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A Study on Path Loss Analysis for KNUST Campus WLAN, Ghana

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ABSTRACT: the growing demand for local area communication are prominent for day-to-day activities, therefore, there is growing interest in optimizing the WLAN infrastructure so as to increase productivity and efficiency in the various school campuses, factories, hotels, among others. Regardless of the enormous benefits offered by WLANs, the environment, including building, trees, bushes, vegetation, climate, and interferences from other RF signals in which the WLAN operates play a critical role in defining the architecture and design of WLAN. In this paper, a mean path loss model was developed and compared with some well-known models and it showed some agreement indicating it can be used to effectively deploy WLAN infrastructure for effective coverage distance, improved client received signal quality, reliability of data transfer, and effective data rate on KNUST campus.

KEYWORDS: RSSI, NLOS, LOS, WLAN, AP.

1 INTRODUCTION

The mean signal strength from an arbitrary transmitter-receiver (T-R) separation is useful in estimating the radio coverage of a given transmitter whereas measures of signal variability are key determinants in system design issues such as antenna diversity and signal coding. In order to accurately estimate the spatial separation between transmitter and receiver, a propagation model must be used that is suitable to a specific operational environment. Radio propagation models are empirical in nature; they are developed based on large collections of data for the specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a channel, rather they predict the most expected behavior the channel my exhibit under specified conditions [1].

2 BACKGROUND STUDY

2.1 RADIO PROPAGATION MODELS

Radio propagation model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance, and other dynamic factors. A single model is usually developed to predict the behaviour of propagation for all similar links under similar constraints. Propagation models are developed with the goal of formalizing the way radio waves propagate from one place to another, such models typically predict the path loss along a link or the effective coveragearea of the transmitter. According to Rappaport and Sandhu [2] propagation models are not only needed for installation guidelines, but they are a key part of any analysis or design that strives to mitigate interference. Hence, propagation models can be categorized into three types, empirical models, deterministic models and theoretical models.

2.1.1 EMPIRICAL MODELS

Empirical models use experimental data and observations alone to predict loss. Empirical models can be split into two subcategories, time dispersive and non-time dispersive [3]. The time dispersive model provides us with information about time dispersive characteristics of the channel like delay spread of the channel during multipath. The Stanford University

Interim (SUI) model [3] is the perfect example of this type. COST 231 Hata model, Hata and ITU-R [3] model are example of non-time dispersive empirical model.

2.1.1.1 FREE SPACE PROPAGATION MODEL

Free space propagation model is used to predict the signal strength at a distance from the receiver when there is no obstruction between the transmitter and the receiver. It is the foundation for all other models. It is derived from Friis's free space equation showed in **Equation 1.**

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (1)$$

The equation of path loss for Friis space model, is written as

$$P_{FSL} = \frac{P_t}{P_r} = \frac{1}{G_t G_r}\left(\frac{4\pi d}{\lambda}\right)^2 \quad (2)$$

For λ = wavelength = $\frac{c}{f}$, c = speed of light ($3 * 10^8$ m/s)

Equation 2 can be simplified into **Equation 3**

$$P_{FSL}\ (dB) = 32.45 - 10logGt - 10logGr + 20logf + 20logd \quad (3)$$

Where P_r = received power, P_t = transmitted power, f = carrier frequency in MHz

G_t = gain of the transmitter, G_r = gain of the receiver

d = antenna separation distance in Kilometres

P_{FSL} = free space path loss

Equations 2 and **3** indicate that free space path loss is frequency dependence and is increasing against distance. The free space attenuation increases by *6dB* whenever the length of the path or the frequency is doubled [4].

