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Research Paper

Propagation Model for Pathloss Measurement through Concrete Wall at 2.4 Ghz

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ABSTRACT
Path loss models are essentials in the analysis of wireless network as they assist to facilitate RF site survey without the necessary physical measurements. It also serves as a guide in determining the best location of network devices. This paper presents the measurementresult obtained in free space and in the presence of concrete wall. Empirically, an access point was used to transmit Wi-Fi signal to the laptop computer with insider software for the indication of signal level and measured results was obtained at every 10m interval. For the theoretical results, Wiener II model was transformed into matlab code and then simulated result was also obtained. The graph was then plotted and compared for both the empirical and theoretical results obtained. The result showed that there is averagely 2dB difference between the measured and calculated path loss in free space and about 13dB in the presence of obstructed medium (concrete wall). The path loss model parameters were tuned based on the measured results and this yields an improved model with averagely 0.32dB difference between the measured and modified model in free space and 0.39dB in the presence of concrete wall. The modified model can now be used to calculate path loss in environment with similar specifications without carrying out the physical measurement.

KEY WORDS: *Concrete Wall, Empirical Model,Path Loss, Wiener-II Model*

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I. INTRODUCTION

Wireless communication in outdoor environments has been extensively studied and addressed with technologies such as GPS (Biu etal., 2020), UWB (Adamu et al., 2018) and openstreetmaps (Tayebi et al., 2019).The wireless communication for indoor environments is, however recognized to be very challenging, mainly due to the presence of obstruction that causes severe signal deterioration due to multi-path and shadow fading (Kang & Seo, 2020; Obiadat et al., 2018;). As such the prediction of wall losses is a fundamental aspect in the planning of wireless communication in indoor area like position information of the mobile user inside large buildings, malls, hospitals, air ports, public places, factories and emergency services (Saito &Omiya, 2018). GPS cannot work in indoor due to poor coverage of radio signal and its requirement of line of sight. A wide range of technologies such as Radio frequency identification (RFID), indoor GPS-based solutions, ultra wide band (UWB)and wireless local area network (WLAN) (Gharat et al., 2017; Alarifi et al., 2016; Adamu et al., 2018) can be used in the analysis of wireless signal in indoor area. In this research Wi-Fi enable RFID which replaced the short range RFID technology uses access point as reader and Wi-Fi devices as tag to measure the signal strength of Wi-Fi signal in the presence of concrete wall. The signal strength measured is converted to path loss for the study of how concrete wall attenuate Wi-Fi signal.

II. WIENER-II PATH LOSS MODEL

In simple terms the path loss is the difference between the transmitted power and the received power of a wireless communication system (Rath et al., 2017). This may range from tens of dB to more than a hundred of dB.

According to the WIENER-II model, the path loss can be calculated as:

$$PL = A\log_{10}(d[m] + B + C\log_{10}(\frac{fc[GHz]}{5.0}) + X \quad (1)$$

$$PL = 20\log_{10}(d) + 46.4 + 20\log_{10}(\frac{fc}{5.0}) \quad (2)$$

Here d is the separation between the transmitter and receiver in meters, f_c is the frequency in GHz, A is the path loss exponent, B is the intercept and C is the frequency dependent parameter. X is the environment specific parameter such as path loss due to a wall. PL_{free} is the path loss in a free space line of sight environment (here A=20, B=46.4 and C=20). Refer to Table 1 for the different environmental scenario defined by Weiner II model. (Pekka et al., 2007).

Equations(1) and (2) are transformed into Matlab code (Mathuranathan, 2013) and then simulated the result is shown in Table 2 below.

Table 1: Parameter Definitions for Various Media for Wiener II Model

Scenario	Path Loss [dB]	Shadow Pading std (dB)	Applicability Range Antenna Height Default Values
LOS	A=18.7, B=46.8, C=20	$\delta = 3$	3m$< d < 100m$, $h_{bs}=h_{ms}$=1…2.5m
NLOS[1]	A=36.8,B=43.8,C=20and X=5(n_w-1)(light walls) X=12(n_w-1) (heavy walls)	$\delta = 4$	3m$< d < 100m$, n_w is the number of walls between the BS and MS ($nw > 0$ for NLOS)
NLOS[2] light walls	A=20,B=46.4,C=20 and X=5n_w	$\delta = 6$	3m$< d < 100m$, n_w is the number of walls between the BS and MS
heavy walls	A=20,B=46.4,C=20 and X=12n_w	$\delta = 8$	

