View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by El Servicio de Difusión de la Creación Intelectual



# Relative Signal Strength Coverage Optimization in Indoor and Outdoor Wireless LAN Environments

**Moses E. Ekpenyong, UduakObong M. Umoren**
Department of Computer Science
University of Uyo, PMB. 1017, 520003, Uyo, NIGERIA
and
**Udoma J. Bassey**
Department of Mathematics and Statistics
University of Uyo, PMB. 1017, 520003, Uyo, NIGERIA

## ABSTRACT

Fading and obstacles constitute major threats to effective quality of service (QoS) delivery in wireless local area network (WLAN) environments. In this contribution, we investigate the signal quality of indoor and outdoor WLANs over a defined coverage area. We present experimental analysis of case studies that will be useful for further research and validate the system's performance in practice. Using an optimized form of the pathloss models, a simulation of the system is carried out over short and extended coverage. Simulation results show that signal quality could be effectively managed to improve the system's performance for both indoor and outdoor environments in the presence of fading and other environmental factors.

**Keywords:** received signal power, multipath fading, pathloss, link quality, network coverage.

## 1. INTRODUCTION

One major challenge encountered in the field of wireless communications is the ability to deal with the phenomenon called fading. A useful approach to tackling this problem is to implement prediction models, taking into account the transmitter, receiver, distance and signal propagation parameters of the study environment. Understanding the propagation characteristics of WLANs is essential for effective network deployment, as this offers network operators a clue of the coverage capacity of the access points based on their locations and possibly eliminating the need for site surveys. As such, the strength, range and coverage area of an access point are mostly affected by its positioning in reference to the environment [1]. Obstacles do also impede signal propagation in WLAN environments. Their presence could reflect, refract, diffract, scatter or absorb signals [2-3]. The rate of signal defect in this case will largely depend on the type and construction of the obstacle(s).

In a wireless LAN, apart from the frequency spectrum, the received signal strength (RSS) determines the link or connection quality of the network system. In today's technology, the signal strength of a WLAN can be boosted using signal amplifiers, thus extending the reach of the signal. Apart from amplifiers, antennas and access points also contribute to effective signal propagation. However, the strength of a signal is hindered by the distance between the transmitting and receiving devices. Therefore, the signal reach of a wireless LAN largely depends on its architectural design. One key to solving the problem of weak reception is to enhance the signal strength and reduce the noise level. However, hardware devices such as cordless phones and microwaves are common culprits of increased noise levels. Wireless access points have built-in WiFi antenna that emits signal uniformly in all directions over a distance range of 250-300 feet (76-91 meters). Antennas that exhibit such behaviour are called omni-directional antennas. An omni-directional antenna produces constant field strength in azimuth (horizontal), but can have a directional radiation pattern in elevation (vertical). It differs from the isotropic antenna, which produces constant field strength in both azimuth and elevation. The signal transmitted by omni-directional antennas can be weakened over long distances due to interference and because the antenna's signaling power radiates in all directions. A condition referred to as attenuation describes the loss in signal strength as signal travel farther from this device. A ground plane (an electrically conducting surface that serves as the near-field reflection point for the antenna) could be constructed to help boost the signal. Materials used for constructing ground planes are large metal sheet, wires or rods. The conductors should be designed to radiate from the base of the antenna.

Fixing dead spots in a building can be achieved by installing an AP with two extended antennas. A repeater could also be used to extend the signal coverage. Repeaters are used to rebroadcast signals from the current wireless APs to clients. But these devices halves the maximum bandwidth because both receive and transmit frames are processed using the same radio frequency (RF) channel, which effectively doubles the number of transmitted frames.

