ISSN: 2449 - 0539
*BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL.13 NO.2, AUGUST, 2018*

# ASSESSMENT OF AN IMPROVED WIENER II PATH LOSS MODEL FOR SIGNAL PROPAGATION ON CONCRETE WALLS

**Sahanunu Dahiru[1] and Hassan A. Bashir[2]**

[1]Department of Computer Engineering, Jigawa State Institute of Information Technology, Kazaure
[2]Department of Electrical Engineering, Bayero University, Kano. PMB 3011, Nigeria

## ABSTRACT

*Path loss analysis of Wi-Fi (IEEE 802.11x) signal propagation plays significant role in the plan and function of wireless local area networks (WLAN) applications. Path loss models are crucial in the planning of wireless network as they facilitate survey and mapping of a site for RF installation via simulation; thus, avoiding tedious physical measurements and serve as a guide to a network designer in determining the best location for network devices. Among others, path loss depends upon signal frequency, distance, antenna height and other environmental (medium) characteristics. Frequency and distance are the most important parameters for path loss calculation. This paper develops a modified Wiener II path loss model suitable for assessing Wi-Fi signal propagation through concrete wall. It analyses the effect of distance and frequency on the received signal quality. Empirically, a computer system running the inSSIDer software (a Wi-Fi network scanner application) was used to measure the received signal strength from a Wi-Fi signal source (access point); the measured results were recorded at every 10 m interval between the source (Wi-Fi Access point) and the destination (a personal computer). For the theoretical results, Wiener II model was simulated in Matlab and the result was also recorded. A comparison of both the empirical and theoretical results revealed that the original Wiener II model consistently deviates from the measured results by an average of 1.11%. The Wiener II model was modified by tuning its parameters based on the medium characteristics. The improved Wiener II model estimates the measured path loss with an average deviation of only 0.38% from the measured results.*

**Keywords:** Path Loss; Wiener II model; RF Signal Propagation; RF Signal Frequency.

## 1.0 INTRODUCTION

When radio waves travel from one device to another there are several issues that describe its characteristics. The radio energy gets attenuated as it propagates through a medium especially when it passes through obstacles like glass, wood, concrete and metal surfaces. There are various approaches to analyse radio frequency (RF) propagation through different media (Jadhavar and Sontakke, 2012). For some applications where physical measurements are tedious or practically impossible, theoretical assessment may be the best. This permits evaluation of signal propagation through structures that are not accessible for measurement. Importantly, such theoretical analyses are expected to be less expensive than physical measurements.

Path loss depends, among other things, upon frequency, distance, as well as antenna height and other environmental characteristics. Frequency and distance are generally taken into account in developing path loss models. Antenna height and medium characteristics are not always explicitly considered as their effects are not easy to include in a particular model.

This paper aims to investigate path loss dynamics when RF signal is passed through concrete walls; both empirical and theoretical methods will be used. An improved Wiener II path loss model is developed; it is then simulated and deployed to assess the effect of frequency and distance variations when RF signal is passed through concrete wall medium. The design aim of the modified Wiener II model, developed by tuning a fitting parameter for the transmission medium, was to predict the measured signal strength more accurately.

Wiener II channel models are commonly used in communication systems (Pekka and Tommi, 2007) with a goal to develop a single ubiquitous radio access system adaptable to a comprehensive range of mobile communication scenarios from short range to wide area. This will be based on a single radio access technology with enhanced capabilities compared to existing systems or their evolutions. The models have been evolved from the Wiener I channel models described in Wiener II deliverable D5.4 and Wiener II interim channel models described in deliverable D1.1.1 (Pekka and Tommi, 2007). The covered propagation scenarios include indoor offices, large indoor halls, indoor-to-outdoor, urban micro-cells, bad urban micro-cells, outdoor-to-indoor, stationary feeders, urban, suburban and rural macro-cells. In the past few decades, Wiener II Path loss models for the various environment scenarios have been developed and deployed for path loss measurement in many different areas. Masoud and Ivica (2013) investigated five propagation models using backhaul link including the Wiener model. Their results revealed that the examined Wiener models performed adequately with fairly similar level of accuracy. Similarly George et al., (2003) used Wiener II model to develop models for 5G millimeter wave propagation channels in urban microcells.

