAN) infrastructure at 2.4 GHz. The models are backed by extensive received signal strength (RSS) measurements acquired from a free space of the primary field data at the University of Benin, Benin City, Nigeria. The study considered distance based on the received signal strength of an ad hoc network for the development of a propagation model at various distances. The collected data were analysed, and a propagation model for the network terrain was developed from the log normal shadowing model. Graphical comparisons between the average RSS value and the predicted RSS value dependent on the distance were demonstrated to reflect that the proposed model can be used to predict RSS in the given propagation environment. Consequently, the utilization of this model can significantly enhance network planning activities by accurately estimating RSS values, aiding in the identification of optimal access point placement, ensuring seamless coverage, and mitigating potential coverage gaps. The findings of this research offer valuable insights for network engineers and provide a solid foundation for optimizing wireless communication within this unique network environment.

Keywords: WLAN, Pathloss, 802.11b/g, Received Signal Strength (RSS), ad-hoc network

INTRODUCTION

Recently, there has been a large-scale proliferation of ad hoc wireless communication links. This trend is likely to continue in the near future. Due to the rapid spread of wireless communication, the need for proper network planning and design is pertinent to ensuring proper implementation and satisfactory network performance. An electromagnetic wave travelling from the transmitter to the receiver can suffer from reflection, diffraction, and attenuation depending on the propagation medium. This can adversely affect the performance of wireless communication links. To ensure a high quality of service to clients, it is important to properly plan a network with the rising deployment, coverage, and congestion issues associated with today's WLAN. The wireless link's performance is dependent on the terrain of deployment (Nekrasov et al., 2019). For proper network coverage planning, it is paramount to understand the various limiting effects poised by various environmental conditions, such as interference and fading, on the propagation of the signal (Ubom et al., 2011). An important performance metric for the proper planning and implementation of the wireless communication system is pathloss. Pathloss is an unwanted acquaintance of energy that affects the best possible gathering and proliferation of signs during its transmission from transmitter to receiver. Pathloss degrades the strength of a travelling electromagnetic wave through space (Zhu et al., 2001). The development of channel models is an important way of estimating the performance of wireless communication links. Channel models are mathematical expressions that describe how signal properties are affected by channel characteristics such as pathloss, shadowing, and multipath effects as they travel through the medium. This model can be classified into three categories: empirical, theoretical, and the combination of the two, which is termed the semi-empirical model (Oguejiofor et al., 2013). The empirical models are developed based on measurements, and the theoretical models are based on the fundamental principles of radio wave propagation phenomena (Stallings, 2005). The importance of channel models necessitated this research work since they assist network engineers in properly planning, designing, and implementing a wireless network based on the IEEE 802.11 standards. Therefore, this study seeks to characterise the propagation environment of a WLAN.

MATERIALS AND METHODS

Experimental Environment

The research work was carried out in the ancient city of Benin, Edo State, located in the southern part of Nigeria. This city has a lot of vegetation and many tall buildings. The city is also densely populated. The research is therefore limited to the University of Benin campus. The University campus can be said to be suburban since it also has many buildings and trees and is sparsely populated. The measurement environment is a free space that has no buildings. This was done in the postgraduate student hostel field within the university. The measurement environment is located at latitude $6^0 23'51''$N and longitude of $5^0 37'28''$E according to Ayidu and Iruansi (2022). The WLAN access point (AP) was supported on a plastic pole 8 feet above the ground. The access point was positioned at one end of the field, and the measurements were taken in three different directions.

Measurement Tools/Procedure

In this study, both hardware and software tools were used to achieve this fieldwork involving data collection. The software used is the inSSIDer 2.1 network scanner. This software was installed and used to measure the received signal strength at the receiver. The insider 2.1 has the ability to sniff any wireless LAN when a packet is sent from server to client within the test area. A GPS was used to indicate the distance of the client as the case maybe from the access point.

The measurements were taken in three directions from the AP, and each direction covered a total distance of 70 m because beyond this, the received signal strength is severely degraded. The total distance for each direction was divided into seven points, and each point has a step distance of 10m from each other. The three directions of measurements are marked A, B, and C. Several measurements are taken for each of the points along the three directions within three months' duration. The average measured received signal strength at each point is collated by dividing the summation of the various measurement values by the total number of samples per position. The pathloss exponent is obtained from the mean measurement values and a pathloss model expression is obtained for the propagation environment from log-normal shadowing model.

Data Presentation

The average value of the primary field data of the received signal strength (RSS) A, B, and C based on the distance and the mean is represented in Table 1.

