

PATH LOSS EXTRACTION OF 2.4GHZ WLAN RADIO WAVES IN VARIOUS MULTI-FLOOR BUILDINGS ACCORDING TO SEIDEL'S MODEL

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ABSTRACT

The 2.4GHz WLAN radio wave received signal strength is proportional to log distance of the transmitter and receiver. The signal strength is characterised using well-known Seidel's path loss model. The characterisation is made by extracting the path loss exponent, floor attenuation factor, and standard deviation of the signal. This paper presents characterisation of the WLAN signal in different types and heights of multi-floor buildings which is important for indoor localisation application. The model shows good agreement with the measured signal strength in all tested buildings. The results of path loss exponent of 1.8 to 3.6 reflect the richness of the multipath environment within the buildings. The floor attenuation factor decreases according to the open-space between floor structures. The low value of standard deviation between 4.6 to 6.6 shows good fit of the model to the measured signal.

Keywords: Wireless Local Area Network (WLAN); propagation model; path loss; multi floor propagation; received signal strength (RSS);

INTRODUCTION

Wireless Local Area Network (WLAN) which widely deployed in indoor environments has previously been used as networking tools but nowadays could be also used as localisation tool. The localisation system could be developed by applying the uniqueness of propagating WLAN signal pattern at different locations in a floor of a building. Additionally in multi-floor building, the signal is also different as the WLAN radio waves travels across the different floors. Therefore it is important to characterise the signal by appropriate propagation model so that the network-connected area could be properly designed for various communication benefits including indoor localization system.

The characterisation of radio wave was done for mainly for single floor building [1], [2] and limited study found for multi-floor case. The study of multi-floor wave propagation at 914MHz in multi-floor environment was made in [3]. The characterization of 2.4

GHz WLAN radio wave in multi-floor building was studied in [4], [5]. The work in [4] considers different path loss models to characterise the measured WLAN signals. In [5], the path loss parameters roughly extracted from path loss model considering averaged signal measurements of all transmitters in a building. The work of this paper is close to [6] which characterised the 2.4GHz WLAN radio wave in multi-floor buildings. However, the analysis has not been extended to consider different structures of multi-floor buildings. Additionally in previous studies, the measurement has been done using customised receiver which could hardly been applied for indoor localisation application.

This paper contribution is twofold. First, the propagation of WLAN radio wave is characterized for multiple multi-floor buildings of different structures. Second, the receiver used in the signal measurement is based on the smart phone flexible printed circuit board antenna which is reliable for indoor localization system.

INDOOR WAVE PROPAGATION MODELS

The signal strength values at multiple measurement locations could be validated using log-distance path loss model. The validation could be done by extracting the path loss parameters of the path loss model and apply the extracted parameters to the model. According to the path loss model in [3], the measured signal strength values at each signal measurement location or referred as fingerprint location should follow the log-distance signal rule. The model employs the signal at reference location from the transmitter and the related signal strength at varying separation distance of the transmitter and measurement or receiver locations. At different separation distance of transmitter and the measurement location, the measured signal should change according logarithmic values. For single-floor case, the most common path loss model [7] is based on the following equation:

$$P_r(d)[\text{dBm}] = P_r(d_0)[\text{dBm}] - 10\eta \log\left(\frac{d}{d_0}\right) + \chi_\sigma \quad (1)$$

where $P_r(d)$ is the measured signal value at the receiver or received signal strength (RSS) value observed at respected fingerprint location which is distance of the location from the transmitter or in this work refers to access point (AP) is d , $P_r(d_0)$ is the RSS value at a reference distance d_0 from the AP (usually chosen as 1 m), η is the path loss exponent, and χ_σ is the Normal random variable having standard deviation of σ . The path loss model is developed using linear regression where the term η and σ could be computed as suggested in [7]. For multi-floor case, the Equation 1 is used together with another path loss model to describe the measured signal at different floor level. The measured RSS at different floor is described as follows [3]:

$$P_r(d)[\text{dBm}] = P_r(d_0)[\text{dBm}] - 10\eta_{SF} \log\left(\frac{d}{d_0}\right) + FAF[\text{dBm}] \quad (2)$$

where η_{SF} is the path loss exponent computed based on the same floor measurement of the transmitter signal, and FAF is the floor attenuation factor which describes the attenuation of the signal travelling across floor. For example if the transmitter is located