Recently, the effect of distance on Wi-Fi signal attenuation in concrete walls have been studied based on Wiener II model by Sahanunu and Hassan (2016). Their results showed that path loss increases with increase in distance. Oni and Idachaba (2017) reviewed different path loss prediction models to investigate the effect of path loss with the goal of minimizing interference. Their results suggested adoption of signal boosters at specific locations in buildings to counter the effect of large path loss introduced by walls.

Joe (2008) investigated the effect of path loss for a frequency range between 2.4 to 5 GHz. The result showed higher frequencies are more affected by obstruction than lower frequencies. To the authors' knowledge, this is the first attempt to study the effect of distance and frequency on RF signal propagation in concrete wall using Wiener II path loss model.

## 2. MATERIALS AND METHOD

### 2.1 Theoretical Model

In simple terms the path loss is the difference between the transmitted power and the received power of a wireless communication system. This may range from tens of dB to more than a 100 dB. To study the effect of path loss dynamics when RF signal is passed through concrete walls, both empirical and theoretical methods are employed in this work. The signal strengths were measured in both free space and in the presence of concrete wall partition by taking 10 m incremental distance intervals from the access point. At each interval signal strength was measured and recorded.

Firstly, physical measurements are conducted for a medium with a concrete wall of 30 cm thickness, relative permittivity of 4 and conductivity of 0.05 S/m. An IEEE 802.11b compliant wireless access point operating at 2.4 GHz was used. The access point has a transmit power of 17 dBm and a bandwidth of 11 Mbps. Signal strengths at the receiving ends were measured using a computer-based software called the inSSIDer software. This is a tool that allows one to identify and measure the signal strength of WLANs.

Secondly, for the theoretical part, Wiener II model (1-2) was deployed to estimate path loss for the various scenarios. According to WIENER-II model the path loss can be calculated as:

$$PL_{free} = 20\log_{10}(d) + 46.4 + 20\log_{10}\left(\frac{f_c}{5.0}\right) \quad (1)$$

$$PL_{wall} = 20\log_{10}(d[m]) + 4.6 + 20\log_{10}\left(\frac{f_c[GHz]}{5.0}\right) + X \quad (2)$$

Where: $d$ is the separation distance between the transmitter and receiver in meters; $f_c$ is the frequency in GHz; $A$ is the path loss exponent; $B$ is the intercept i.e. path loss in dB reference to 1m distance and $C$ is a frequency dependent parameter. $X$ is an environment specific parameter such as path loss due to wall. $PL_{free}$ is the path loss in free space, i.e. a line of sight environment (for free space medium, $A = 20,\ B = 46.4$ and $C = 20$ (Pekka et al., 2007).

Table 1 presents, in detail, the parameters for the various environments defined in the WEINNER-II model. Once an environment is selected the path loss parameters ($A$, $B$ and $C$) can be selected from the table.

**Table 1: Parameter Definitions for Various Media for Wiener II model**

| Scenario | Path loss [dB] | Shadow fading std [dB] | Applicability range and antenna height (default values) |
|---|---|---|---|
| Line-of-sight (LOS) | $A = 18$ | $\delta = 3$ | , $hbs = hms = 1 \ldots 2.5m$ |
| Non-Line-of-sight (NLOS) | $A = 36$ and $X = 5(nw-1)$( light walls) $X = 12(nw-1)$ (heavy walls) | $\delta = 4$ | , is the number of walls between the BS and MS ( for NLOS) |
| NLOS (light walls) | $A = 2$and | $\delta = 6$ | , is the number of walls between the BS and MS |
| NLOS (heavy walls) | $A = 2$and | $\delta = 8$ | |

