Model of Indoor Signal Propagation using Log-Normal Shadowing

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***Abstract*— Indoor signal propagation characteristics can be difficult to predict accurately. Factors such as building layout and building materials can have a major effect on signal propagation. In this paper we will model indoor signal propagation using log-normal shadowing characteristics. The benefit of this model over others is its simplicity. The accuracy of this model at predicting the relationship between received signal strength (RSS) and the distance from transmitter to receiver will be determined. The link that was tested and modeled uses the IEEE 802.11n standard. Both 2.4 GHz and 5 GHz Industrial Scientific and Medical (ISM) bands were tested and modeled.**

I. Introduction

A Wireless Local Area Network (WLAN) is a flexible data communications system implemented either as an extension or as an alternative for a wired LAN. WLANs transmit and receive data over the air using radio frequency (RF) technology without the need to physically connect cables. Therefore, they provide the advantage of mobility, ease of access, and the ability to share and manage network resources. The predominant WLAN technology used today is the IEEE 802.11 standard. Several variations of the IEEE 802.11 include, 802.11a, 802.11b, 802.11g, 802.11n, and 802.11ac [1]. The 802.11n standard uses 2.4 GHz and 5 GHz ISM bands. These frequency bands have different propagation characteristics, therefore they must be modeled separately.

Wireless communication channels used in different standards are usually described by considering three major aspects, namely, path loss, shadowing, and multipath fading [2]. Path loss is the attenuation suffered by a signal traveling along a given trajectory between the transmitter and the receiver. The attenuation may be a dispersion of the signal into different paths in order to reach the receiver (multipath or fast fading); which causes the signal to arrive at different times. The obstacles between transmitter and receiver increase these signal fluctuations (shadowing or slow fading). Large scale fading denotes the gradual loss of received signal power over long distances; also called slow fading or shadowing, it is characterized because its amplitude has log-normal probability density function [3].

These aspects need to be calculated in order to design or optimize a new or existing wireless network that effectively delivers the coverage, data rates, and Quality of Service (QoS) requirements of a specific area. Engineers use wireless site surveys for this purpose. Wireless site surveys also allow for the determination of optimal locations on access points in the network.

In this project the characteristics of slow fading were measured and demonstrated, with and without shadowing effects by assuming log-normal distribution. The standard deviation, variance and path loss exponent were calculated. To do this, a router was placed as a fixed antenna and measured the RSS at 2.4 GHz and 5 GHz bands over different distances from the antenna at different locations. The locations chosen were three classrooms and three hallways on the second floor, and another hallway on the first floor.

II. System Modeling

As mentioned in section I, large scale or slow fading represents an average of the attenuation of the signal power over large areas. In practice, either the sender or the receiver is in motion which causes the fading to last several seconds or minutes and be relatively constant during that period of time. Since slow fading predicts the average behavior of the received power for distances greater than the signal's wavelength (λ), it is useful for modeling the scope and planning of the system.

The path loss exponent, n, measures the rate at which the RSS decreases with distance, and its value depends on the specific propagation environment. Figure 1 shows the path loss exponent, n, for different environments [4].

Environment	Path Loss Exponent (n)
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
Inside a building – Line of Sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in Factory	2 to 3

Fig. 1: Path loss exponent n for different environments

The change in amplitude caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the path loss distance model. Log-normal means that the local-mean power expressed in logarithmic values, such as dB, has a normal (i.e., Gaussian) distribution [5]. According to a zero-mean, μ, Gaussian random variable, the measured loss in dB varies about this mean, Xσ, with standard deviation σ. This was the model followed during this project.

III. Data Collection

In order to demonstrate slow fading, which depends on the path loss exponent n, over one hundred measurements were taken. In this section, the materials used and setup are described.

A. Hardware used

The hardware used in this project include: two laptops running Windows 7; one BOSCH GLM 15 range meter; one NETGEAR WNDR3800 wireless router; and one Tektronix RSA306 real time spectrum analyzer.

