INDOOR PATH LOSS PREDICTION FOR WI-FI NETWORK IN ULTRAHIGH FREQUENCY BAND USING ONE-DIMENSIONAL MULTI-RESOLUTION TECHNIQUE.

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ABSTRACT

In this work, Wi-Fi received signal strength was monitored in an indoor environment at 2437 MHz in ultrahigh frequency band of channel 6. The received signal strength was compressed, decomposed, filtered and reconstructed using one dimensional multi – resolution technique in order to predict how Wi-Fi received signal strength fades (path loss). The prediction result showed that the received signal strength was attenuated at 5.56 dB, fades 3 times and followed more of Gaussian than the Log – Normal and Rayleigh distributions with mean of 64.44 dBm and standard deviation of 0.568 dB. Cumulative frequency distribution was used to validate the wavelet prediction

Keyword: Wavelet, Signal Strength, Wireless, Prediction, Path Loss, Channel and Model

INTRODUCTION

The implementation of a wireless sensor network (WSN) has become essential where it is very expensive or difficult to deploy a fix wired access communication network. Moreover, WSN provides mobility within its coverage range to the user. Wireless local area network (WLAN), is usually called Wi-Fi, and has the following standards: IEEE 802.11, data rate up to 72 Mpbs and coverage range of 100-200m (Neskovic et *al*, 2000 and Samir, 2011). In order to determine the efficiency of the coding, processing and transmission techniques of a channel, there is the need to constantly monitor and come out with an accurate bill of the activities taking place on the channel. This can be achieved by developing a model of the channel for a particular environment using empirical data collected from the study area. Accurate prediction model can help in reducing the complexity of the channel, enhance data rate and, also increase the efficiency of the network in general. There are several models developed by different authors to improve performance of communication channels, both in indoor and outdoor environments, for example, (Okumura, 1986; Wu and Yuan, 1998; Erceg and Greenstein, 1999; Robert *et al*., 2006; Yarkony and Blaunstein, 2006; Biplab and Xianbo, 2007; Nadir et *al*., 2008; Jadhavar and Sontakke, 2012 and Sami, 2013). However, these models are generally accepted as reference models. Since, they cannot serve all the environments around the globe. This work will adopt and modify Log – Distance Model based on the empirical data collected in the study area (Erceg and Greenstein, 1999) and cumulative frequency distributions (CFD) will be utilized to confirm the prediction.

THEORETICAL APPROACH

Log – Distance Model

This type of model can be used in either indoor or outdoor environment, the model experiences attenuation, based on propagation exponent (γ) especially, with the materials in the indoor areas such as wall partition, furniture & others (Loyka, 2012), as γ increase, the received signal strength decrease and vice – visa. γ can only vary from 1.2 – 8 (Neskovic *et al.,* 2000) which means when **γ** is maximum say, 8 then the obstruction is large. Also, quite a number of channels have been modeled using Log – Distance path loss model (Goldsmith, 2005; Yarkony and Blaunstein, 2006; Bertoni, 2013). It is an extension of free space model and it is given by

$$P_L = P_L(d_0) + 10\gamma \log\left(\frac{d}{d_o}\right) \quad (1)$$

Where, γ represents propagation index, d represents the distance between transmitter and receiver, d_0 represents the reference distance and $P_L(d_0)$ is free space path loss, also given by

$$P_L(d_0) = 20\log(d) + 20\log(f) - 27.55 \quad (2)$$

Where f is the operating frequency usually measured in MHz (Rappaport, 2000).