Table 2: Calculated Path Loss based on Wiener-II Model

Distance (M)	Free Space Path Loss(dB)	Path Loss (dB) Concrete Wall (One Wall)
10	60.0248	72.0248
20	66.0454	78.0454
30	69.5672	81.5672
40	72.0660	84.0660
50	74.0042	86.0042
60	75.5878	87.5878
70	76.9268	88.9268
80	78.0866	90.0866
90	79.1097	91.1097
100	80.0248	92.0248

III. EXPERIMENTAL SET UP

The measurements are done using one access point and which is IEEE 802.11b compliant and operates on 2.4 GHz (Wi-Fi signal frequency). It also provides a transmit power of 17dBm and a bandwidth of 11 Mbps. The signal measurements were done using a laptop computer with 'inSSIDer'' which is a software tool that allows one to identify and measure the signal strength of WLANs. Using this software the measurements were taken. The signal strength was measured at 10m distance interval from access points first with line of sight and then with concrete wall obstruction having a thickness of 30cm,relative permittivity 4.6 and conductivity 0.05s/m. At each interval signal measurements were taken and recorded. Measuring tape was use for distance measurement. Table 3 shows the values of signal strength in dBm and corresponding path loss as calculated using equation (3) below.

$$\frac{P1}{P2} \equiv 10log_{10}\left(\frac{P1}{P2}\right) \text{dB} = 10log_{10}\left(\frac{P1}{1mw}\right) - 10log_{10}\left(\frac{P1}{1mw}\right)$$
$$= P1|dBm - P2|dBm \qquad (3)$$

Table 3: Measured Power and Corresponding Path Loss

Distance (m)	Transmit Power(dBm)	Measured Power(dBm) Free Space	Measured Power (dBm) with Wall Obstruction	Path Loss Free Space (dB)	Path Loss with Wall (dB)
10	17	-44	-56	61	73
20	17	-50	-62	67	79
30	17	-54	-65	71	82
40	17	-56	-68	73	85
50	17	-58	-70	75	87
60	17	-59	-72	76	89
70	17	-61	-73	78	90
80	17	-62	-74	79	91
90	17	-63	-75	80	92
100	17	-64	-76	81	93

Table 4: Theoretical and Empirical Path Losses in Free Space and Obstructed Medium

Distance (m)	Measured Path Loss (dB) Free Space	Measured Path Loss (dB) with Wall	Predicted Path Loss (dB) Free Space	Predicted Path Loss (dB) with Wall
10	61	73	60.0248	72.0248
20	67	79	66.0454	78.0454
30	71	82	69.5672	81.5672
40	73	85	72.0660	84.0660
50	75	87	74.0042	86.0042
60	76	89	75.5878	87.5878
70	78	90	76.9268	88.9268
80	79	91	78.0866	90.0866
90	80	92	79.1097	91.1097
100	81	93	80.0248	92.0248