The deployment of Voice over Internet Protocol (VoIP) and TCP/IP-based applications on WLAN constitutes a major deployment difficulty due to the quality of service demands by the network [4] for several reasons:

(i) The variability of WLAN QoS parameters (bandwidth, packet loss, delay and jitter) is high in realistic systems. This condition leads to instability within the network and significantly reduces the application performance.
(ii) Contention is likely to occur when two or more services share same communication channel.
(iii) Multimedia applications such as VoIP or video streaming require timely servicing of the traffic. This is a challenging task in WLANs, even when QoS enforcement is implemented, as most existing QoS mechanisms concentrate on bandwidth provisioning.
(iv) Roaming between access points, a typical WLAN event, introduces communication gaps that may cause service interruptions, an undesirable state for real-time applications.

Consequently, a detailed analysis is required to investigate WLAN applications deployment, especially when considering their use in environments with specific requirements such as safety/mission-critical systems or disaster management.

This paper therefore adopts an experimental approach to optimizing the signal quality of indoor and outdoor WLANs, subject to network coverage constraints between the transmitting and receiving devices. A starting point for this paper is to conduct a study of existing WLAN environments (with network applications) to understand the basic properties of the system and their interaction within the network. To achieve a high degree of realism, we shall combine the observations in real life with the analytical model and arrive at an optimized model adapted to the study environment and suitable for easy prediction of the system. The field measurements are obtained from existing indoor and outdoor WLANs within Uyo (urban) Metropolis in Akwa Ibom State, Nigeria. The essence of data collection is to enable us predict the system with some degree of confidence.

## 2. RELATED RESEARCH

Due to growing interest in mobile data applications, In recent years, WLANs have been successfully deployed worldwide and will probably be used to interconnect cellular systems for the provision of high speed data services in the next generation (fourth generation) wireless networks, where handovers between WLAN cells and cellular cells are possible [5]. Several researches have been carried out in the area of wireless LAN. In [6], the signal strength of 802.11n WLAN equipment is studied. They foresee an upgrade in the performance of the equipment, as well as predict the network coverage as an extension to the new standard using a mathematical model. In [7], experimental data that validates the use of the log distance path-loss model for dealing with signal attenuation is presented. Measurements were performed using off-the-shelf IEEE 802.11b hardware at distance varying from 1 to 50 meters. Also, the model was used to predict the signal strength within and around a standard office environment.

In [8], studies of the WLAN and Bluetooth piconet range interference are presented. The authors propose an interference range model that allows a user to determine an acceptable range of interference in a given environment. In [9], the RSS is used to estimate the position of a mobile node inside a building (indoor). In [5], measurements of the RSS of WLAN beacons in an indoor environment are presented and from theoretical analysis, Gamma random variables are used to model the RSS variation from the average power. His results show that the theoretical model correlates well with measured data.

In [10], a study of Georgia Institute of Technology has been carried out using direct-ray, solo path-loss exponent, adapted to the Seidel-Rappaport propagation model with 2.4GHz, 801.11g outdoor WiFi network deployment. The standard deviation of the prediction error for their proposed model is approximately 5.5dB on the average, which agree with other path-loss models in the outdoor domain [11]. Liechty [12] outlines the achieved prediction accuracy of the propagation model used in [10], by measuring and analysing an established 2.4 GHz, 802.11g outdoor WiFi network deployed on the campus (i.e. the Georgia Institute of Technology). The proposed model performs with accuracy compared to other models and offers a simple design with a strong predictive model for network planning and deployment.

One major aspect of assessment that research literature has ignored, is accounting for low and peak network loads and a relative analysis and modeling of both indoor and outdoor environments. We therefore study these WLAN environments with the goal of optimizing the received signal quality from same distances away from the access points of these networks and then derive optimized performance models for effectively assessing the network's QoS.

## 3. EXPERIMENTAL SETUP AND ANALYSIS OF EXISTING INDOOR AND OUTDOOR WLAN

### Experimental Setup

The experiments described in this paper were conducted in typical office environments. The setup in Figure 1 shows the location of existing masts and bridges in the University of Uyo. But the WLAN building (environment) we are dealing with is indicated using an arrow.