Table 1: Average Received Signal Strength (A, B and C)

DISTANCE(m)	RSS A(dBm)	RSS B(dBm)	RSS C(dBm)	MEAN RSS(dBm)
10	-38.96	-37.50	-40.17	-38.88
20	-48.69	-46.32	-52.53	-49.18
30	-54.50	-52.71	-53.01	-53.41
40	-62.50	-58.80	-63.50	-61.60
50	-67.93	-65.33	-66.31	-66-52
60	-69.51	-70.02	-69.70	-69.74
70	-71.01	-70.51	-70.13	-70.55

Table 1 shows the average received signal strength (RSS) for three different signals, labeled A, B, and C, at various distances. The distances range from 10 meters to 70 meters. The received signal strengths are measured in decibels (dBm), which is a unit used to quantify the power level of the signals. At a distance of 10 meters, the average RSS for signal A is -38.96 dBm, for signal B is -37.50 dBm, and for signal C is -40.17 dBm. The mean RSS, which is the average of the three signals, is calculated as -38.88 dBm. As the distance increases to 20 meters, the average RSS values for the three signals decrease. Signal A has an average RSS of -48.69 dBm, signal B has -46.32 dBm, and signal C has -52.53 dBm. The mean RSS at this distance is -49.18 dBm. Similarly, at distances of 30, 40, 50, 60, and 70 meters, the average RSS values for the three signals continue to decrease. The mean RSS values for each distance are -53.41 dBm, -61.60 dBm, -66.52 dBm, -69.74 dBm, and -70.55 dBm, respectively. Table 1 thus, provides an overview of how the received signal strength changes as the distance between the transmitter and receiver increases. As the distance grows, the signal strength decreases, which is a common phenomenon in wireless communication systems

Existing Prediction Models For Outdoor Propagation

Network engineers employ propagation models that are suitable for the terrain into which the network is to be deployed for proper planning and design. This is to ensure a satisfactory performance and a high quality of service for the clients. A common approach by network engineers is to deploy radio infrastructure in a small area and verify coverage through several measurements. This is done for other areas until full coverage is achieved. This approach does not ensure a satisfactory performance for the network. It is more professional and suitable to deploy propagation models that successfully characterise the propagation environment into which a given network is to be deployed to ensure satisfactory performance (Stalling, 2005).

Free Space Pathloss Model (FSPL)

The gradual degradation of the signal strength of an electromagnetic wave travelling through space as a result of a line-of-sight path without any obstacle to cause reflection or diffraction is called free space pathloss. Free-space pathloss is directly proportional to the square of the distance between the transmitter and the receiver and also proportional to the square of the frequency of the radio signal. The equation of FSPL in decibels is explained by equation 1 (Miah et al., 2011).

$$PL = 20\ \mathrm{Log}_{10}(d) + 20\mathrm{Log}_{10}(f) + 32.45 \quad (1)$$

where f is the signal frequency (in MHz).

The antenna's distance from the location is d, measured in kilometres (km).

Cost 231 Hata Model

A mathematical phrase called the Hata model is used to reduce the best match of the graphical data that the Okumura model provides. This mathematical expression can be helpful in predicting the median route loss for d, up to a maximum of 20 kilometres, between the transmitter and receiver antennas. The reception antenna height is between 1 to 10 metres, and the transmitter antenna height is between 30 to 200 metres. The Hata model is suitable for the frequency range of 150 MHz to 1500 MHz. The cost 231 Hata is developed as an extension of the Hata model to predict the pathloss in the frequency range of 1500 MHz to 2000 MHz. The pathloss in urban, suburban, and rural environments can be predicted with this model. This model offers a straightforward method for calculating pathloss, and because of its limited complexity and correction factors, it can forecast pathloss in the frequency ranges of 2.5 GHz and 3.5 GHz, which are outside of its measurement range. The fundamental pathloss equation for the cost 231 Hata model is shown in equation (2), as described by Miah et al. (2011).

$$PL=46.3+33.9\log_{10}(f)-13.82\log_{10}(h_b)-ah_m+(44.9-6.55\log_{10}(h_b))\log_{10}(d)+c_m \quad (2)$$

where the distance between the transmitter and receiver = d.

Frequency (MHz) = F.

H_b = the transmitter antenna height in meter. The correction parameter c_m has different values for different environment like 0dB for suburban areas and open rural environment while 3dB is assigned for urban areas. The remaining parameter ah_m is defined in urban areas as

$$ah_m= (1.11\log_{10}(f)-0.7)\ hr-(1.5\log_{10}(f)-0.8) \quad (3)$$

h_r = the receiver antenna height (m).