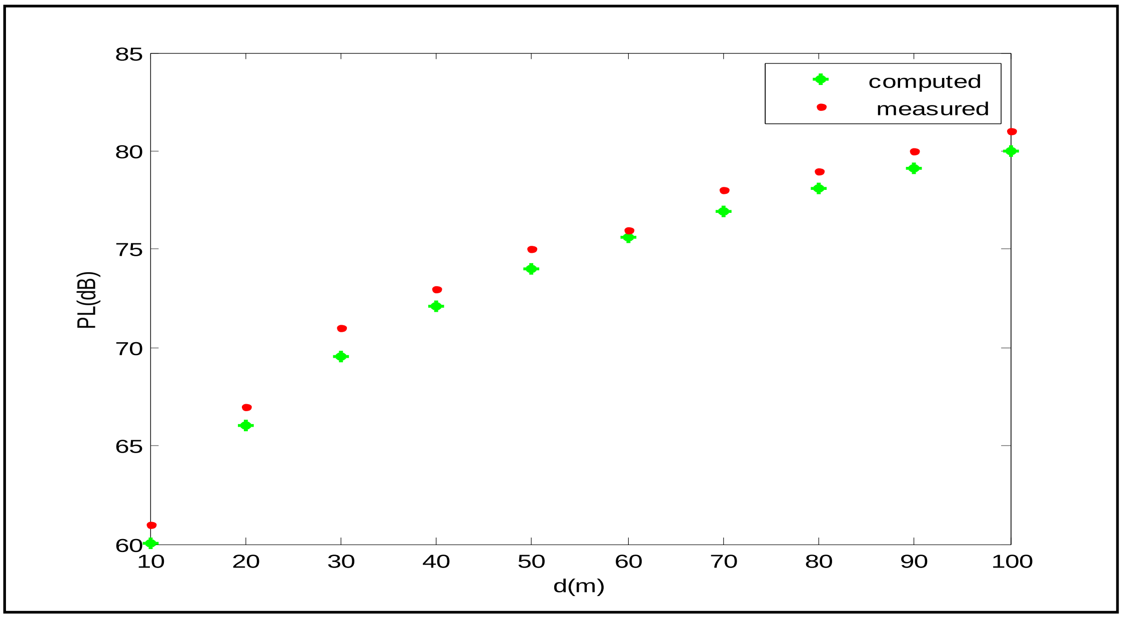

Figure 1: Theoretical Wiener II Model and Empirical Path Loss in Free Space

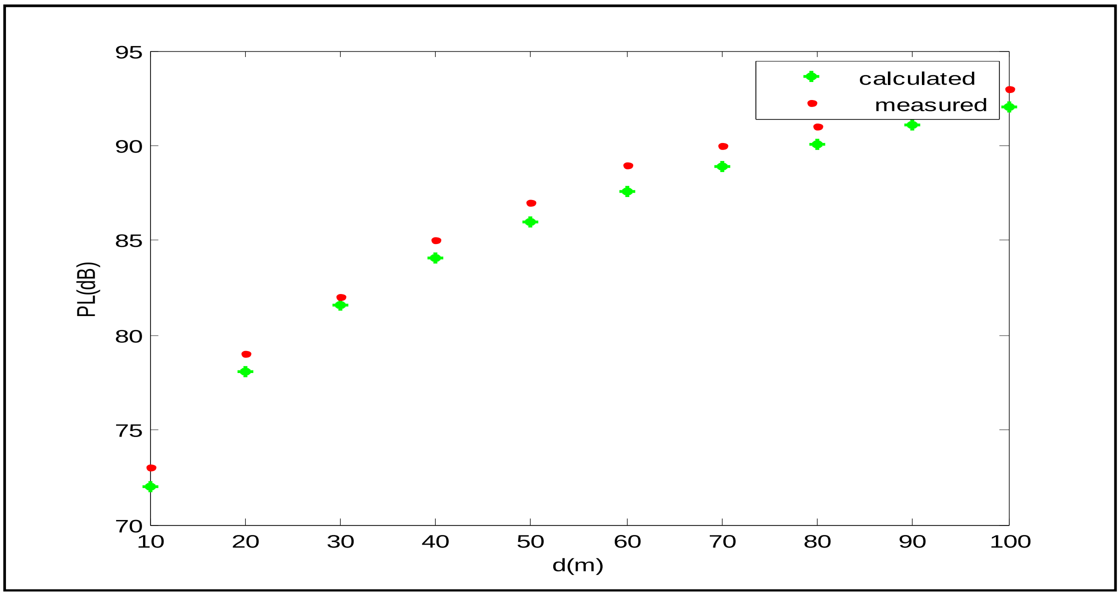

Figure 2: Theoretical Wiener II Model Path Loss and Empirical Path Loss in the Presence of Wall

The result showed that there is averagely 2dB difference between the measured and calculated path loss in free space and about 13dB in the presence of obstructed medium (concrete wall). The path loss model parameters were tuned based on the measured results and this yields an improved model shown in equation 3 and 4 below

$$PL = 20\log_{10}(d[m] + 46.4 + 16\log_{10}(\frac{fc[GHz]}{5.0}) + X \qquad (4)$$