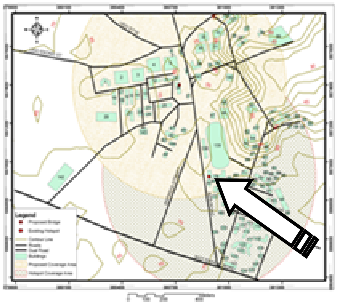

Figure 1. Experimental setup for the indoor wireless LAN

Figure 2 shows the experimental setup for the outdoor WLAN. The WLAN building is also indicated with an arrow.

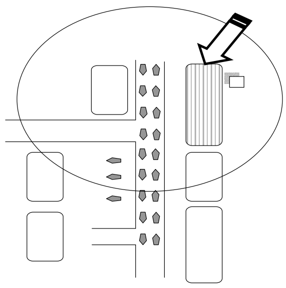

Figure 2. Experimental setup for the outdoor wireless LAN

The required data were captured using a Dell wireless LAN card utility analyzer/monitor (software). This card is controlled with special DELL driver installed on a client laptop which permits the collection of RF monitoring mode measurements. In this mode, the card is prohibited from associating itself with any access point (AP), but instead scans available Wireless Fidelity (WiFi) channels and display measurements of the RSS of the WiFi selected, indicating the RSS for each AP it samples. With this method, it is possible to measure all APs whose RSS is within the dynamic range of the card at any given point. The indoor environment operated at a frequency of 2.4GHz and its signal was transmitted via a Linksys Wireless-G access point (WRT54G) with 802.11g wireless network standard and compatible with 802.11b standard with maximum data transfer rate of 54Mbps. The outdoor signal transmitted using three sector beam forming antennas at 90$^{o}$, each facing different directions with connected amplifiers. Its transmitting frequency also operated at 2.4GHz. Both transmitting routers were set to infrastructure mode. The data were obtained over a distance of 10m and 100 m in steps of 1m and 10m respectively, from the access points in both environments. The reason for choosing same measurement lengths is that both case studies had same operating capacity and the necessity of obtaining balanced readings from both environments. The data measurements were done at the opposite side of the building where there was free-space for measurements. During data collection, we classified the measurements into link status (signal and noise) and data packets transfer (data sent and received). Daily measurements of these parameters were taken for a period of two weeks at three different intervals (morning, afternoon and evening) - to accommodate low and high traffic.

**Analysis of experimental data**

In Figure 1, we observed a sharp reduction in signal quality between 10m and 40m from the access point of the Student care café (WLAN indoor) environment. After the 40m mark, the signal stabilized till the 100m mark. This sudden drop in signal quality could be attributed to the huge activity and frequent mobile obstacles (movement of persons) within the environment, as the location of the WLAN is at the entrance of the University of Uyo and close to the hostels. Also at Webcenta (outdoor WLAN) environment, the network experienced signal degradation between 30m-40m distance, as observed in Figure 2. This could be due to the non-line of sight noticed during field measurements or readings, as the mast of the WLAN was obstructed by the office building, thus obscuring signal transmission. Average readings were compiled for both environments. These readings will be used as predictors in the optimized pathloss model and will enable us predict the performance of both systems.

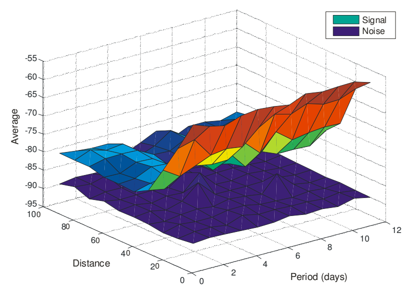


Figure 1. Analysis of observed signal and noise data for Student-care café (indoor) WLAN environment at various distances for the study period

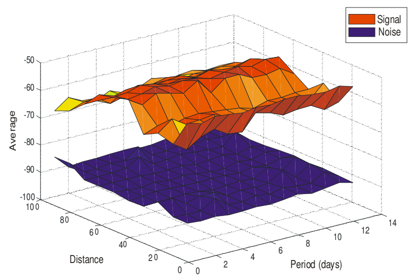


Figure 2. Analysis of observed signal and noise data for Webcenta (outdoor) WLAN environment at various distances for the study period

