Indoor Measurement And Propagation Prediction Of WLAN At 2.4GHz

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Abstract

*With the low cost and high-speed data rate capabilities, installations of IEEE 802.11-based wireless local area networks (WLANs) are growing exponentially. Most wireless access points are deployed in the immediate vicinity of where wireless coverage is desired and the system typically seems to work. The performance of such an ad-hoc deployed network is much less than what could be achieved by proper network design. Indeed, many organizations are already noticing the actual data rate limitations of large scale, highly loaded WLANs that have been installed in an ad-hoc fashion***.** *To assist in optimal deployment of indoor wireless system, characterization of the indoor radio propagation channel is essential. This project achieves this by carrying out extensive field strength measurements at different coverage angles in an already existing IEEE 802.11g WLAN network at 2.4GHz. Based on the statistics of the measured data, empirical propagation channel model is developed. By using this propagation model, network analysis and simulations can be efficiently carried out. This will facilitate faster and more accurate deployment of wireless networks.*

1. Introduction

For a radio communication system, the channel describes how the electromagnetic propagation of a transmitted signal provides the signal at the receiver [1, 2]. WLANs operate mainly in an indoor environment. It is very difficult to predict how RF wave travels in an indoor environment. So there is the need for developing an indoor propagation model to predict RF wave behaviour more accurately.

In order to evaluate the effectiveness of coding and processing techniques for a given channel prior to construction, a model of the channel must be developed that adequately describes the environment. Such analysis reduces the cost of developing a complex system by reducing the amount of hardware required for evaluation of performance.

Indoor channels are highly dependent upon the placement of walls, partitions and other obstructions within the building. Placement of these walls and partitions dictates the signal path inside a building. In such cases, a model of the environment is a useful design tool in constructing a layout that leads to efficient communication strategies.

By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model may be developed that highlights the important characteristics of a given indoor environment. Generic models of indoor communications can then be applied to specific situations to describe the operation of a radio system, and may also be used to generate designs that are particularly suited to supporting radio communication systems.

2. Propagation Models

A propagation model is a set of mathematical expressions, diagrams and algorithms used to represent the radio characteristics of a given environment [2]. The prediction models can be either empirical (also called statistical) or theoretical (also called deterministic), or a combination of these two (semi-empirical) [3, 4]. While the empirical models are based on measurements, the theoretical models deal with the fundamental principles of radio wave propagation phenomena.

On the basis of the radio environment, the prediction models can be classified into two main categories: - outdoor and indoor propagation. This study aims at developing an indoor propagation model from measurements taken using 802.11 compliant access point and client adapters.

2.1 Empirical Path loss Models

The empirical model used in this study is the Log-distance Path Loss Model. In both indoor and outdoor environments the average large-scale path loss for an arbitrary transmitter-receiver (T-R) separation is expressed as a function of distance by using a path loss exponent, *n* [4, 5, 6,7]. The average path loss *PL(d)* for a transmitter receiver separation, *d* is:

$$PL(d) \propto \left(\frac{d}{d_0}\right)^n \qquad (1)$$

$$PL(dB) = PL(d_0) + 10n\,log\left(\frac{d}{d_0}\right) \qquad (2)$$

In this model, PL represents the average path loss experienced between the receiver and sender in dB. $PL(d_0)$, represent the reference path loss in dB, when the receiver-to-transmitter distance is at reference distance (d_0) which is normally 1m for an indoor environment. *n* is the path loss exponent which indicates the rate at which path loss increases with distance *d*. *d* represents the distance between the transmitter and receiver in meters.

Path loss represents the level of signal attenuation present in the environment due to the effects of free space propagation, reflection, diffraction and scattering. The path loss is given by:

$$PL(dB) = 10\log\left(\frac{p_t}{p}\right) \qquad (3)$$

Table 1 below lists typical path loss exponents ranges obtained in various radio environments [6].

Table 1: Path loss exponent for different environment

Environment	Path loss exponent(*n*)
Free Space	2
Home	3
Office building (multiple floor)	2 to 6
Office building (same floor)	1.6 to 3.5
Factory	1.6 to 3.3
Store	1.8 to 2.2
Urban microcells	2.7 to 3.5
Urban macro cells	3.7 to 6.5

2.2 Log-normal Shadowing

Random shadowing effects occurring over a large number of measurement locations which have the same T-R separation, but different levels of clutter on the propagation path is referred to as Log-Normal Distribution. This phenomenon is referred to as log-normal shadowing [6]. Variations in environmental clutter at different locations having the same T-R separation are not accounted for in equation 2. This leads to measured signals which are vastly different than the average value predicted by equation 2. To account for the variations described above, equation 2 is modified as:

$$PL(dB) = PL(d_0) + 10n\,log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (4)$$

Where X_σ a zero-mean Gaussian is distributed random variable with standard deviation σ.