**Table 2: Path loss results for a concrete wall medium with varying distances showing the empirical measurement, the original and the modified Wiener II model at 2.4 GHz**

| Distance (m) | Measured Path Loss (dB) | Original Wiener II Path Loss (% Deviation From Measured value) in dB | Modified Wiener II Path Loss (% Deviation From Measured value) in dB |
|---|---|---|---|
| 10 | 73 | 72.0248 (1.34%) | 73.2999 (0.41%) |
| 20 | 79 | 78.0454 (1.21%) | 79.3205 (0.41%) |
| 30 | 82 | 81.5672 (0.53%) | 82.8423 (1.03%) |
| 40 | 85 | 84.0660 (1.10%) | 85.3411 (0.40%) |
| 50 | 87 | 86.0042 (1.14%) | 87.2793 (0.32%) |
| 60 | 89 | 87.5878 (1.59%) | 88.8629 (0.15%) |
| 70 | 90 | 88.9268 (1.19%) | 90.2018 (0.22%) |
| 80 | 91 | 90.0866 (1.00%) | 91.3617 (0.40%) |
| 90 | 92 | 91.1097 (0.97%) | 92.3847 (0.42%) |
| 100 | 93 | 92.0248 (1.05%) | 93.2999 (0.32%) |
| | | Average Deviation = 1.11% | Average Deviation = 0.38% |

## 2.2 The Modified Path Loss Model

In order to analyse the applicability of the simulated path loss model to predict the measured result, comparative analysis between the measured and simulated original Wiener II model was done. It is found that, the model does not accurately predict the path loss of the measured signal passing through a concrete wall medium (see Table 2). This deviation is attributed to the characteristic properties of the concrete wall. Thus, based on the parameters of the concrete wall (i.e. thickness, relative permittivity and conductivity), the parameters of the standard Wiener II path loss model were empirically tuned to improve the quality of the results of the simulated model. Similarly, the parameters of the free space model were also tuned.

As a result, improved Wiener II models for the free space and concrete wall medium are proposed as described in (3) and (4) respectively.

$$PL_{free} = 20\log_{10}(d) + 46.4 + 16\log_{10}\left(\frac{f_c}{5.0}\right) \quad (3)$$

$$PL_{wall} = 20\log_{10}(d[m]) + 46.4 + 16\log_{10}\left(\frac{f_c[GHz]}{5.0}\right) + X$$

While all the parameters are as defined in (1) and (2), the constants are also tuned to $A = 20$, $B = 46.4$ and $C = 16$.

# 3. RESULTS AND DISCUSSION

## 3.1 Results

In order to analyze the applicability of the simulated path loss model to predict the measured data, and to come up with better communication frequency, the results obtained from the measurements are compared with the simulated result of Wiener II model. Table 2 presents the empirically measured path loss and the theoretical path loss estimated using the original as well as modified Wiener II models for 10 m through 100 m distance intervals. Table 2 also presents the percentage deviations when Wiener II models are used. The percentage deviation from the measured path loss for both the original and the proposed modified Wiener II models are obtained as follows:

$$\%\,Deviation = \frac{|Measured\ Path\ Loss - Estimated\ Path\ Loss|}{Measured\ Path\ Loss} \times 100\% \quad (5)$$

Similarly, Table 3 shows the path loss for varying frequency range between 2.4 to 5.8GHz.