**Experimental Pathloss Models**

Pathloss models are used to predict the coverage area and signal propagation of the environment. Presented in Figure 3 is a graph comparing the computed mean pathloss of the indoor and outdoor WLAN environments. Traditionally, pathloss is computed using the relation:

$$P_L = P_t - S_p \quad (1)$$

where

$P_L$ is the pathloss

$P_t$ is the transmitter power

$S_p$ is the signal power

Extracting the average pathloss for both indoor and outdoor environments using equation (1), and plotting these losses against distance, yields Figure 3. Transmitter powers obtained from the field - 15dB for indoor WLAN and 28dB for outdoor WLAN, were used to compute the respective pathlosses. We observed that both indoor and outdoor wireless LANs intersected (experienced same pathloss) at (30m, 88.64dB), but on the average, the degree of pathloss was higher in the indoor WLAN. Generally, the pathloss tend to follow same pattern in both environments. For the purpose of further research, the computed pathlosses for both environments are presented in the Appendix.

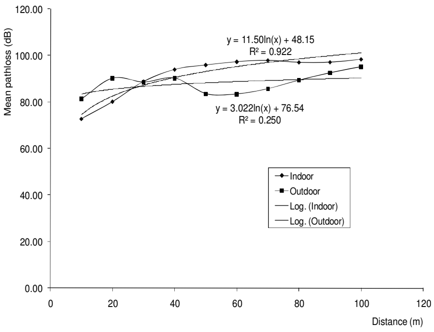


Figure 3. Comparative analysis of mean pathloss vs. distance for indoor and outdoor WLANs

From the trend line equation, we construct a simple predictive pathloss model with log distance component as:

$$PL = \alpha + 10n\log(d) \quad (2)$$

where

$\alpha$ represents environmental constant

$n$ is the propagation or pathloss exponent

$d$ represents the distance

Note that $10n$ is the slope of the fitted curve. Therefore the pathloss exponents for the indoor and outdoor WLANs are 1.15 and 0.30 respectively. Studying the variability in both environments, we observed that both WLANs initially showed high variability. This could be attributed to signal attenuation and nature of obstacles surrounding the environments.

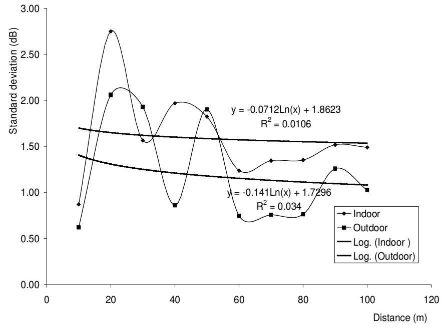


Figure 4. Comparative analysis of standard deviation vs. distance for indoor and outdoor WLANs

The average standard deviation was obtained as 1.59 for indoor environment and 1.19 in outdoor environment, which confirmed the efficiency of the outdoor WLAN over indoor WLAN.

## 4. OPTIMIZATION MODEL

**Notation**

The following notations are used to describe the optimization model:

| | |
|---|---|
| $a_j,\ j = 1,\cdots,N$ : | Access Point (AP) |
| $r_i,\ i = 1,\cdots,M$ : | User/receiver |
| $pl(a_j, r_i)$: | Pathloss from user $r_i$ to AP $a_j$ |
| $pl_{\max}$ : | maximum tolerable pathloss |

We assume here that $a_j$ has unknown coordinates, while the coordinates of users $r_i$ are assumed to be known and users are distributed in design area according to the design specification.