Cumulative Frequency Distribution (CFD)

The CFD of the Gaussian distribution is defined as

$$\frac{1}{2}\left[1+erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] \quad (3)$$

The Gaussian random variables usually, have zero or negative mean. In the case of no fading, the random variables become zero and when the random variables have Gaussian distribution and high value of σ(dB), the received signal strength may result in Log – Normal distribution, as given by the relation.

$$\frac{1}{2}+\frac{1}{2}erf\left[\frac{\ln x-\mu}{\sqrt{2}\sigma}\right] \quad (4)$$

If non of these conditions is applied then, receive signal strength is likely to follow fast fading which may come inform of CFD of Rayleigh distribution (Scott *et al* 1992; Molley and Keenan, 1999) is expressed as

$$1-e^{-\frac{x^2}{2\sigma^2}} \quad (5)$$

In this work, Wavelet Multi-Resolution Techniques will be used to predict path loss in a WLAN, with the following objectives; collect received signal strength at different distances in an indoor environment, decompose and filter the signal received, compare the original and the approximated received signal strength, obtain the type of fading, and finally, modify the adopted model and the total amount of the received signal strength will be computed as given by

$$\sum_{i=1}^{n} P_i(dBm) = P_1 + P_2 + \ldots + P_n \quad (6)$$

The mean and standard deviation of the modified path loss model and the CFDs will be obtained as given in the following expressions

$$\mu = \frac{\sum fx}{\sum f} \quad (7)$$

$$\sigma = \sqrt{\frac{\sum x-\mu}{f-1}} \quad (8)$$

Where x and f represent received and total number signal strength measured respectively. The root mean square error between the approximated signal and the received signal, will be obtained as given by

$$RMSE = \sum_{i}^{n}\left(\sqrt{\frac{(P-P_a)^2}{n}}\right) \quad (9)$$

Where n and P_a are the number of the measured data and the approximated signal respectively.

METHOD OF DATA COLLECTION AND ANALYSIS

The data was collected on a first floor of a three storey building with a long one side open corridor of Administrative block of Adamawa State University, Mubi. The study area is located at the University campus in Mubi town. Mubi is the second largest city in Adamawa State of Nigeria, and falls within Sudan Savannah belt vegetation zone. The zone is made of Mountains, Streams, dry land interspaced by shrubs and woody plants (Mohogani, Neem, Shear butter, Cashew, Guava, Mango, Tamarin and others) typically of 7 – 12 m height. Mubi lies on longitude 9^0 20'N and Latitude 12^0 30'E. A mobile equipment (ME1) is used as the source of Wi-Fi signal (Hotspot), placed on a stool of 1 m height close to the end of the corridor. While, ME2 was used to monitor the received signal strength at different distances starting from 2 – 44 m. Measurement was taken at an interval of 2 m each. The samples of receive signal strength in (dBm) were collected at the 2437MHz band of Wi-Fi signal on channel 6 ultrahigh frequency (UHF), using NETWORK SIGNAL PRO software, down loaded from ANDROID play store of a ME2 (Samsung Galaxy Tab 4). The software is available only on Android Smart Phones. The software implements Zeebee protocol stack, meets IEEE 802.11 standard and operates in UHF 2.4GHz frequency band with ±1% packet error rate. The 'system info' is calibrated from – 104 dBm to -16 dBm where, from -104 dBm to – 80 dBm, -79 dBm to -41 dBm and -40 dBm to -16 dBm are classified as weak, good and excellent received signal strength respectively. However, the smaller the number of the dBm receives by the ME, the worse the reception or the quality of service (QoS). Therefore, -16 dBm is much better than -104 dBm. The sample of the received WiFi signal strength collected is depicted in Figure 1, presented as signal strength measured (dBm) against distance (m). It can be seen that, the received signal strength decreases as the distance increases, the variation may be attributed to fading phenomenon cause due to transmission impairments as mentioned in the study area.