**Table 3: Path Loss Results (**in dB**) for the Modified Wiener II Model for varying Distance and Frequency Ranges (2.4 to 5.8 GHz)**

| Distance (m) | Operating Frequencies | | |
|---|---|---|---|
| | 2.4 GHz | 5 GHz | 5.8 GHz |
| 10 | 73.2999 | 78.4000 | 79.4313 |
| 20 | 79.3205 | 84.4206 | 85.4519 |
| 30 | 82.8423 | 87.9424 | 88.9738 |
| 40 | 85.3411 | 90.4412 | 91.4725 |
| 50 | 87.2793 | 92.3794 | 93.4107 |
| 60 | 88.8629 | 93.9630 | 94.9944 |
| 70 | 90.2018 | 95.3020 | 96.3333 |
| 80 | 91.3617 | 96.4618 | 97.4931 |
| 90 | 92.3847 | 97.4849 | 98.5162 |
| 100 | 93.2999 | 98.4000 | 99.4313 |

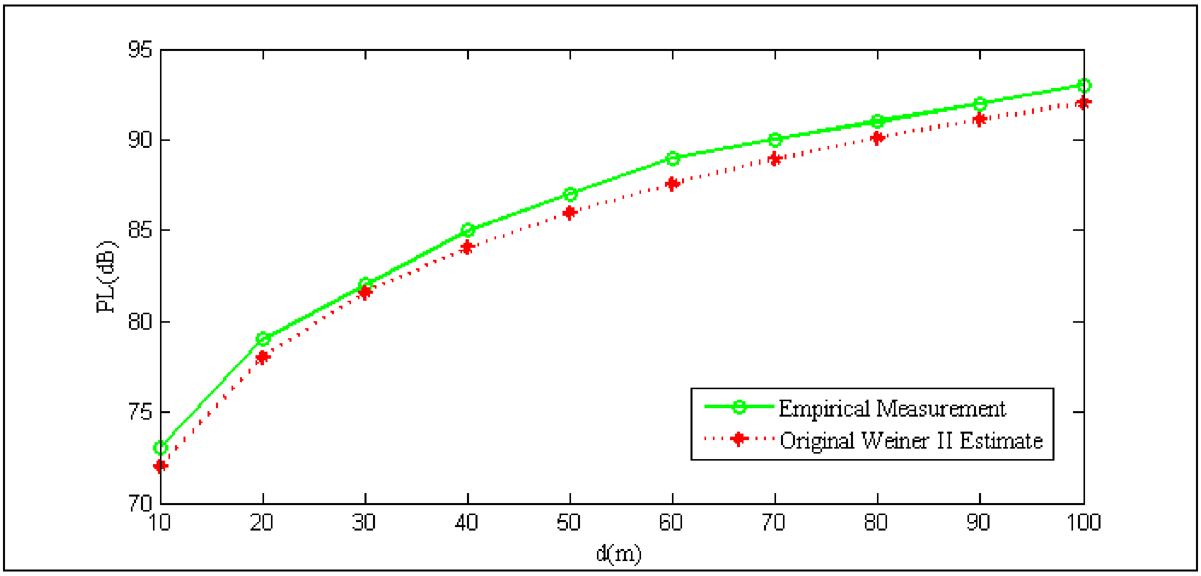


**Figure 1: Comparison of the Measured versus the Original Wiener II model results in a Concrete Wall medium at various distances.**

### 3.2 Discussion and Analysis of Results

The Comparison of the measured and Wiener II model based results shown in Figure 1 revealed a mismatch of approximately 1 dB between them. As shown in Table 2, over the examined range of 10 to 100 m intervals, the original Wiener II model suffered on average 1.11% deviation from the measured path loss. This leaves an ample room for improving the estimation accuracy obtained from the original Wiener II model. Thus, the original model was improved through parameter tuning which led to the proposed modified model described above.

Table 2 further revealed that the proposed modified Wiener II model had an average deviation of only 0.38%. Thus, the close agreement between the proposed modified Wiener II model and the empirical measurement is graphically demonstrated in Figure 2 for clarity.