**Model Description**

In this paper, the objective function is based on pathlosses. The pathloss for each receiver should satisfy the following condition:

$$\min_{j=1,\dots,N} pl(a_j, r_i) \le pl_{\max} \quad \forall i \in 1,\cdots,M \quad (3)$$

So, we state our first constraint from equation (1), that pathloss is evaluated against the maximum tolerable pathloss $pl_{\max}$. This ensures that at each receiver's location, the signal quality does not fall below a certain threshold. The threshold value, $pl_{\max}$ can be computed by subtracting the receiver's threshold ($R_{th}$) from the transmitter power $P_t$, thus:

$$pl_{max} = P_t - R_{th} \quad (4)$$

Equation (4) can be expressed as an equality form, thus:

$$\left(\min_{j=1,\dots,N} pl(a_j, r_i) - pl_{\max}\right)^{+} = 0 \quad (5)$$

where $(\gamma)^+ = \max(\gamma, 0)$

Therefore, a feasible solution is possible *iff*:

$$\sum_{i=1}^{M} \left( \min_{j=1,\dots,N} pl(a_j, r_i) - pl_{\max} \right)^+ = 0 \quad (6)$$

**Pathloss Model**

Following from Equation (2), the pathloss function at a distance $d(a_j, r_i)$, above the reference distance $(d_0)$ is given by:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 10\log\left(\frac{d(a_j, r_i)}{d_0}\right) \quad (7)$$

Thus, $pl(d_0)$ is equal to the free space pathloss with respect to $d_0$ [12, 13-15], $d_0$ is typically 1m, 100m or 1km, depending on the environment [16]. The RF path between the transmitter and the receiver is influenced by the separating distance and the nature of obstacles (doors, walls, furniture, people, etc) scattered around the environment. Including the loss caused by these obstacles, we rewrite equation (7) as:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 10\log\left(\frac{d(a_j, r_i)}{d_0}\right) + \sum_{i=1}^{n} obs_i\, l_i \quad (8)$$

where $obs$ represents the obstacle and $l$ represents loss in $dB$, created by the obstacle. Observe that equation (8) is discontinuous because of the presence of obstacles.

**Log Normal Shadowing**

Equation (8) does not consider the difference in received signal power for same transmitting distances. This difference is caused by different environmental disorders which may differ at two different locations having same distance from the transmitter. Equation (8) provides the expected mean signal strength when the separated distance is $d$. The actual received signal strength may surround this mean value. Practical measurements show that the distance $d$ at any given location is random and log-normally distributed about the mean distance value. Considering this, equation (8) becomes:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 10\log\left(\frac{d(a_j, r_i)}{d_0}\right) + \sum_{i=1}^{n} obs_i\, l_i + X_\sigma \quad (9)$$

where $X_\sigma$ is a zero mean Gaussian distributed random variable measured in $dB$ with standard deviation $\sigma$, also measured in $dB$ (i.e. $X_\sigma \sim N(0,1)$ or $M_{X_\sigma}^{(t)} = e^{x^2/2}$). This variation or loss in signal strength caused by blockage or absorption in environments from points of equal distance to the transmitter is referred to as shadow fading. The Gaussian random variable is added to the pathloss to compensate for unpredictable shadowing. Equation (9) is suitable for modeling pathlosses under diverse environmental conditions. Next, we adapt equation (9) to our case study environments. First, we account for the pathloss exponents in both environments, by introducing the parameter $n$, representing the pathloss or propagation exponent. Substituting this into equation (9) yields:

$$pl(a_j, r_i)[dB] = pl(d_0)[dB] + 10n\log\left(\frac{d(a_j, r_i)}{d_0}\right) + \sum_{i=1}^{n} obs_i\, l_i + X_\sigma \quad (10)$$

We will simulate equation (10) using observed data means as predictors to the optimized model, for short and extended distances.