B. Software used

Software required were: Xirrus Wi-Fi Inspector; Microsoft Excel 2010; Visual Studio C++; Tektronix SinalVu-PC; MATLAB R2013A and dd-wrt.

C. Detailed setup

For the radio frequency (RF) transmission source we used a NETGEAR WNDR3800 wireless router as an access point (AP) as showed in Figure 2. This model was chosen because it can transmit at 2.4 GHz and 5 GHz simultaneously, it also supports dd-wrt. dd-wrt is a UNIX based operating system for routers. It includes several monitoring and control features not found on the factory operating system. The AP was positioned at the center of the Electrical Engineering Technology wing on the second floor of Lupton Hall. All distance measurements were taken with the BOSCH range meter.

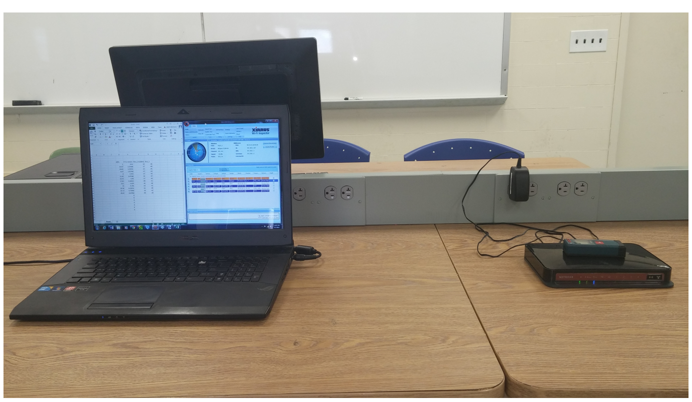

Fig. 2: Setup. Laptop, BOSCH GLM 15 range meter and NETGEAR WNDR3800 wireless router

D. Procedures

The first measurement was taken a 0.5 meters from the AP. This location was set to be $d0$ and is also where the far region started. The formula for calculating where the far field region begins has several variations [6], some of the variations include 2λ, 3λ, $\frac{5\lambda}{2\pi}$, and $\frac{\lambda}{2\pi}$. 0.5 meters was chosen for $d0$ because it is 4 times the wavelength, λ, of 2.4 GHz and the Received Signal Strength (RSS) was stable at this distance. C++ and Windows Application Program Interface (API's) were used to measure RSS from the Network Interface Card (NIC). Xirrus Wi-Fi Inspector was used to verify the data from the C++ program. Tektronix SinalVu spectrum analyzer verified the accuracy of the values from the NIC.

Line of sight (LOS) measurements of RSS were taken at 2 meter intervals up to 24 meters. Non-LOS measurements were taken at various intervals, with focus on even coverage of the entire site survey area. All data was recorded in an Excel spreadsheet.

Measurements inside the Electrical Engineering Department and three classrooms (247, 248 and 249) of the department were also acquired, plus the wings of the Architectural Department on the second floor and the Automotive Department on the first floor.

Finally, after all the samples were taken, the next step was to analyze the data using a MATLAB script in order to calculate the path loss exponent n, and show the average received power $\hat{pr}$ over distance d.

IV. Data Analysis and Results

In order to determine the path loss exponent n and standard deviation σ the following equations are used. The calculated received power at each distance d is determined using the following formula, its value contains the unknown variable n:

$$\hat{pr}(d) = pr(d0) - 10nlog(\frac{d}{d0}) \quad (1)$$

where d is the distance between Tx and Rx antennas, $d0$ is a distance close to the Tx antenna but outside the near field, and $pr(d0)$ is the received signal at $d0$.

$$\text{J} = \sum([pr(d) - \hat{pr}(d)])^2 \quad (2)$$

where j is the sum of the square errors between the measured signal pr and calculated signal $\hat{pr}$.

$$MMSE = dj = 0 \quad (3)$$

MMSE (minimum mean square error) can be found by setting the derivative of j equal to zero.