This shows the classic square-law loss of signal energy as it propagates. It has been shown to be a good approximation of distance dependant loss in a wireless system [4]. To simplify this equation for meters, we will reduce the distance and frequency units by a factor of 10^3 so the equation becomes:

$$P_{FSL}\ (dB) = 32.45 + 20log_{10}d + 20log_{10}f \quad (4)$$

For 2.4 GHz WLAN systems, the **Equation 4** for free space loss using the distance in meters can be simplified to become [48]:

$$P_{FSL}(dB) = 40 + 20log_{10}d \quad (5)$$

The frequency dependant portion of the equation can be explained since the path loss increase as a square of the frequency. The effective aperture of a ¼ wavelength isotropic antenna commonly used in WLAN systems varies inversely to frequency. Therefore, if we double the frequency, the linear size of the antenna decreases by one-half and the capture area by a factor one-quarter [4]

2.1.1.2 COOPERATE IN SCIENCE AND TECHNOLOGY (COST) 231 MODEL

The COST 231 model was developed as an extension to the Hata model in order to extend its frequency range to 1500 MHz to 2000 MHz, which is used in personal communication systems (PCS). The formula for this model is in **Equation 5**, where the equation for receiver antenna height correction α(hr) from the Hata model is used. The environment correction factor C_M is 0dB for suburban and rural areas and 3dB for urban areas. The same constraints apply to this model as the Hata model, except for the change in frequency [5].

$$PL = 46.3 + 33.9\log(fc) - 13.82\log(ht) - \alpha(hr) + (44.9 - 6.55\log(ht))\log(d) + C_M \quad (5)$$

Although the frequency constraint for COST 231 is relatively close to what is used by IEEE 802.11 b/g networks, a large difference still remains between the recommended antenna height and the antenna heights used in this study [6][1].

2.1.1.3 STANFORD UNIVERSITY INTERIM (SUI) MODEL

The proposed standards for the frequency bands below 11 GHz contain the channel models developed by Stanford University, namely the SUI models. Note that these models are defined for the Multipoint Microwave Distribution System (MMDS) frequency band which is from 2.5 GHz to 2.7 GHz. This makes SUI a good candidate for use with IEEE 802.11b/g networks, their applicability to the 3.5 GHz frequency band that is in use in the United Kingdom (UK) has so far not been clearly established [3]. The SUI models are divided into three types of terrains, namely Type A, Type B and Type C. Type A is associated with minimum path loss and applies to flat terrain with light tree densities. Type B is characterized with either mostly flat terrain with moderate to heavy tree densities or hilly with light tree densities. The basic path loss equation with correction factors is presented in [7] [8].

$$PL = A + 10\gamma \log\left(\frac{d}{d_o}\right) + X_f + X_h + S\ ,\ for\ d > d_0 \qquad (6)$$

Where, **d** is the distance between the Access Points (AP) and the Customer Premises Equipment (CPE) antennas in meters, *do* = 100 m and *S* is a log normally distributed factor that is used to account for the shadow fading owing to trees and other cluster and has a value between 8.2dB and 10.6dB [8]. The other parameters are defined as,

$$A = 20log_{10}(\frac{4\pi do}{\lambda}) \qquad (2.16), \qquad \gamma = a - bh_b + \frac{c}{h_b} \qquad (7)$$

Where, the parameters h_b is the base station height above ground in meters and should be between 10m and 80m. The constants used for a, b and c is given in **Table 1**. The parameter γ in **Equation 7** is equal to the path loss exponent. For a given terrain type the path loss exponent is determined by h_b.

Table 1: The Parameters of SUI Model in different types of environments

Model Parameters	**Terrain Type A**	**Terrain Type B**	**Terrain Type C**
A	4.6	4	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The correction factors for the operating frequency and for the CPE antenna height for the model are [9] [10].

$$X_f = 6.0log_{10}\left(\frac{f}{2000}\right) \qquad (8)\ \text{And} \quad X_h = -10.8log_{10}\left(\frac{h_r}{2000}\right) \quad (9) \quad ,for\ Terrain\ types\ A\ and\ B$$

$$= -20.0log_{10}\left(\frac{h_r}{2000}\right) \quad ,for\ Terrain\ type\ C \qquad (10)$$

Where, *f* is the frequency in MHz and *hr* is the CPE antenna height above ground in meters. The SUI model is used to predict the path loss in all three environments, namely rural, suburban and urban. Although the frequency range for the SUI model is a close match for IEEE 802.11b/g, the model exhibits unexpected behavior when the transmit antenna height is below the recommended value [1], and therefore makes this model not suitable for this study.