Ericsson Model

The Ericsson model is a piece of software offered by the Ericsson business. Network engineers use this software to forecast the pathloss of a wireless communication channel (Fili, 2005). Based on the modified Okumura-Hata model, this one can accept parameter changes in response to the propagation environment. This model's pathloss is provided by Badri et al. (2011).

$$PL = a_o + a_1 \mathrm{Log}_{10}(d) + a_2 \mathrm{Log}_{10}(h_b) + a_3 \mathrm{Log}_{10}(h_b)\mathrm{Log}_{10}(d) - g_1(h_r) + g_2(f) \quad (4)$$

$g_1(h_r)$ and $g_2(f)$ are given by

$$g_1(h_r) = 3.2\,(\mathrm{Log}_{10}(11.75h_r)^2) \quad (5)$$

and

$$g_2(f) = 44.49\,\mathrm{Log}_{10}(f) - 4.78\,(\mathrm{Log}_{10}(f))^2 \quad (6)$$

where f is given as the frequency (MHz), h_b and h_r represent the transmitter antenna height and receiver antenna height in meters (m).

Table 2 provides the default values of the parameters (a_0, a_1,a_2 and a_3) for the various terrain types (Alshami et al., 2011).

Table 2: Default value for different terrain

ENVIRONMENT	a_0	a_1	a_2	a_3
Urban	36.20	30.20	12.00	0.1
Suburban	43.20	68.93	12.00	0.1
Rural	45.95	100.6	12.00	0.1

Calculation of Pathloss Exponent

The equation that predicts the mean pathloss $P_L(di)Db$ at a transmitter receiver separation di is given as:

$$P_L(di)dB = P_L(d_0)Db + 10n\log_{10}\left[\frac{di}{do}\right] \quad (7)$$

Where n is the pathloss exponent

$P_L(d_0)$ is the pathloss at known reference distance d_o

The propagation environment affects the empirical constant known as the pathloss exponent n. By adding n as a subject in Eqn. (7), the equation below can be manually utilised to calculate the pathloss coefficient n of the test bed environment.

$$N = \frac{\{P_L(di) - P_l(do)\}}{10log_{10}\left[\frac{di}{do}\right]} \quad (8)$$

Applying linear regression, determine the value of n by minimizing the total error R^2 as depicts in equation (9);

$$R^2 = \sum_{i=1}^{m}\left[P_L(di) - P_L(do) - 10nlog_{10}\left[\frac{di}{do}\right]\right] \quad (9)$$

By differentiating equation 9 and equating to zero, the pathloss coefficient can be obtained as follows;

$$\frac{\partial R^2}{\partial n} = 0$$

$$-20\log_{10}(d)\sum_{i=1}^{m}\left[P_L(di) - P_L(do) - 10nlog_{10}\left[\frac{di}{do}\right]\right] = 0$$

$$\sum_{i=1}^{m}\left[P_L(di) - P_L(do) - 10nlog_{10}\left[\frac{di}{do}\right]\right] = 0$$

$$\sum_{i=1}^{m}\left[[P_L(di) - P_L(do)] - \sum_{i=1}^{m}\left[10nlog_{10}\left[\frac{di}{do}\right]\right]\right] = 0$$

$$\sum_{i=1}^{m}\left[P_L(di) - P_L(do) = \sum_{i=1}^{m}\left[10nlog_{10}\left[\frac{di}{do}\right]\right]\right]$$

$$n = \frac{\sum_{i=1}^{m}[P_L(di) - P_L(do)]}{\sum_{i=1}^{m}\left[10\mathrm{nlog}10\left[\frac{di}{do}\right]\right]} \quad (10)$$

Equation (10) is used to obtain the pathloss exponent for the test bed environment used in the research work. The pathloss exponent has a value of n = 3.72.

n is assumed to be 2 for the free space model. The propagation signal is usually affected by reflection, diffraction, and scattering. This results in a loss of signal strength, and the effects are dependent on the environment. Hence, the free space model is an ideal case scenario (Rappaport, 1998).

Development of Pathloss Prediction Model

A fundamental approach to predicting the RSS for the test bed environment is proposed in equation 11 below. This approach has been used by network engineers because of its simplicity of application to develop models that can predict the RSS of any propagation environment with near accuracy (Rappaport, 1998).

$$RSS = 10n\,\mathrm{Log}_{10}\left[\frac{\mathrm{di}}{\mathrm{do}}\right] + A \quad (11)$$

RSS is the signal power at the receiver, n is the pathloss exponent of the test bed environment, d_i is the distance between the transmitter and receiver, d_o is the reference distance from the transmitter, and A is the RSS at 10m distance from the transmitter (which is -33.88 as shown in Table 3).