$$PL = 20\log_{10}(d) + 46.4 + 16\log_{10}(\frac{fc}{5.0}) \qquad (5)$$

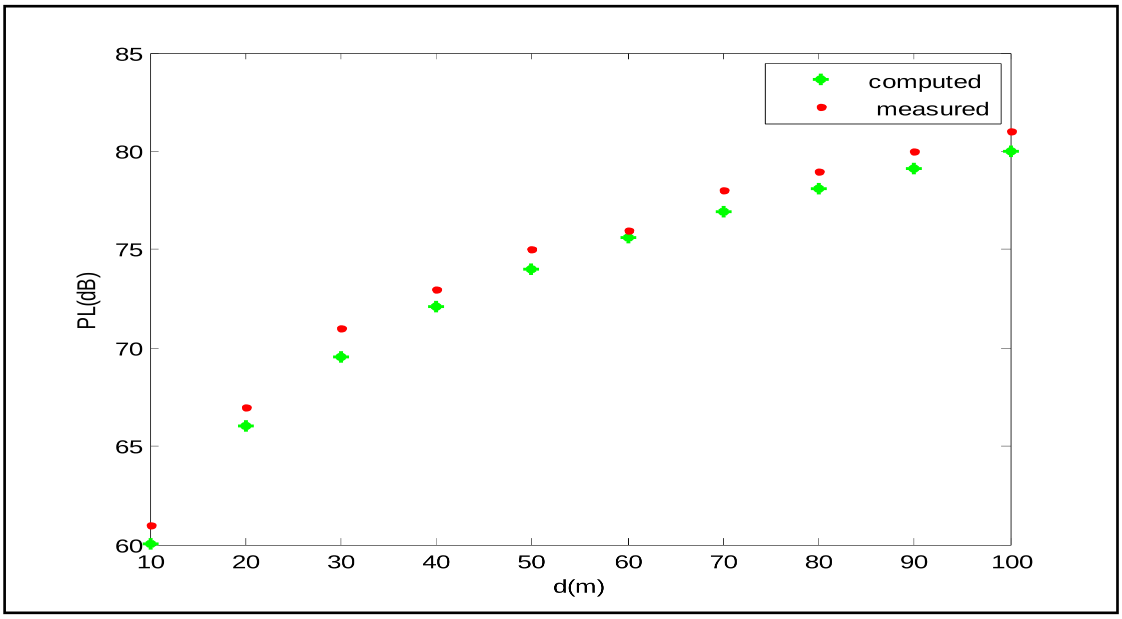

Figure 3: Theoretical Modified Wiener II Model path loss and Empirical Path Loss in Free Space

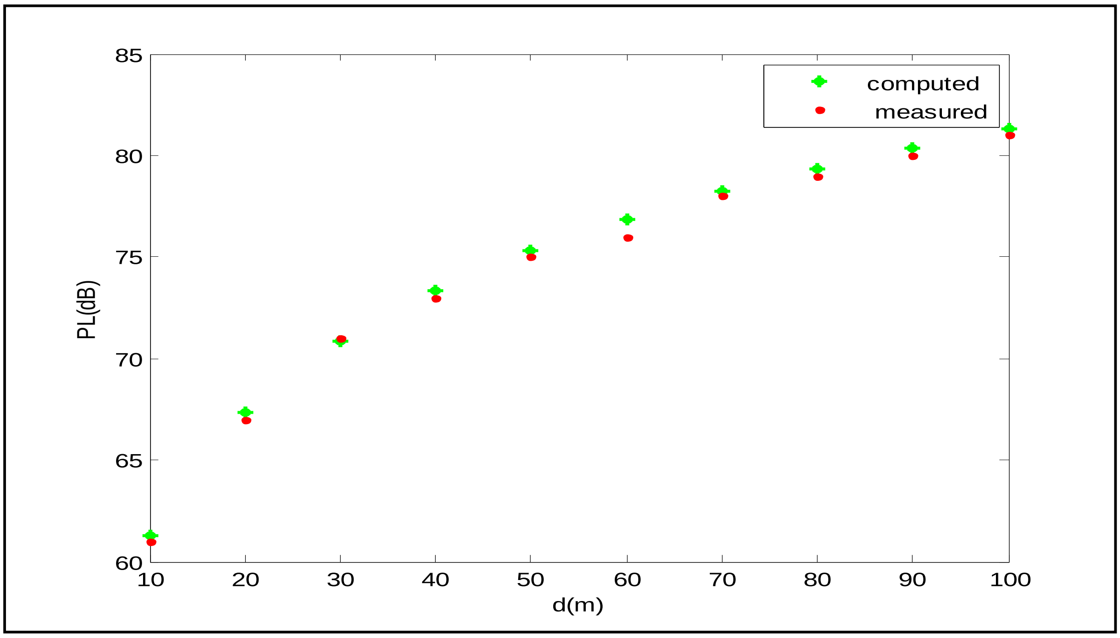

Figure 4: Theoretical Modified Wiener II Model Path Loss and Empirical Path Loss in the Presence of Wall

IV. RESULT DISCUSSION

The result of the research is discussed by comparing the graph of the empirical and theoretical data obtained. Figure 1 is a graph of result that compares theoretical and Empirical result in free space which shows approximately 2dB difference between the two. Similarly figure 2compare both the result of data obtained from the theoretical Wiener II model and empirical which also proves the result obtained in figure 1 hence the model cannot accurately predict the path loss of the signal passing through the concrete wall. The path loss model parameters were tuned based on the measured result and this yields an improved model with averagely 0.32dB difference between the measured and modified model in free space and 0.39dB in the presence of wall. Theoretical modified Weiner II model proves this by showing a better agreement with measured result as shown in figure 3 and 4respectively.

V. CONCLUSION

This paper present 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 is used as the path loss prediction model and compared with the empirical result. The results obtained from theoretical model shows 2dB deference from the empirical measurements in free space and 13dB in the presence of obstructed medium (concrete wall). The paper proposed a modified Wiener II model which minimized thedeviation of the measured and empirical results to 0.32 and 0.39dB respectively.

This work could 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.

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