2.1.1.4 LOG-DISTANCE PATH LOSS PROPAGATION MODEL

In both indoor and outdoor environments, the average path loss for an arbitrary Transmitter-Receiver (T-R) separation is expressed as a function distance by using a path loss exponent, *n*. [11, 12, 13]. The average path loss PL(d) for a transmitter and a receiver d is

$$PL(d) \propto (\frac{d}{d_o})^n \qquad (11)$$

Where d is the distance between transmitter and receiver, do is a reference distance (typically assumed to be 1m) and *n* is the attenuation factor. From this relationship the path loss function, in dB is defined by:

$$PL(d)[dB] = PL(d_o)[dB] + 10nlog\left(\frac{d}{d_o}\right) \qquad (12)$$

Equation 13 indicates that the path loss at a given distance d is the sum of the path loss observed at a reference distance d_o and the additional loss imposed by **Equation 12.** The attenuation factor *n* is found experimentally.

Log-distance path loss propagation model with shadow fading is given by

$$PL(d)[dB] = PL(d_o)[dB] + 10nlog\left(\frac{d}{d_o}\right) + S \qquad (13)$$

Where:

n is path loss exponent with values between *2* to *4*, *d* is the distance between the mobile node and WLAN access point (AP) and S represents shadow fading modeled as Gaussian with mean μ = 0 and standard deviation *σ* with values between *6* and *12dB* depending on the environment [14]. This model was used in this study.

3 METHODOLOGY USED FOR MEASUREMENT

A laptop equipped with a wireless card running on Microsoft windows XP platform with netstumbler software installed was used to collected RSSI data from the Aps. 60 samples of measured data were taken randomly in 129 seconds at every 10m mark from the AP to 100m. This was done for both LOS and NLOS environment scenarios. The data were taken at worst case scenario between September to December from 14:00 GMT to 19:00 GMT when most of the students were around and using the AP. LOS and NLOS were chosen based on whether the is presents of obstructions between AP and Mobile device. If obstructions present it was marked as NLOS and if no obstructions or minimal obstructions it was marked as LOS.

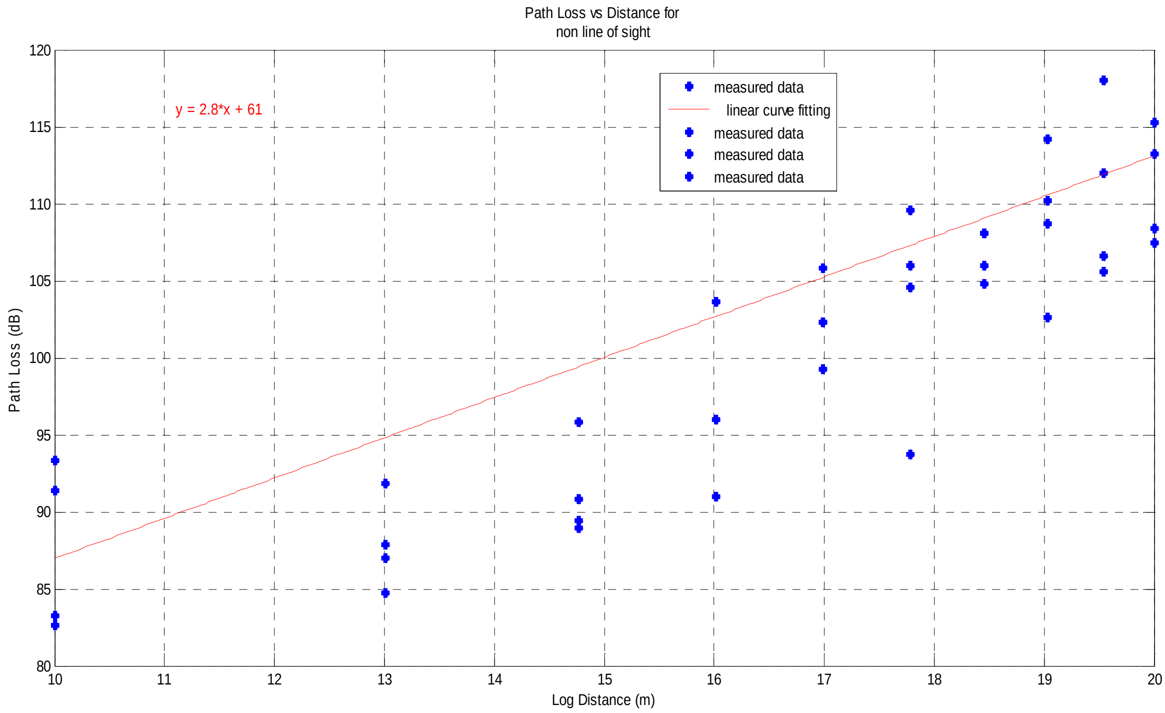
4 MODEL PERFORMANCE RESULTS AND EVALUATION