By substituting values for n and A into (11), the propagation model can be obtained as

$$Y = -37.2\log_{10}x - 38.88 \quad (12)$$

Where $x = \frac{d_i}{d_o}$

Table 3: Average RSS VS Predicted RSS

DISTANCE(m)	**AVERAGE RSS**	**PREDICTED RSS**
10	-38.88	-38.88
20	-49.18	-50.08
30	-53.41	-56.63
40	-61.60	-61.27
50	-66.52	-64.88
60	-69.74	-67.82
70	-70.55	-70.31

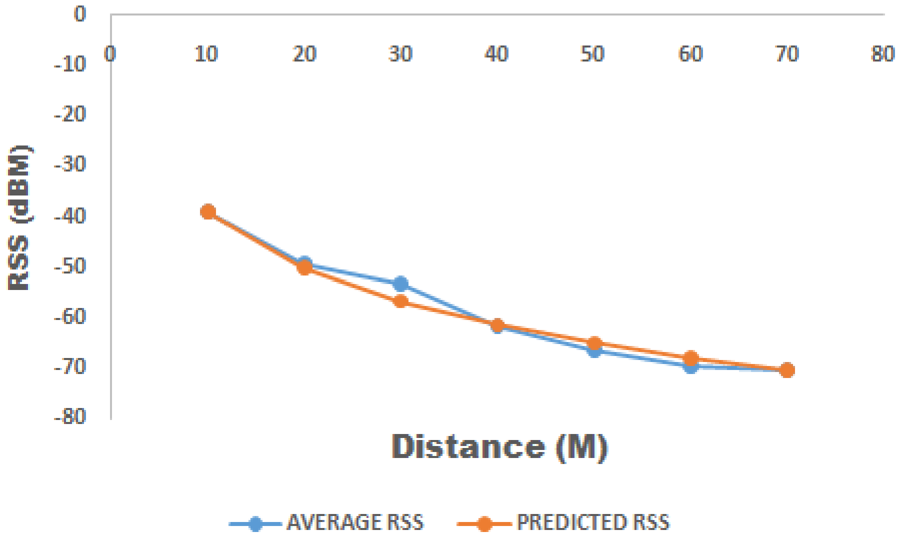

Figure 1: Graph of average value of measured RSS Vs Predicted RSS against distance

Figure 1 shows a close alignment between the average value of measured RSS and the predicted RSS at various distances from the access point.

The existing models for outdoor propagation enable the prediction of path loss in urban, suburban, and rural environments. These models can be adapted to accommodate parameter adjustments based on the specific propagation characteristics of each environment. In this study, the empirical constant (path loss exponent n) was influenced by the propagation environment. Equation (10) was employed to calculate the path loss exponent, with a value of 3.72 determined for the test bed environment. By substituting the values of n and A into Equation (11), the received signal strength (RSS) was obtained. Equation (12) derives the propagation factor used to solve for the predicted values presented in Table 3.

The developed model utilised the standard log-normal shadowing model to predict RSS. Notably, the predicted RSS closely aligned with the average values at distances of 10m, 20m, 40m, and 70m. This graphically demonstrates the model's satisfactory performance in predicting received signal strength within the test bed environment. The model successfully characterises the propagation environment and accurately describes the loss of signal strength as the signal travels in the test bed environment. The research findings align with the conclusions published by Nguyen et al. (2018) in their work titled "Improved Localization Accuracy Using Machine Learning: Predicting and Refining RSS Measurements."

CONCLUSION

The findings of this research hold significant implications for the deployment of an ad hoc WLAN operating at 2.5 GHz within the University of Benin main campus. The proposed signal propagation model, developed using the pathloss exponent obtained from measurement data and incorporating the log-normal shadowing model, demonstrates its suitability for predicting received signal strength (RSS) in the specific propagation environment. Comparing the average RSS with the predicted RSS for each measurement location, as depicted in Figure 1, it becomes evident that the proposed model provides reliable predictions in the given propagation environment. Notably, at distances of 10m, 20m, 40m, and 70m, the disparity between the average and predicted RSS is minimal. This finding emphasises the model's effectiveness and establishes its potential as a valuable tool for network engineers in planning and implementing a WLAN network within the unique network terrain of the University of Benin main campus.

Consequently, the utilization of this model can significantly enhance network planning activities by accurately estimating RSS values, aiding in the identification of optimal access point placement, ensuring seamless coverage, and mitigating potential coverage gaps. With its demonstrated performance, this model offers practical benefits and serves as a reliable guide for network engineers seeking to design and deploy a robust WLAN network tailored to the specific propagation characteristics of the University of Benin main campus.

In conclusion, the findings of this research offer valuable insights for network engineers and provide a solid foundation for optimising wireless communication within this unique network environment.

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