The path loss exponent n is the value which minimizes the mean square error.

$$\sigma^2 = \frac{MMSE}{numberofsamples} \quad (4)$$

where σ is the standard deviation from the mean.

$$\sigma = \sqrt{\frac{MMSE}{numberofsamples}} \tag{5}$$

To model the effects of shadowing the following formula was used:

$$pr(d) = pr(d0) - 10nlog(\frac{d}{d0}) + X_\sigma \tag{6}$$

where X_σ is a random number with a zero mean and standard deviation of σ.

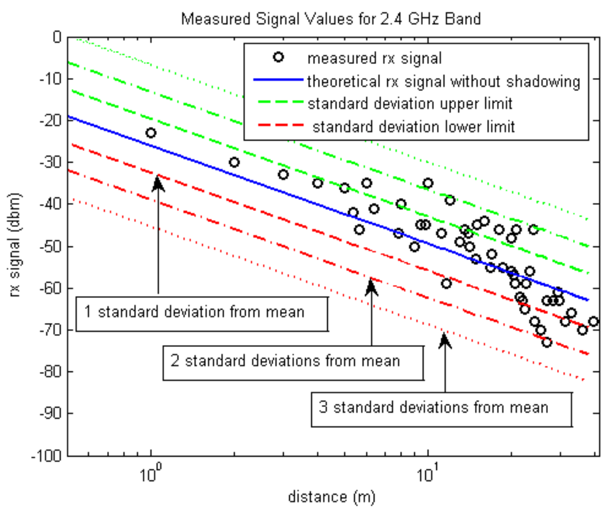

Fig. 3: Measured values for 2.4 GHz band

Figure 3 shows the measured received signal values. The x-axis represents distance in meters in a logarithmic scale from 0.5 to 30 meters. The y-axis represents received signal strength in decibel-milliwatts (dBm), it is in a linear scale from -100 to 0 dBm. The values of n and σ were calculated using half of the data points collected during the site survey. In this case $n = 2.31$ and $\sigma = 6.42$. The dotted lines represent the standard deviation upper and lower limits. Since there is a normal distribution, 95% of the values should fall within two standard deviations, 2σ, from the mean. The second half of the data points collected were used as control data to test the accuracy of the model. These points are represented by the "o" symbols on the graph. From this graph it can be seen that 50 out of 52 points or 96% of the values fall within two standard deviations, 2σ, from the mean, μ. Also, 35 out of 52 points or 67% of the values fall within one standard deviation, σ of the mean μ. This is close to the normal distribution of 64% . This indicates that at distances up to 30 meters the model appears to be accurate for the 2.4 GHz band.

Figure 4 displays the modeled data. The model shows the lower limits of one and two standard deviations from the mean. The upper limits are not important to this model because above average signal does not have a negative effect on the system. Therefore, instead of 95% of data falling between two standard deviations, it can be said that 97% will fall above -2 standard deviations, -2σ, and 84% will fall above -1 standard deviation, -1σ. From this model it can be determined that about 97% of locations within 21.46 meters from the AP will have at or above -70 dBm RSS. It can also be said that within 40 meters, 84% will have above -70 dBm RSS. -85 dBm was the point where it was found to be difficult to maintain communication with the AP. In this model this point is within 94 meters for 97% of the values.