## 5. MODEL SIMULATION AND DISCUSSION OF RESULTS

**Experimental Data Analysis**

In this section, we analyze the experimental data under the following QoS parameters:

(i) Signal and noise levels: In both case studies (indoor and outdoor environments), the commercial nature of the environments caused instability in noise levels. This is seen in Figures 1 and 2 respectively. In Figure 1, significant spikes were noticed in the indoor WLAN environment on days 5, 6 and 9 at the 40th, 50th and 60th meter distances, respectively. In the outdoor environment, there was disruption at the 30m mark. These defects could be attributed to disturbances by the wind and the presence of obstacles. Generally, the signal strength deteriorated as the receiver went farther from the transmitter.

(ii) Signal-to-Noise Ratio (SNR): The 802.11b/g WLAN performance is observed to deteriorate with increasing distance and obstacles. In Figure 5, the noise level increased in the indoor environment as the receiver went farther from the transmitter. This occurred between 10m-40m, after which the SNR stabilized. The outdoor WLAN experienced more SNR distortions compared to the indoor WLAN, because of the increased network capacity (number of users the network can support).

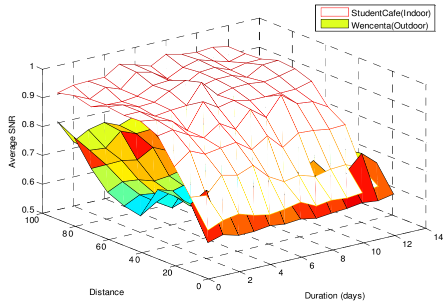


Figure 5. Comparative analysis of average SNR in indoor and outdoor WLANs

(iii) Average data sent: Apart from the 6th and 7th day when the average data sent drastically dropped due to system downtime, the readings tend to differ slightly from each other in the indoor environment. In Figure 6, the average data sent is generally higher over all distances in the indoor environment than in the outdoor environment.

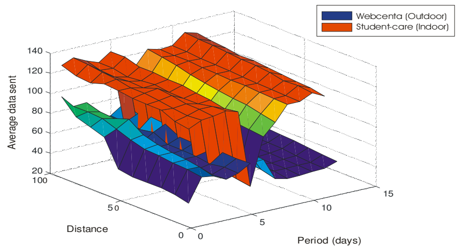


Figure 6. Comparative analysis of the average data sent in both indoor and outdoor WLANs

(iv) Average data received: In Figure 7, a drop in received data rate was noticed on the 6th day in the outdoor WLAN. But in general, data received tend to stabilize over the study period in both environments.

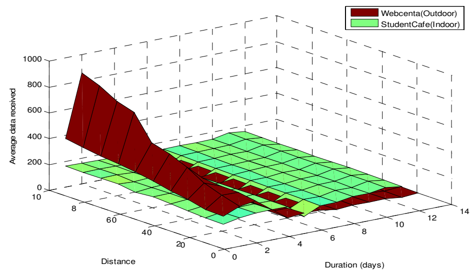


Figure 7. Comparative analysis of the average data received in both indoor and outdoor environments

**Model Simulation**

The optimized pathloss model is expected to reveal the true behaviour of the real system. In order validate the model, data already acquired from the existing (real) system were used as input to a program simulating the model, and coded in MATLAB. These data are shown in Table 1.

Table 1. Simulation parameters/input data

| Parameter | Value |
|---|---|
| Indoor environmental constant | 48.15dB |
| Outdoor environmental constant | 76.54dB |
| Pathloss exponent for indoor Environment ($n$) | 1.15 |
| Pathloss exponent for outdoor Environment ($n$) | 0.30 |
| Distance ($d$) | 1m-10m, 10m-100m |
| Standard deviation ( $\sigma$ ) | 1.59 for indoor, 1.19 for outdoor |
| Zero mean Gaussian random numbers ( $X_\sigma$ ) | N(0,1.59) for indoor, N(0,1.19) for outdoor |

The model was then simulated over short (1m-10m) and long (10m-100m) distances to ease the study of the overall effect of pathloss on both systems.