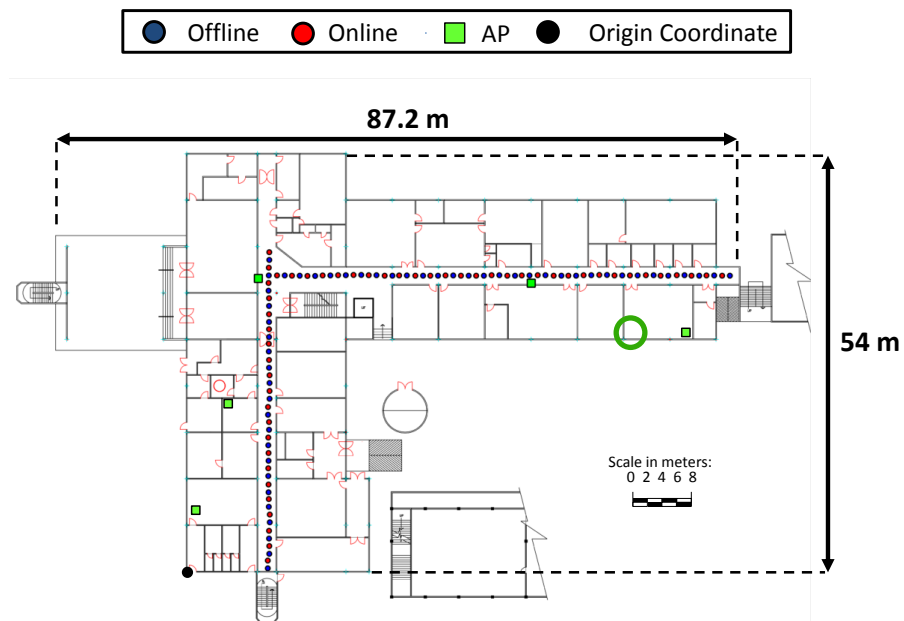
at Floor 3 of the building, the measured RSS at different fingerprint locations is verified using Equation 1. Additionally, to verify the signal from the same AP which is measured on Floor 2, Equation 2 is used.

The path loss parameters are obtained empirically by applying linear regression of signal strengths at each fingerprint on the log of separation distance between the AP and the fingerprints. According to [3], the gradient (m) and intercept (c) of the line ($y = mx + c$) correspond to path loss exponent, η , and RSS value at reference location d_0 for the same-floor locations of AP and the fingerprint measurements. The RSS value at reference location $d_0 = 1$ (meter) is measured by the device.

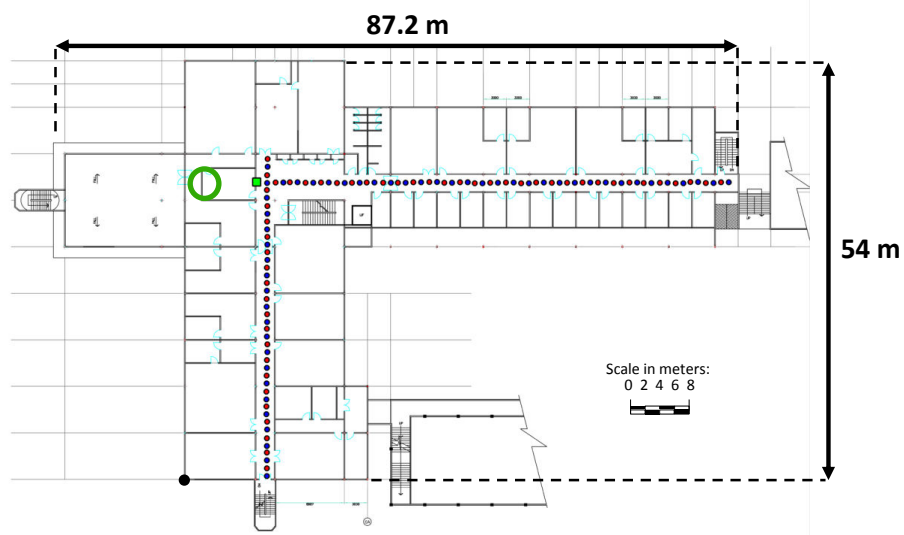
EXPERIMENTAL

The measurement of the WLAN fingerprint signal data is done using a Google Nexus 5 smartphone with Airplace Logger [8] Android signal strength measurement application which act as the receiver. The receiving antenna type within the phone is the embedded flexible printed circuit board. The WLAN AP installed within the building used as the transmitter. During the signal recording, the phone is held in on a tripod where the height of the phone is about 1 m from the ground. The recorded signal data is processed using MATLAB computation software.