Curve fitting method was used to evaluate the path loss exponent *n*, in Log-distance path loss model. The curve fitting process fits equations of approximately lines to the raw field data. A curve with minimal deviation from all data points is desired. This best-fitting curve can be obtained by the method of least squares.

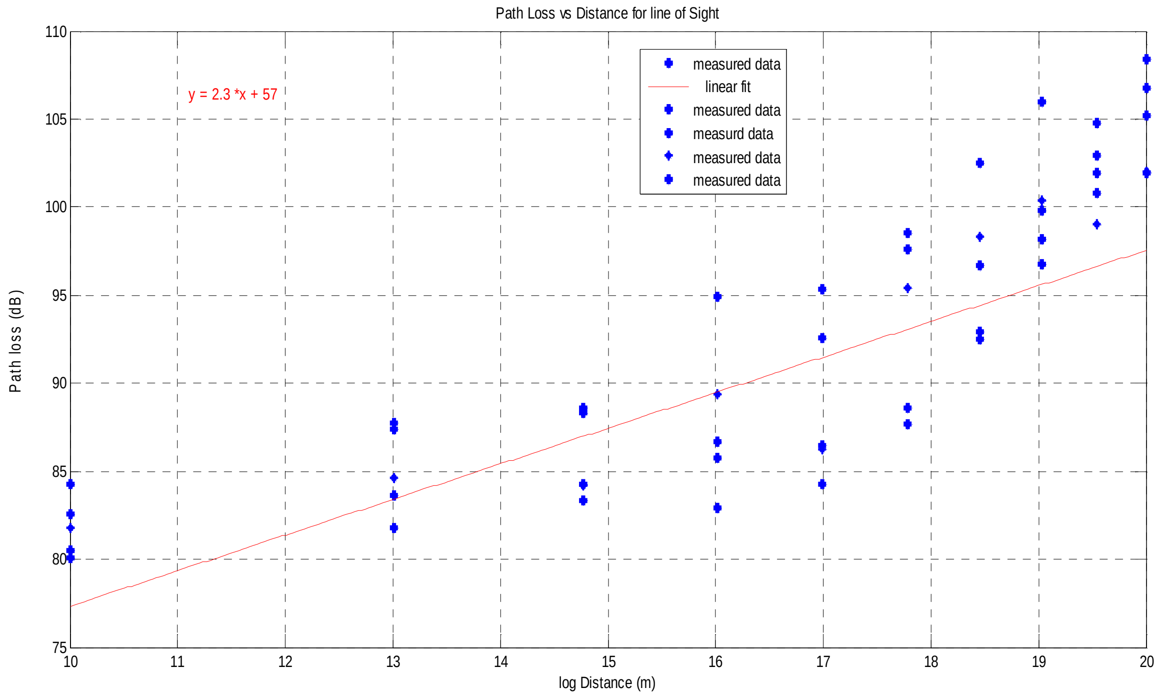
The least-square uses a straight line equation of the form (14)

$f(x) = \beta_1 x + \beta_2$ (14) Where: β_2 is the intersect of the straight line.