## 6. DISCUSSION OF RESULTS

In indoor environments, it has been observed that the signal strength is impaired by complex propagation defects such as reflections, refractions and multi-path effects [17]. This accounts for the wide variation in signal strength across the environment, and is akin to our observation in Figure 9. In Figure 8, we observed that for short distance range (1m-10m), indoor WLAN experienced lesser pathloss compared to outdoor WLAN. We can attribute this trend to the fact that the sensitivity of indoor equipment tends to be stronger around the vicinity where the radio is installed to complement for certain propagation defects. Similar plots, but with extended coverage range (10m-100m) is shown in Figure 9. Here, the performance of indoor WLAN deteriorates faster as the distance increases, compared to outdoor WLAN. This calls for a check of the sensitivity level of transmitting devices, as well as proper network planning techniques to improve the expected quality of service. Comparing Figure 9 to Figure 3, we notice that the simulated/predicted performance (Figure 9) for indoor environment is higher than the empirical plot (Figure 3). The wide deviation reveals the absence of fading prediction in the existing system or the inability of the indoor device to transmit beyond a certain distance. As expected, both plots follow same trend, as the outdoor WLAN outperformed indoor WLAN.

Important implications can be drawn from the simulation. It is observed that the optimized model resulted in less variance associated with the position and range plot, and thus yielding better localization. The optimized pathloss models can also reduce the cost of active site surveys. This is achieved in this paper by using parameters relating to the study environment. With the simulated models, more production runs could be made to predict the signal attenuation between the transmitter and receiver at different signal propagation (distance) range, with the inclusion of parameters that concerns the terrain profile, and its surface features. We have observed that using field measurements of the study environment as model predictors is advantageous because it accounts for the environmental factors, regardless of separate parameter recognition [18].

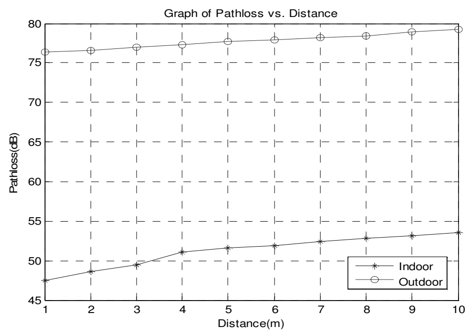


Figure 8. A graph of Pathloss vs. distance, for indoor and outdoor WLANs

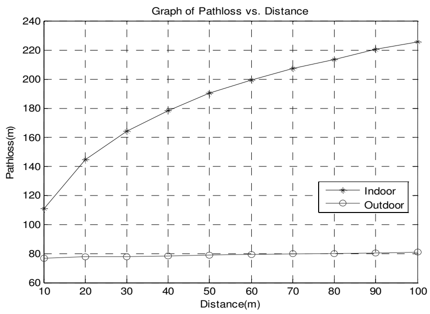


Figure 9. A graph of pathloss vs. distance, for indoor and outdoor WLANs

From the results we discovered that most WLAN operators are most likely to mis-predict the network performance, thus giving room to wrong problem detection.

## 7. CONCLUSION AND FUTURE WORKS

We have modeled the signal strength of indoor and outdoor WLAN environments, by studying the propagation characteristics of both environments, considering fading effects as well as obstacles. In tackling these issues, we took measurements of QoS parameters over a defined distance and compute the pathloss for both environments. An optimized model that predicts the signal quality of WLANs over various distances was then derived from the experiment. Experimental data obtained from the field were used to validate the models. In both environments, we could predict the distance at which wireless signal quality received was optimal. We observed that the link quality (SNR) degrades with distance and other environmental factors. The fading phenomenon was also approached with the aim of proffering a practical solution. This approach was accomplished by monitoring the signal quality coverage (at various distances). As an outlook, we shall investigate indoor localization and the problem of interference.

## 7. REFERENCES

[1] M, Iskander and Z. Yun, "Propagation Prediction Models for Wireless Communication Systems", IEEE Transactions on Microwave Theory and Techniques, Vol. 50, No. 3, 2002, pp. 662-673.