3. Measurement Environment

Experiments are conducted in the WLAN coverage area in ground floor of the administrative Block 2 of Nnamdi Azikiwe University, Awka, Nigeria. In this indoor environment, obstructions such as doors, table, chairs, walls, partitions, moving people and devices operating in 2.4GHz and so on are present. Six different angles from the access point (AP) were considered. These different propagation angles used will help in developing signal loss equations, by which a generalization for propagation prediction in this described indoor environment at 2.4 GHz above can be obtained. Different angles considered (31m each) in the coverage area, from 180^0 sector antenna access point (AP) are shown in the figure1 below.

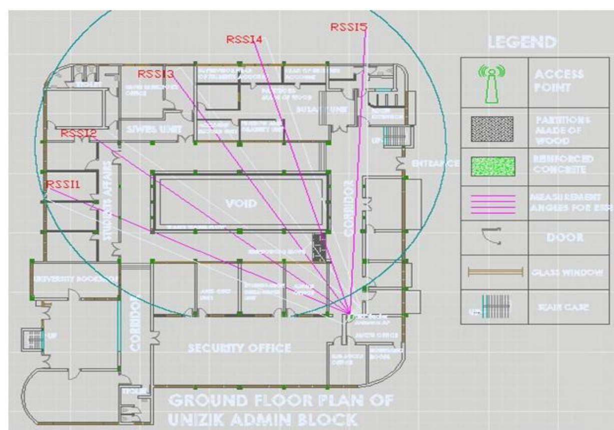

Figure 1: Different angles considered from the access point on the coverage area

3.1 Data Acquisition

A laptop attached with a wireless client adapter was used to measure the signal strength. The signal measurements were done using the software NetStumbler [6] which is a tool for Windows that allows one to measure the signal level of WLANs using 802.11a, 802.11b or 802.11g.

Firstly a site survey in the coverage environment was carried out, and a plan of the building drawn using AUTOCAD 2007. This plan was carefully divided into six sectors as shown in figure 1. In each sector, a line of 31m is drawn. Then on the site, these lines were marked out. Starting from a reference distance of 1m, received signal strength were measured at intervals of 3m along the six lines to ensure that most of the signal strength attenuating factors, affecting the entire coverage area was considered. See figure1 and figure 2.

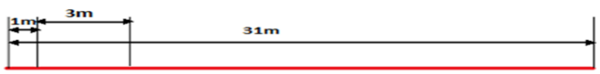

Figure 2: Description of the intervals of RSS measurements

Using NetStumbler version 0.4.0, measurements were taken for the above described propagation angle. In each angle the signal strength was measured from the EnGenius access points (AP) at regular increments of distance. At each interval signal measurements were taken by rotating the laptop twice along its axis

3.2 Measurement Result

Results of the field measurement for the six considered angles, showing the interval distance from the transmitter and its corresponding received signal strength are shown in the table 2 below.

Table 2: Received Signal Strength Levels

Distance (m)	RSS_1 (dBm)	RSS_2 (dBm)	RSS_3 (dBm)	RSS_4 (dBm)	RSS_5 (dBm)	RSS_6 (dBm)
d_0= 1	-20	-18	-21	-20	-22	-20
4	-26	-25	-25	-23	-27	-25
7	-37	-30	-35	-36	-37	-34
10	-41	-40	-41	-42	-44	-39
13	-46	-44	-47	-44	-48	-47
16	-53	-52	- 54	-50	-51	-52
19	-57	-56	-58	-54	-55	-54
22	-59	-58	-60	-57	-58	-57
25	-64	-63	-64	-61	-64	-63
28	-69	-67	-68	-66	-70	-67
31	-71	-69	-69	-68	-70	-69

Parameters of the EnGenius Access Point (AP):

- Transmitting Power (P_t) = 600mW
- Gain of the Antenna = 10dB

4. Data Analysis

In order to extract useful information from the raw measurement data (e.g. like a path loss model for the considered WLAN network), data processing is necessary. As the measurements vary at the same distance with different angles the mean received signal strength was used for the model development. The measured path loss (Pi) shows increasing trend with distance from the transmitter. The modeled path loss ($\hat{P}i$) for each distance considered was calculated using log-distance path loss model equation.

To truly characterize propagation pathloss for the environment, values should be established for these parameters: Pi , n ,X_σ . The path loss exponent n, which characterizes the propagation environment of the Administrative Block 2 in Nnamdi Azikiwe University, is obtained from the measured data by the method of linear regression (LR) analysis [8]. In the LR analysis the difference between the measured and predicted path loss values are minimized in a mean square sense. The sum of the squared errors is given by [8].

$$e(n) = \sum_{i=1}^{k} (pi - \hat{pl})^2 \qquad (5)$$

Where pi is the measured path loss and $\hat{pl}$ is the modelled path loss obtained using equation 2. The value of n which minimizes the mean square error $e(n)$ is obtained by equating the derivative of equation 5 to zero and solving for n.