The measurement is done in three buildings of different scenario. The buildings are located within Universiti Putra Malaysia (UPM) campus in Selangor, Malaysia. Building A, B, and C are an academic building, a laboratories and office tower building, and a student's residential building respectively. Each building comprises different number of floor levels i.e. Building A has 5 floors, Building B has 11 floors, and Building C has 8 floors, and also has different floor plan dimensions. The vertical height of each floor level of all buildings is 3 m. The measurement is made at allocated location within the building which is called as fingerprint locations. The RSS measurement is recorded from three randomly chosen APs in each of the buildings. The fingerprint locations on the floor plan of the three buildings with related AP locations are shown in the Figure 1 to 3 respectively.



(a)



(b)

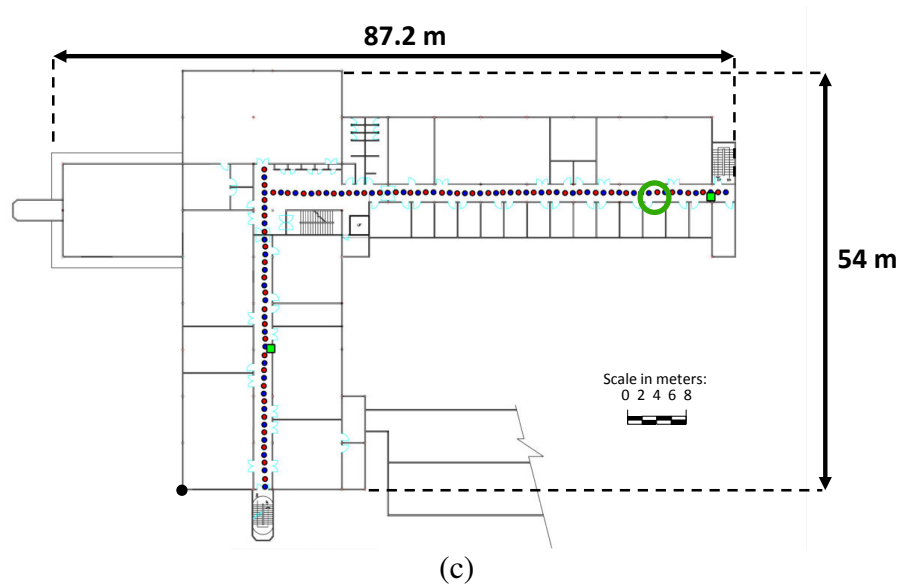


Figure 1: Location of related AP (green circle) and the signal measurement location (Offline) on (a) Floor 1, (b) Floor 3, and (c) Floor 4 of Building A