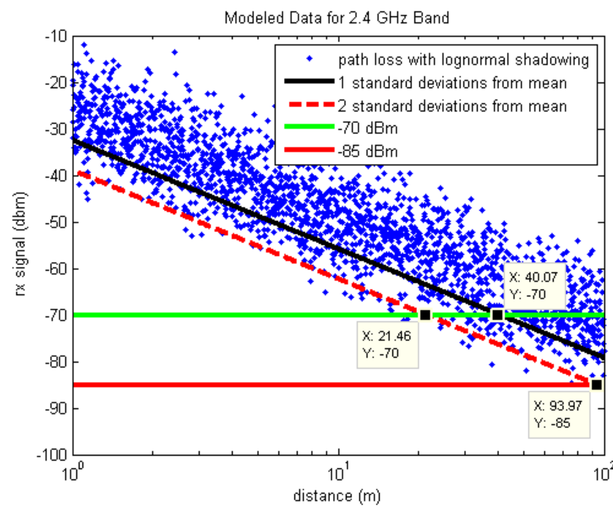

Fig. 4: Modeled data for 2.4 GHz band

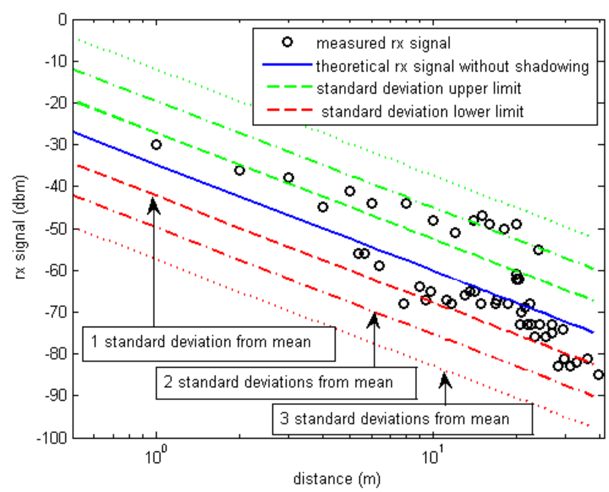

Fig. 5: Measured values for 5 GHz band

Figure 5 is similar to Figure 3. It shows the measured control values against the modeled path loss and standard deviation.

For the 5 GHz band a path loss exponent $n = 2.55$ with a standard deviation $\sigma = 7.58$ were calculated. To determine the accuracy of the model, the control data was checked to determine if it fitted the normal distribution of the model. In this case 47 out of 52 points or 90% fall within two standard deviations from the mean. This is slightly lower than the expected 95% . Within one standard deviation 35 out of 52 points or 67% were contained. The slightly lower values between two standard deviations are likely random due to the relatively small sample size. It is still safe to say that this model appears to be accurate.

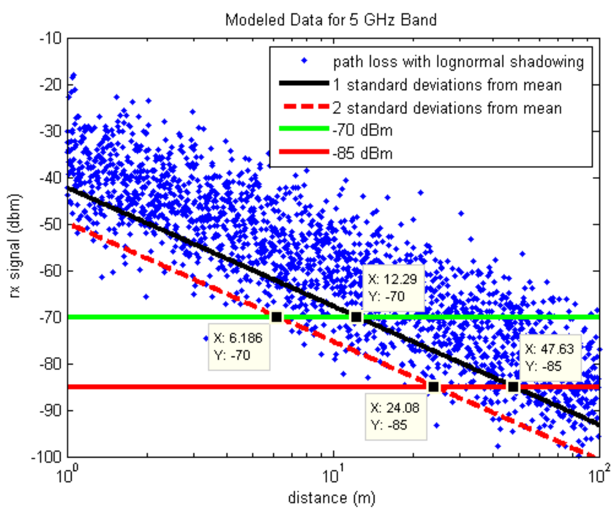

Fig. 6: Modeled signal levels for 5 GHz band

Figure 6 is similar to Figure 4. It shows the modeled data for the 5 GHz band. From this model it can be determined that within 6.18 meters from an AP 97% of RSS values will be at or above -70 dBm. Within 12.29 meters 84% of RSS values will be at or above -70 dBm. It was also determined that within 24 meters 97% of RSS values will be at or above -85 dBm. For locations within 47.6 meters of the AP, 84% of RSS values will be at or above -85 dBm.

V. Conclusion

The ability to predict signal propagation is important in the planning and design of any wireless system. It can be difficult to predict how different variables will effect propagation. In this paper it was examined how with a relatively quick site survey the signal propagation characteristics of a building can be modeled. The Gaussian or log-normal shadowing model, though simple, provided a reasonable degree of accuracy. For the 2.4 GHz band it was determined that about 97% of locations within 21.4 meters will have a RSS level of -70dBm or higher. For the same RSS value in the 5 GHz band the distance decreased to only 6.18 meters. This type of data is helpful when planning a wireless network.

Acknowledgments

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