[2] D. Hucaby, CCNP BCMSN Official Exam Certification Guide. Fourth Edition, CISCO Press, 2007.

[3] G. Durgin, T. Rappaport and H. Xu, "Measurements and Models for Radio Pathloss and Penetration Loss in and Around Homes and Trees at 5.85 GHZ", IEEE Transactions on Communications, Vol. 46, No. 11, 1998, pp. 1484-1496.

[4] R. Beuran, L.T. Nguyen, K. T. Latt, J. Nakata, and Y. Shinoda, QOMET: A Versatile WLAN Emulator, In Proceedings of The 21st IEEE International Conference on Advanced Information Networking and Applications (AINA 2007), Niagara Falls, Ontario, Canada, pp. 348-353, 2007.

[5] W. Zhang, Modeling of WLAN Beacon Signal Strength Measured in an Indoor Environment. In Proceedings of the International Conference on Wireless Networks, ICWN'03, Las Vegas, Navada, USA, pp. 70-75, 2003.

[6] J.N. Davies, V. Grout and R. Picking, Prediction of Wireless Network Signal Strength Within a Building. In Proceedings of the 7th International Network Conference, University of Plymouth, pp. 193-207, 2008.

[7] D.B. Faria, D. B., Modeling Signal Attenuation in IEEE 802.11 Wireless LANs – Vol. 1. Technical Report TR-KP06-0118, Kiwi Project, Stanford University, 2005.

[8] P. O. Bobbie, and A.L. Yussif, Modeling and Simulation of IEEE 802.11 Wireless-LAN and Bluetooth Piconet Range Interference. In Proceedings of IASTED CIII Conferences, St. Thomas, Virgin Islands, pp. 44-49, 2004.

[9] K. Sayrafian-Pour and D. Kaspar, A Novel Model-based Indoor Positioning Using Signal Strength. In Proceedings of 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07), Athens, pp. 1-5, 2007.

[10] P. Petrus, J.H. Reed, and J.S. Rapport, Geometrically Based Statistical Channel Model for Macrocellular Mobile Environments. In Proceedings of IEEE Global Telecommunication Conference, pp. 1197-1291, 1996.

[11] S.Y. Elchakwi, Propagation Prediction and Measurement on Outdoor Wireless LAN 2.4GHz Applications at Universiti Teknologi, Malaysia, M.Sc. Thesis. Universiti Teknologi, Malaysia, 2006.

[12] L.C. Liechty, Path Loss Measurements and Model Analysis of a 2.4 GHz Wireless Network in an Outdoor Environment. M.Sc. Thesis, Georgia Institute of Technology, 2007.

[13] K. Pahlavan and K. Prashant, Principles of Wireless Networks: A Unified Approach. Prentice Hall, New Jersey, USA, 2002.

[14] M. Panjwani., A.L. Abbott and T.S. Rappaport, "Interactive Computation of Coverage Regions for Wireless Communication in Multifloored Indoor Environments", IEEE Journal on Selected Areas in Communications, Vol. 14, 1996, pp. 420-430.

[15] R. Morrow, Wireless Network Coexistence. McGraw Hill, USA, 2004.

[16] J. B. Anderson, T.S. Rappaport and S. Toshida, Propagation Measurements and Models for Wireless Communication Channels. IEEE Communications Magazine, pp. 42-49, 1995.

[17] M. Hassan-Ali and K. Pahlavan, "A New Statistical Model for Site-specific Indoor Radio Propagation Prediction Based on Geometric Optics and Geometric Probability", IEEE Transactions on Wireless Communication, Vol. 1, No. 1, 2002, pp. 112–124.

[18] V. Gupta, S.C. Sharma and M.C. Bansal, "Fringe Area Path Loss Correction Factor For Wireless Communication", International Journal on Recent Trends in Engineering, Vol. 1, No. 2, pp. 30-32.

Received: July 2012. Accepted: December 2012.