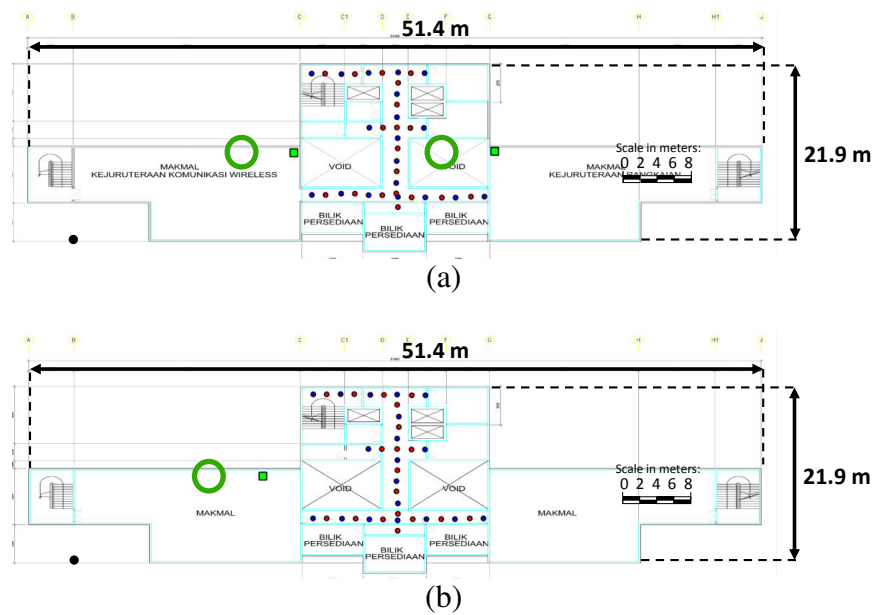
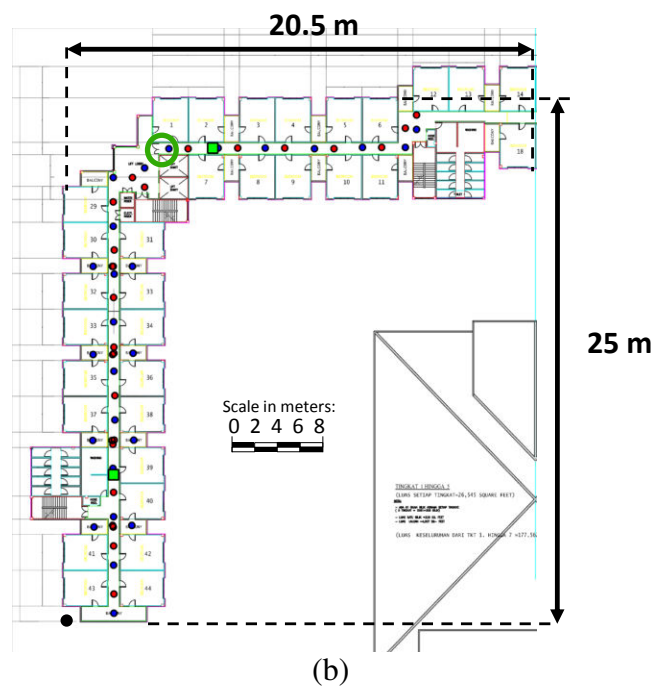
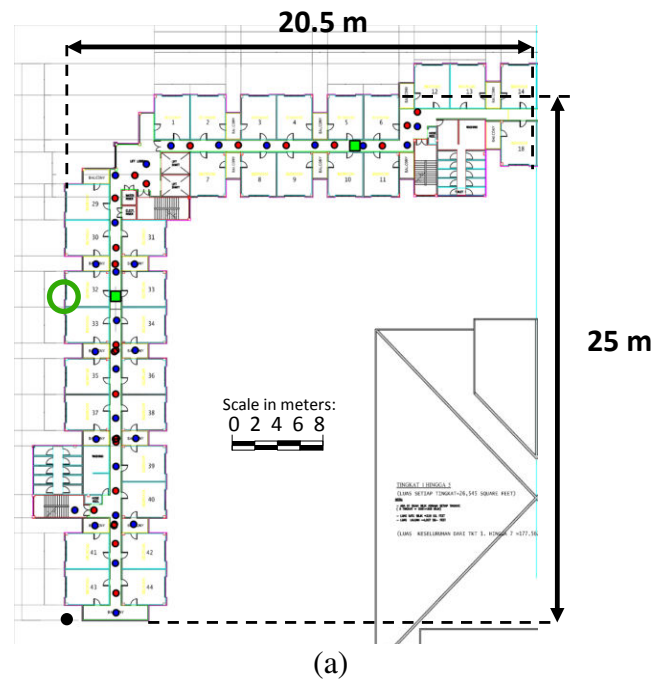


Figure 2: Location of related AP (green circle) and the signal measurement location (Offline) on (a) Floor 3, and (b) Floor 4 of Building B