Finally, to investigate the effect of frequency variation on path loss suffered by RF signal passing through concrete walls, a similar set of experiments was conducted with varying frequency ranges. The results in Table 3 revealed that, the propagation of higher radio frequencies (such as 5 GHz and 5.8 GHz) is more severely affected by obstruction than that of a lower frequency (2.4 GHz – Wi-Fi) signal. Figure 3 shows that the attenuation caused by concrete wall at 2.4 GHz is consistently about 5 dB smaller than that of a 5 GHz signal; it is also about 6 dB lower than that of a 5.8 GHz RF signals.

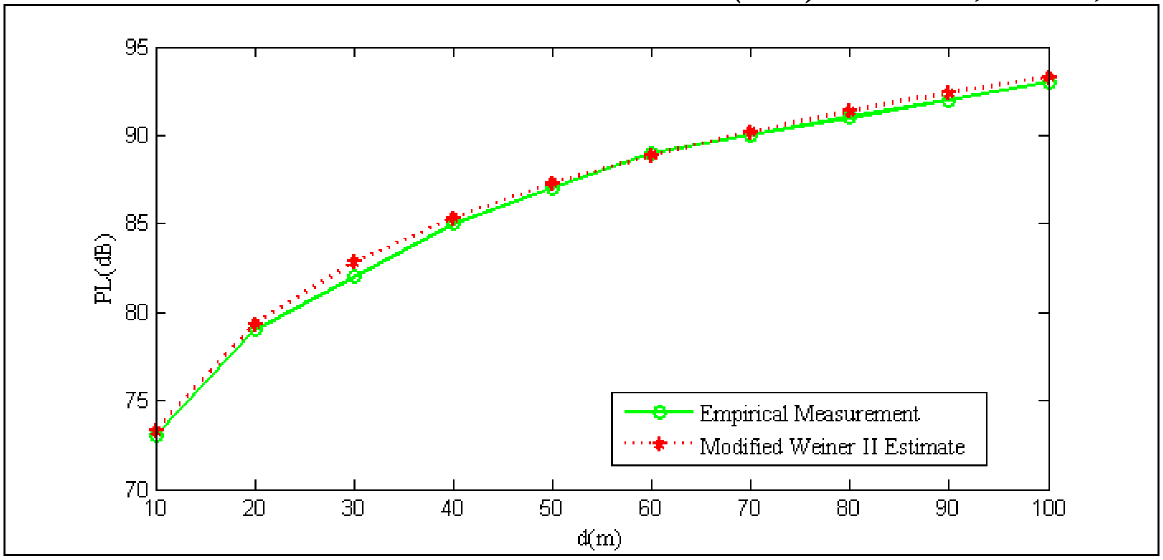


**Figure 2: Comparison of the Measured versus the Modified Wiener II model results in a Concrete Wall medium at various distances**