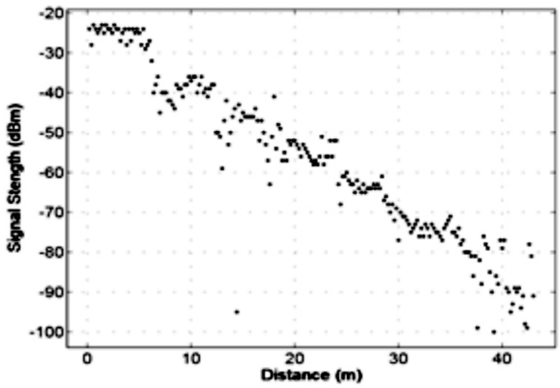

Figure 1: Samples of receive signal strength

Wavelet Multi-Resolution Prediction Algorithm

Wavelet simply means wave with short duration with an average value zero. Wavelet algorithm is one of the vital tools used in signal processing to analyze smallest part of the signal that older tools like Fourier transform could not be able to analyze. Generally, Wavelet tool is used in varieties of works but in this work, the tool is used as a filter. There are different types of Wavelet tools; this includes Debauches, Haar, Morley and Bio and many others. To successfully achieve the filtering process a couple of things have to be done. For example, decomposition, filtering and reconstruction of the discrete signal strength received.

Discrete Signal Decomposition, Filtering and Reconstruction Processes

In order to achieve signal full decomposition process, the discrete receive signal strength has to be decomposed into two parts called approximated and the detailed coefficients. The decomposed signal has to be passed through the quadrature mirror filters which consist of high and low pass filters given by the symbols g(n) and h(n) respectively. Usually, the approximated signal passes through the low-pass filter and the detailed signal passes through high-pass filter (Ratnakar *et al.,* 2009 and Rodrigo, 2011) as depicted in Figure 2, assuming the receive signal strength to be decomposed is given by y[n]. The approximated signal is denoted as cA_J and the detailed signal is denoted by cD_j both on octave respectively.

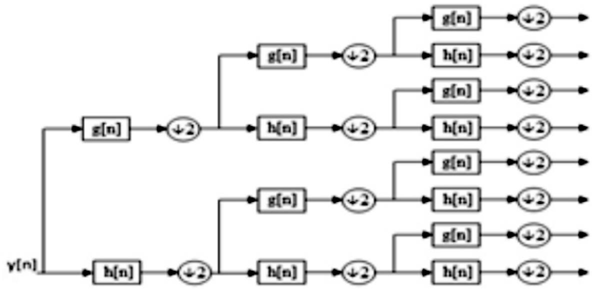

Figure 2: Wavelet Decomposition Levels

Reconstruction of the decomposed signal can be achieved by re - assembling back the components of the signal into original signal without losing meaningful information sometimes referred to as inverse discrete wavelet transform (IDWT). However, during filtering, attention must be paid to the choice of the appropriate filters so that, the signal structure will not be compromised. Because, at that time the information about the signal may not be clear. Full wavelet decomposition of the attenuated receive signal strength measured usually provides information about the frequency of the signal at numerous scales as shown in Figure 3.

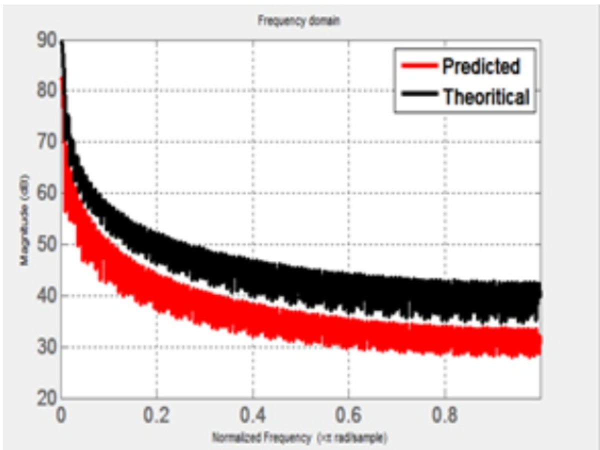

Figure 3: Predicted and Theoretical Path Loss in Frequency Domain.