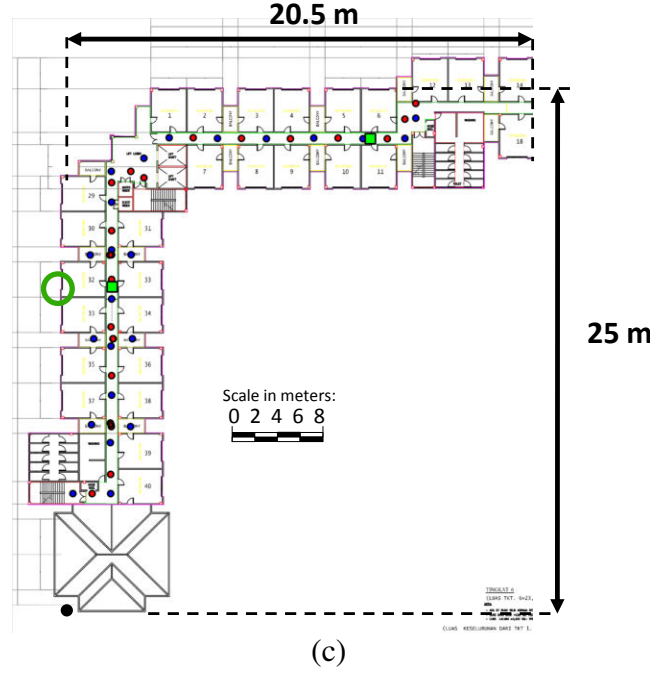


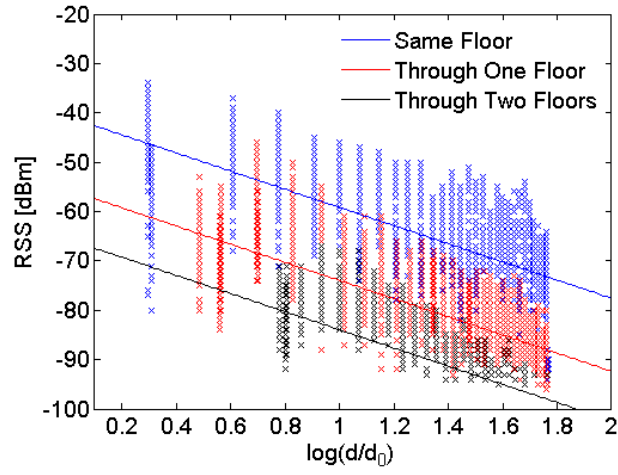
Figure 3: Location of related AP (green circle) and the signal measurement location (Offline) on (a) Floor 5, (b) Floor 6, and (c) Floor 7 of Building C

RESULTS AND DISCUSSION

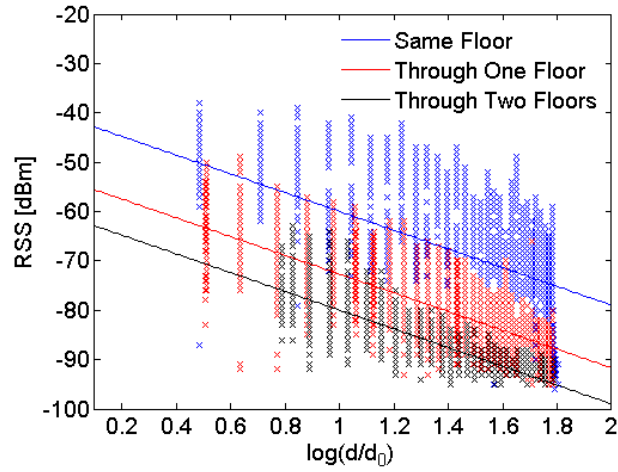
Table 1 in column 5 and 6 lists the values of η , and σ obtained from the regression line according to measured RSS values (blue cross markers) at different fingerprint locations of three chosen APs as shown in Figure 1 to 3. It can be seen that the signal strength at d_0 is around -40 dBm for all buildings. The values of η is within the expected values which is identical to previously reported values for indoor locations. The η and σ values in Building A is around 1.8 to 1.9 and 5.7 to 6.0 respectively which are comparable to 1.57 and 4.02 reported in [9] of which the measurement is also made in a closed corridor. The values obtained in this work are slightly higher because the signals found fingerprint locations in corridor on the east side are non-line of sight (NLOS) to the APs. The values of η in Building B and C are marginally larger because the NLOS fingerprint locations increases compared to Building A. The empirical values of η , and standard deviation, σ , from the linear regression are used as the parameters of path loss models (Equation 1). Substituting η and σ into Equation 1 will give the path loss model (blue line) as plotted in Figure 4 to 6 for APs in Building A, B, and C respectively. The models shows good fit with the measured RSS values in tested environments.