To approximate the given set of data, $(x_1, y_1), (x_2, y_2)..., (x_n, y_n)$, where >=2. The best fitting curve f(x) has the least error (15) $\Pi = \sum_{i=1}^{n}[y_i - f(x_i)]^2 = \sum_{i=1}^{n}[y_i - (\beta_1 x_i + \beta_2\,]^2$ (15)



Figures 1: shows the linear curve fitting for the data collected from the study area in NLOS



Figures 2: shows the linear curve fitting for the data collected from the study area in LOS

The plot of distance *d* versus the path loss *PL* on a log-log scale is a straight line with a slope of *10n* as in **Equation 12.** The slope (β_1) of the linear equation of the form (14) from the curve fitting were compared to the slope of Log-distance path loss model *(10n),* and path loss exponents computed for both LOS and NLOS environments and presented in **Tables 4-8** and **4-9**. The standard deviations (σ), coefficient of determination (R^2) and root mean square errors (RMSE) were determined by applying **Equations 16 to 18** in MATLAB tool and presented in **Table 2**

$$\sigma = \sqrt{\frac{\sum_{i=1}^{M}(y_i - \bar{y}_i)^2}{M}} \quad (16), \quad RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(yi - \tilde{y}i)^2} \quad (17)$$

Where $\tilde{y}_i$ denotes the estimate of data y_i , M is the data length and $\bar{y}_i$ is the mean of the measured data. The statistical measure R^2 on the other hand is given as

$$R^2 = 1 - \frac{\sum_{i=1}^{M}(yi - \tilde{y}i)^2}{\sum_{i=1}^{M}(yi - \bar{y}i)^2} \quad (18)$$

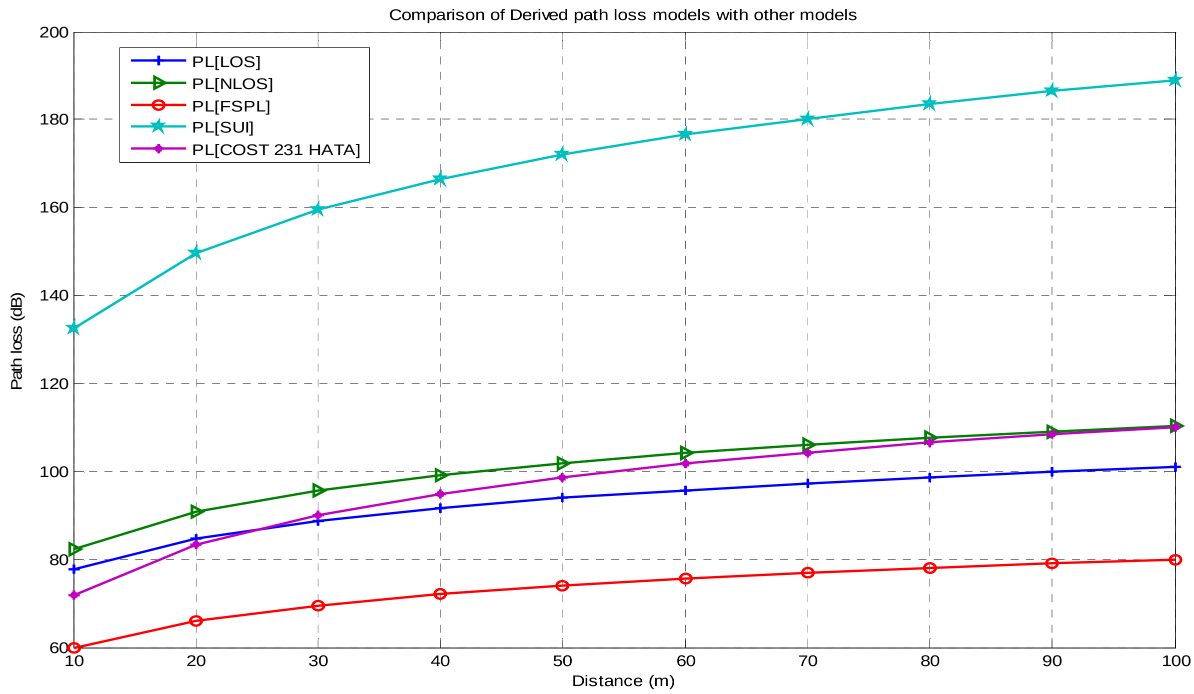
Table 2: Summary of Parameters from data