Thus, the receive signal strength can also be seen in detailed and approximated form both on the octave axis (j, J) respectively as shown in Figure 4. The approximated signal is situated on the upper scale ranging from $1 \le J \le Jn$, with low frequencies considered to be the vital part of the signal and the detailed on the lower scale ranging from $1 \leq j \leq Jn$ with high frequencies considered to be the unwanted part of the signal (noise). The wavelet coefficients $A_x(J,k)$, $D_x(j,k)$ are derived from the equation below after full decomposition.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (10)$$

Where in Equation (10), a is the positive number which defines the scale and $b$is the real number that defines the shift (Biplab and Xiaobo, 2007; Xiaobo and Biplab, 2008). Equation (10) sometimes called child wavelet derived from the mother wavelet. But full wavelet decomposition (FWD) is composed of the combine wavelet coefficients of the approximated and the detailed signal as given by

$$y(n) = A_x(J,k)\,\psi_0(J,k) + \sum_{k=1}^{j} D_x(j,k)\psi_0(j,k) \quad (11)$$

y is decomposed using Haar at level 3, this means that, n = 3. At this level the decomposition produced $2^n=2^3=8$ coefficients. Haar is chosen for this purpose because of the following reasons; physical appearance of the experimental data and the wavelet Haar, coefficient of correlation is approximately equal and the wave energy is almost the same. The following gives numerical example of the Wi-Fi signal strength decomposed and reconstructed. Normally, Haar wavelet has the following transforms at level-1 as

i. Running average; that is the average sum of the two successive signal received by the ME2

$$C_m = \frac{P_{2m-1} + P_{2m}}{\sqrt{2}} \quad (12)$$

ii. Running difference; that is the average difference of the two successive signal received by the ME

$$d_m = \frac{P_{2m-1} - p_{2m}}{\sqrt{2}} \quad (13)$$

Where m=1, 2, 3, 4,. . . .n/2

For example, consider the first 12 successive signal received by the ME as $P_1, P_2, P_3, P_4, \ldots P_{12}$ which corresponds to the -24 dBm, -28 dBm, -23 dBm, -24 dBm, -25 dBm, -24 dBm, -23 dBm, -25 dBm, -23 dBm, -24 dBm, -24 dBm and -24 dBm.

To decompose and reconstruct the received signal strength; there is a need to satisfy the conditions in (i) and (ii). The received signal is decomposed using the equation given by

$$C_m^2:\ C_1 = \sqrt{2}\left(\frac{P_1+P_2}{2}\right),\ C_2 = \sqrt{2}\left(\frac{P_3+P_4}{2}\right),$$

$$C_3 = \sqrt{2}\left(\frac{P_5+P_6}{2}\right),\ldots,C_6 = \sqrt{2}\left(\frac{P_{11}+P_{12}}{2}\right) \quad (14)$$

The introduction of $\sqrt{2}$ is to ensure sufficient energy conservation.

C_m^2:$-26\sqrt{2}$ dBm, $-23.5\sqrt{2}$ dBm, $-24.5\sqrt{2}$ dBm, $-24\sqrt{2}$ dBm, $-23.5\sqrt{2}$ dBm, $-24\sqrt{2}$ dBm.

$$d_m^2 : d_1 = \sqrt{2}\left(\frac{P_1-P_2}{2}\right),\ d_2 = \sqrt{2}\left(\frac{P_3-P_4}{2}\right),$$

$$d_3 = \sqrt{2}\left(\frac{P_5-P_6}{2}\right),\ldots,d_6 = \sqrt{2}\left(\frac{P_{11}+P_{12}}{2}\right) \quad (15)$$

d_m^2 :$-2\sqrt{2}$ dBm, $-\frac{\sqrt{2}}{2}$ dBm, $\frac{\sqrt{2}}{2}$ dBm, $-\sqrt{2}$ dBm, $-\frac{\sqrt{2}}{2}$ dBm, 0 dBm

Filtering of the decomposed received signal strength is done using the expression given by

$$P = C_m^2 - d_m^2 \quad (16)$$

$$P - \left(-26\sqrt{2}, -23.5\sqrt{2}, -24.5\sqrt{2}, -24\sqrt{2}, -23.5\sqrt{2}, -24\sqrt{2}\right) - \left(-2\sqrt{2}, -\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, -\sqrt{2}, -\frac{\sqrt{2}}{2}, \sqrt{2}\right)$$