The table 3 below summarizes the mean square error obtained.

Table 3: Evaluation of Mean Square Error

Distance(m)	$Pi\ (dB)$	$\hat{P}i\ (dB)$	$Pi - \hat{P}i\ (dB)$	$(Pi - \hat{P}i)^2$
$d_0 = 1$	47.78	47.78	0	0
4	52.78	$47.78 + 6.02n$	$5 - 6.02n$	$25 - 60n + 36n^2$
7	62.78	$47.78 + 8.45n$	$15 - 8.45n$	$225 - 253n + 71n^2$
10	68.78	$47.78 + 10n$	$21 - 10n$	$441 - 420n + 100n^2$
13	73.78	$47.78 + 11.14n$	$26 - 11.14n$	$676 - 579n + 124n^2$

16	79.78	$47.78 + 12.04n$	$32 - 12.04n$	$1024 - 771n + 145n^2$
19	83.78	$47.78 + 12.78n$	$36 - 12.78n$	$1296 - 920n + 163n^2$
22	85.78	$47.78 + 13.42n$	$38 - 13.42n$	$1444 - 1020n + 180n^2$
25	90.78	$47.78 + 13.98n$	$43 - 13.98n$	$1849 - 1202n + 195n^2$
28	95.78	$47.78 + 14.47n$	$48 - 14.47n$	$2304 - 1389n + 209n^2$
31	96.78	$47.78 + 14.91n$	$49 - 14.91n$	$2401 - 1491n + 222n^2$

Therefore the value of the mean square error from the table gives;

$$\sum_{i=1}^{k}(pi-\hat{p}l)^2 = 1447n^2 - 8106n + 11685 \qquad (6)$$

Differentiating equation 6 and equating to zero gives the value for *n*.

$$\frac{dj(n)}{dn} = \frac{d(1447n^2 - 8106n + 11685)}{dn} = 0 \qquad (7)$$

$n = 2.8$

The standard deviation σ(dB) of the random shadowing effects is computed using the relationship below [6];

$$\sigma(dB) = \sqrt{\sum_{i=1}^{k}(pi-\hat{p}l)^2 / k} \qquad (8)$$

But n=2.8, and $k = 11$, therefore substituting in the above equation gives;

$\sigma(dB) = 5.5\ dB$

Substituting the above calculated path loss exponent n and the standard deviation σ into the log-normal shadowing model in equation 4 above gives the model for the above described indoor WLAN network as shown below.

$PL(dB) = 47.78 + 10(2.8)\ log(d) + 5.5$

$PL(dB) = 53.28 + 28\ log(d) \qquad (9)$

The equation $PL(dB) = 53.28 + 28\ log(d)$, hence gives the path loss mathematical model for any random distance *d* from the transmitter, for the above described indoor WLAN network.

This model obtained is then simulated on MATLAB [9], to show the output below;

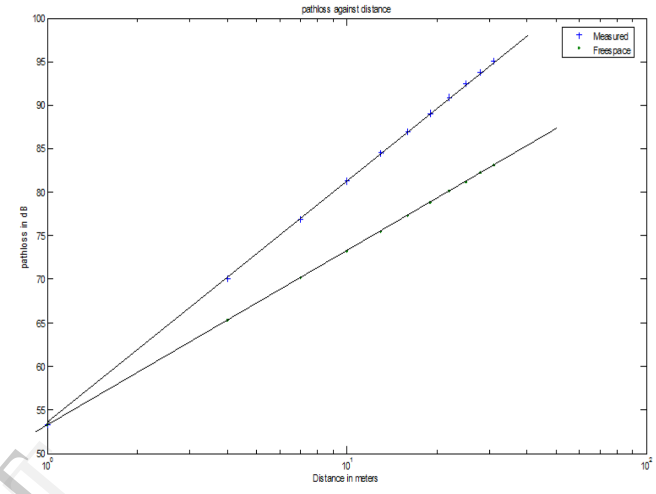

Figure 3: Output Graph of path loss versus distance

5.0 Conclusion

The objectives of this project have been achieved. The indoor radio propagation channel despite its many obstructions (such as walls, doors, tables, chairs, partitions, moving people, devices operating in the same frequency etc) has been characterized. In this research work, the indoor path loss prediction parameters obtained using the log-normal shadowing model reveals that the path loss exponent value and the standard deviation caused by the shadowing effect are 2.8 and 5.5dB respectively. This path loss exponent is therefore considered to be accurate since it falls within the range of values as shown in table 2. Also a graphical output of the simulated model in MATLAB is shown in the figure above to further analyze the model. For example, one can easily find the expected path loss for a random distance from the AP from the graph.

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