Environment Scenario	Path loss exponent (n)	Standard Deviation (σ) dB	Coefficient of Determination (R^2)	RMSE (dB)	intercept
LOS	2.3	8.21	0.916	0.192	57
NLOS	2.8	9.55	0.878	0.148	61

The derived mean propagation path loss models can be obtained from **Table 2** for LOS and NLOS environments as **Equations 19** and **20:**

$$PL(d)[LOS][dB] = 57 + 23\log\left(\frac{d}{d_o}\right) \quad (19), \quad PL(d)[NLOS][dB] = 61 + 28\log(\frac{d}{d_o}) \quad (20)$$

The standard deviations, root mean square error (RMSE) and coefficient of determination (R^2) of the derived models from the actual measurements were parameters used to evaluate the quality of the models as a quantitative of its accuracy. In this paper, the overall mean standard deviations for LOS environment were less than ± 9dB. The coefficient determination with a magnitude near 1 represents a good fit. As the fit gets worse, the coefficient of determination approaches zero, the values of coefficient determination for LOS was 0.916 indicating a good fit. The RMSE for LOS environment were < *1dB* which is a satisfactory result.



Figurer 3: Comparison of derived mean path loss model with other known models

The derived propagation path loss models were compared with COST 231 Hata model, Stanford University Interim (SUI) model and Free Space Propagation Loss (FSPL) model as shown in **Figure 1** and **2.** The figures shows similarities and differences between models utilizing the same or nearly the same parameters.

SUI model showed the highest path loss prediction at a base station antenna height (h_b) of 10m and a Terrain Type B environment which is similar to the environment of the study area. FSPL showed the least path loss prediction as expected, since it does not include any additional losses from the environment but only its loss depends on only distance and frequency. The derived models were observed to show good agreement with COST 231 Hata model with a mean deviation of 5.3dB between PL[LOS] and 3.6dB between PL[NLOS]. The figure also showed very little worst agreement between the path loss prediction by derived path models and SUI model, with a mean deviation of 76.6dB between PL[LOS] and SUI model and also a mean deviation of 68.9 dB between PL[NLOS] and SUI model. The large deviation between derived models and SUI model could be explained by the small value of transmitting antenna $(h_b = 10m)$ chosen for this comparison.

5 Conclusion

In this study, RSSI data were collected in both LOS and NLOS environment scenarios on KNUST campus and path loss exponents were determined to be 2.3 for LOS and 2.8 for NLOS respectively using the method of least-squares logarithmic regression analysis, Standard Deviation and RMSE were also determined to be 8.21dB and 0.192 for LOS and 9.55dB and 0.148 for NLOS respectively. Mean path loss models were derived and compared with some world known radio propagation models such COST 230 Hata, SUI and Free Space loss model and showed some level of agreement indicating the derived models could potentially be used successfully in wireless network deployment and planning at KNUST without propagation measurements which are expensive and time consuming.

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