IDWT equation is applied to reconstruct back the original signal given by

$$P = \left(\frac{C_1+d_1}{\sqrt{2}}, \frac{C_1-d_1}{\sqrt{2}}, \ldots\ldots, \frac{C_{n/2}+d_{n/2}}{\sqrt{2}}, \frac{C_{n/2}-d_{n/2}}{\sqrt{2}}\right) \quad (17)$$

$$P = \frac{-26\sqrt{2}+2\sqrt{2}}{\sqrt{2}}, \frac{-26\sqrt{2}-2\sqrt{2}}{\sqrt{2}}, \ldots$$

$$\ldots, \frac{-24\sqrt{2}+0}{\sqrt{2}}, \frac{-24\sqrt{2}-0}{\sqrt{2}}$$

Where P_1= -24 dBm, P_2= - 28 dBm. . . .P_{11}= -24 dBm, P_{12}= -24 dBm

As it can be seen, P is successfully reconstructed without compromising the signal structure. The same principles can be applied to the other parts of the decomposition levels.

RESULTS AND DISCUSSION

In this work, an alternative method of path loss prediction is employed called wavelet prediction technique. The prediction is done by filtering the unwanted part of the signal received. The ideal wavelength (λ) of propagation of the study area may be obtained as $\lambda = C/f$; where C is the speed of the propagated wave and it can be evaluated by $C = d/t$; where, d is the distance between the ME1 and the ME2 given by $d = \left(x_{BS}^2 + x_{ME}^2\right)^{1/2}$. The total amount of the signal strength received in the study area was obtained from expression (6), and the total amount of the received (p_i) and the approximated (P_a) signal strength were compared as the ratio of P_i/P_a and was found to be equal to 3:1, this means that, the frequency of the signal strength received fades 3 times and the wavelength becomes $\lambda_n = C\alpha/f$ greater than the normal wavelength of the propagation. Where α, is the fading factor and λ_n is the faded wavelength. Therefore, it can be deduced that, the ratio of the signal strength approximated at level 3 fades about 3 times the wavelength of the propagation. It is worthy to say that the signal received corresponds to the slow fading scale as shown in Figure 4.