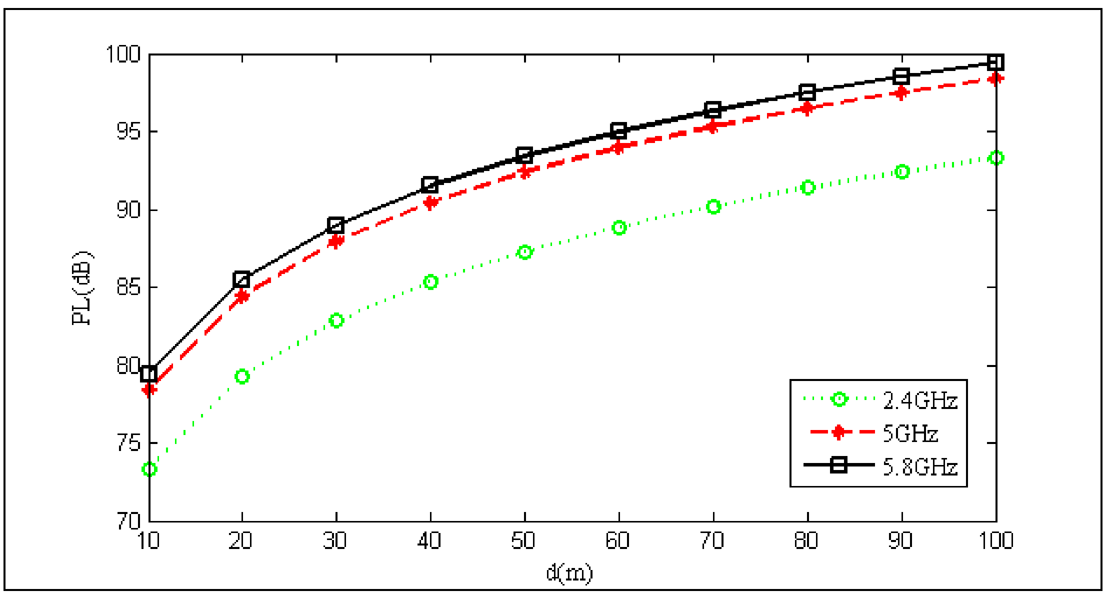


**Figure 3: Path Loss variations with Distance for various RF Signal Frequencies. The Lower the frequency, the smaller the path loss.**

## 4. CONCLUSION

This paper outlined the theoretical and empirical methods for the determination of Wi-Fi signal propagation using path loss models in a concrete wall medium. Wiener II model was used as the path loss prediction model and was compared with the empirically measured behaviour. The results obtained from Wiener II model shows significant deviation from the empirical measurements with an average deviation of 1.11%. Thus, this paper proposed a modified Wiener II model which minimized the estimation error by reducing the deviation from the measured results to an average of 0.38%.

The findings in this work could be used to significantly improve the processes of modeling the Wi-Fi signal propagation using path loss models in both free space and concrete wall obstructed medium. The proposed model can be deployed to estimate RF signal quality in indoors; it can also be used to estimate the path loss due to concrete wall at various distances.

Moreover, this work revealed that higher frequencies (such as 5.0 GHz and 5.8 GHz) are more susceptible to severe path loss than lower frequencies like the Wi-Fi (2.4 GHz). Further research could be carried out to determine the path loss of Wi-Fi signal in other transmission media such as wood and glass which are commonly found in home and office environments.

## REFERENCES

George R. M., Junhong Z., Shuai N. and Theodore S. R. (2003). Path loss Model for 5G Millimeter Wave Propagation Channels in Urban Microcells. 2013 IEEE Global Communications Conference (GLOBECOM). Atlanta, GA, USA.

Jadhavar, B. R. and Sontakke, T. R., (2012). 2.4GHz Propagation Prediction Models for Indoor Wireless Communication within Building. International journal of Soft Computing and Engineering 2(3):2278-3075.

Joe B., Debunking the Myth: 2.4 GHz and 5 GHz Path Loss. Connect802 Corporation: "https://www.wlanpros.com/resources/debunking-myth-2-4-ghz-5-ghz-path-loss-joe-bardwell/" ONLINE. Accession Date: Sept. 2017.

Masoud H. and Ivica K. (2013). Path loss Models for LTE and LTE - A Relay Stations. Universal Journal of Communications and Network 1(4): 119-126.

Oni O. O. and Idachaba F. E. (2017). Review of Selected Wireless System Path loss Prediction Models and its Adaptation to Indoor Propagation Environment. Proceeding of the International Multiconference of Engineers and Computer Scientist. Vol II.

Pekka K. and Tommi J. (2007). Complexity Comparison of MIMO Channel Modelling Methods, ISWCS'07, Trondheim, Norway.

Pekka K., Juha M., Lassi H., Xiongwen Z., Tommi J., Christian S., and Milan N. (2007). WINNER II Channel Models for Link and System Simulation. Deliverable D1.1.2 V1.2.

Sahanunu D. and Hassan A. B. (2016). Path loss Model for of Wi-Fi signal Propagation in Concrete Walls. ACICon 2016 Conference Proceedings. Bayero University, Kano. pp: 125-128.