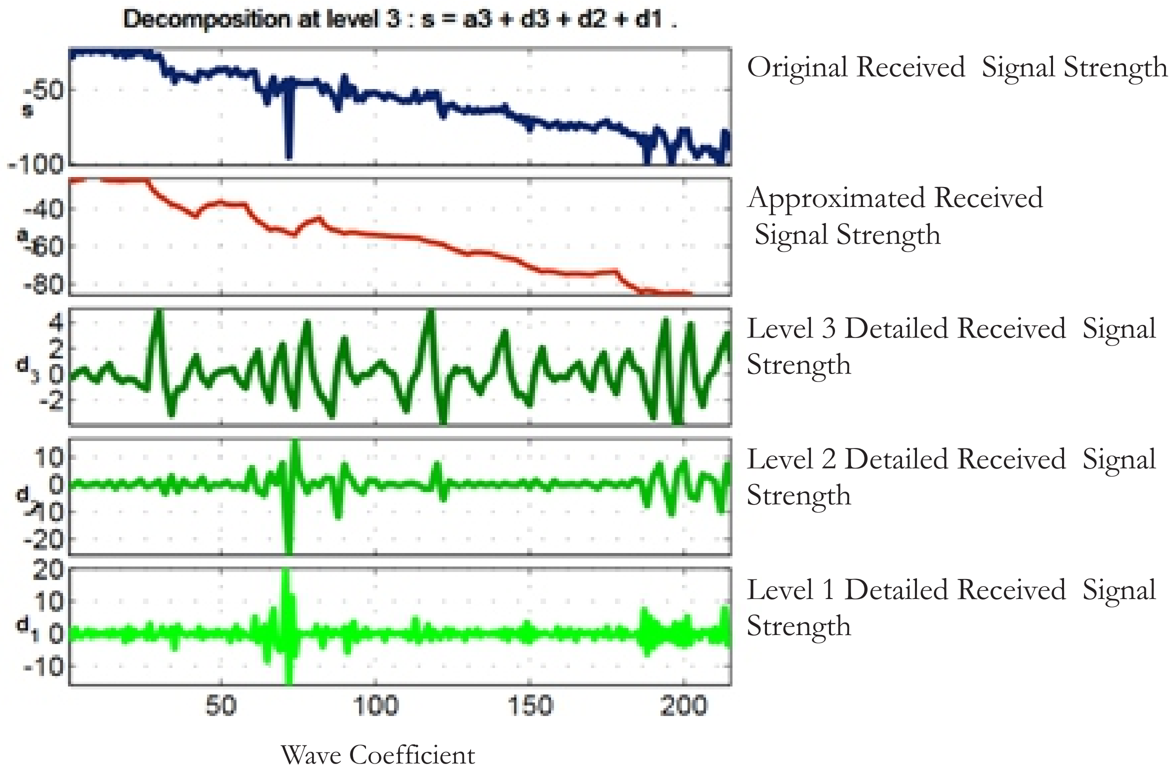

Figure 4: Approximated and Detailed Receive Signal Strength

The RMSE is obtained from Equation (9) as 5.56 dB, this value is subtracted from Equation (1), to modify the model

$$P_L = P_L(d_0) - 5.56 + 10\gamma \log\left(\frac{d}{d_o}\right) \qquad (18)$$

Equation (18), called the modified model and two models are further compared as depicted in Figure 5.

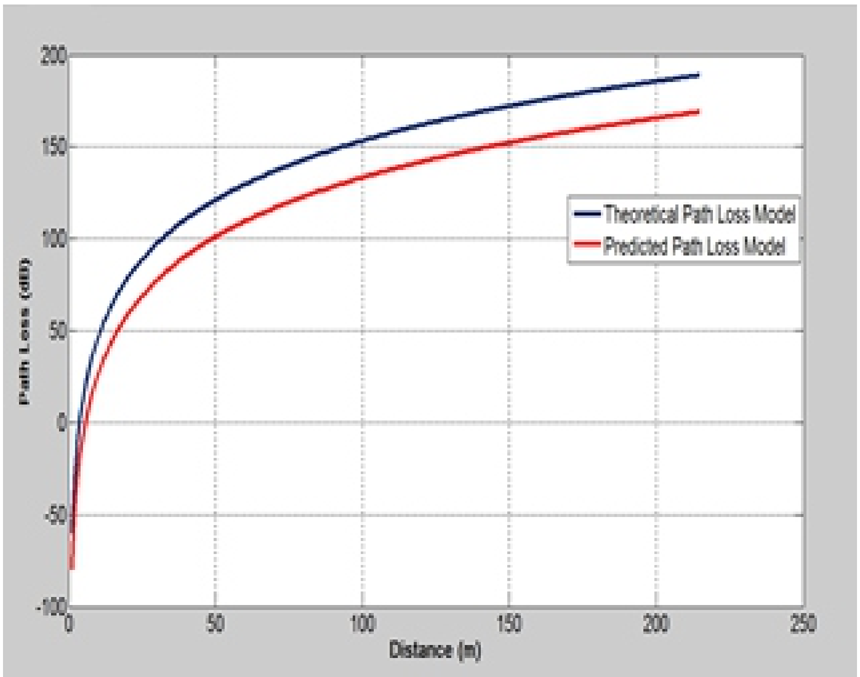

Figure 5: Theoretical and Modified Path Loss Models

From Figure 5, it is noticed that, the theoretical path loss experienced more losses by approximately an average of 5.56 dB than the predicted path loss. As described in Equation (2-4), wavelet prediction is further validated using cumulative frequency distribution of the path loss in terms of Gaussian, Log – Normal and Rayleigh distribution as shown in Figure 6. The path loss follows more of Gaussian distribution than Log – Normal and Rayleigh distribution. This is because, the mean of path loss predicted is equal to the mean of the Gaussian distribution as given in Table 1.

Table 1: Comparison of the Mean of Receive Signal Strength and the Distributions\

Items	**μ (dBm)**	**σ (dBm)**
Path Loss	64.44	0.568
Gaussian distribution	64.44	0.567
Log –Normal Distribution	64.53	0.010
Rayleigh Distribution	57.58	1.567

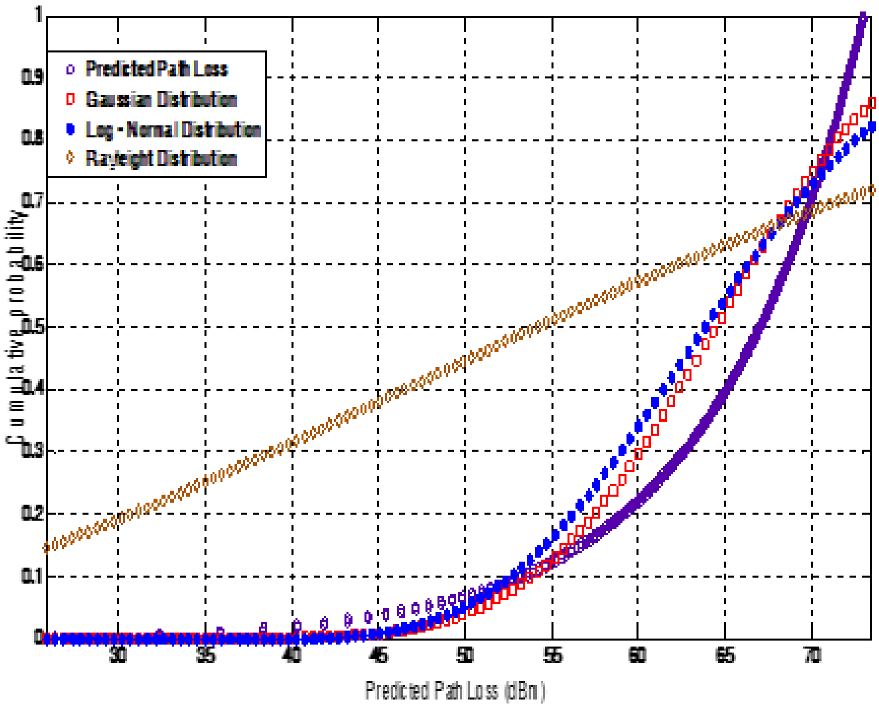

Figure 6 CFDs of the Receive Signal Strength

(Yarkony and Blaustein, 2006) conducted similar research on the first floor of a storey building located at Ben – Gurion University, Israel using empirical method in terms of slow or fast fading but obtained an average prediction error of 7.2 dB and (Samir, 2011) also, carried out similar work on the first floor of a storey building at home in Iraq. However, Samir, did not consider types of fading phenomenon but arrived at a prediction error of 8.38 dB. In comparison with the result obtained in this work, wavelet prediction technique minimized the errors obtained by 1.64 dB and 2.82 dB, respectively. Therefore, in this regards, wavelet prediction technique has efficient prediction performance than what was reported by Yarkony and Blaustein (2006) and Samir (2011).

CONCLUSION

In this work, one-dimensional multilevel wavelet is used to predict the Wi-Fi received signal strength attenuation in an indoor environment in terms of fading phenomenon. The prediction result revealed that, the received signal strength is attenuated by 5.56dB and confirmed as a slow fading signal, since the path loss followed more of Gaussian than Log – Normal and Rayleigh distributions. The mean of the path loss obtained in the study area is 64. 44 dBm, this means, significant part of the signal strength received is rated good and CDF is used to validate the wavelet prediction algorithm.

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