Table 1: Path loss model parameters for chosen APs in Building A, B, and C

Bldg.	AP Location	Floor Level	RSS at Reference Location, (d0 = 1) (Averaged)	Path loss Exponent, η	Standard Deviation, σ	One Floor FAF [dBm]	One Floor Standard Deviation, σ	Two Floors FAF [dBm]	Two Floors Standard Deviation, σ
A	(71.3,37.7)	1	-41.0	1.9	5.8	12.7	4.2	20.0	3.6
	(9.4,36.9)	3	-40.8	1.8	6.0	14.8	4.1	24.8	3.3
	(68.4,37.7)	4	-40.4	1.9	5.7	13.7	3.8	22.5	3.3
B	(16.5,5.1)	3	-40.5	3.2	4.6	5.2	4.5	8.7	3.6
	(28.3,5.2)	3	-40.3	3.6	4.9	2.5	4.6	5.7	3.6
	(14.6,5.1)	4	-40.1	2.5	4.8	9.2	3.9	14.9	3.7
C	(5.3,13.6)	5	-40.0	2.6	5.3	6.8	4.8	12.8	3.5
	(12.6,23.1)	6	-39.8	3.5	5.5	3.6	4.9	8.3	4.8
	(5.9,18.7)	7	-41.7	2.4	6.6	12.4	5.4	16.0	3.4



(a)



(b)

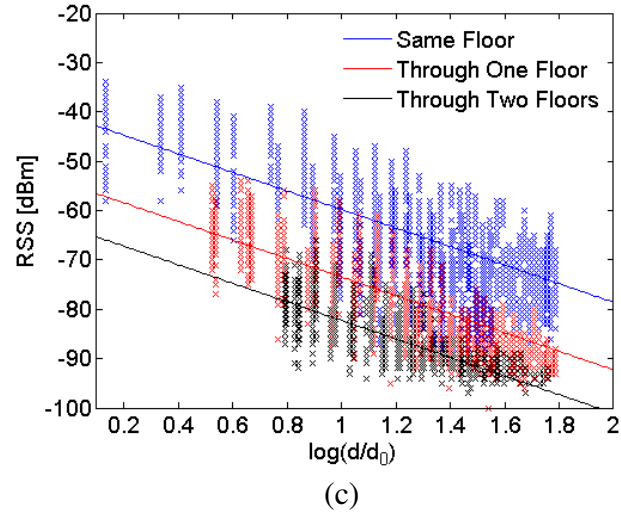
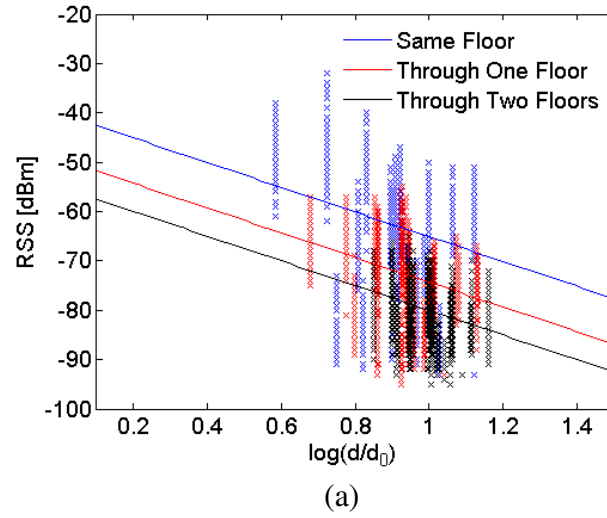
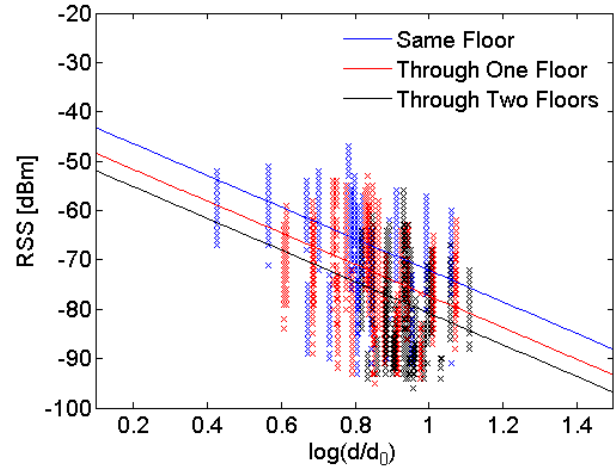
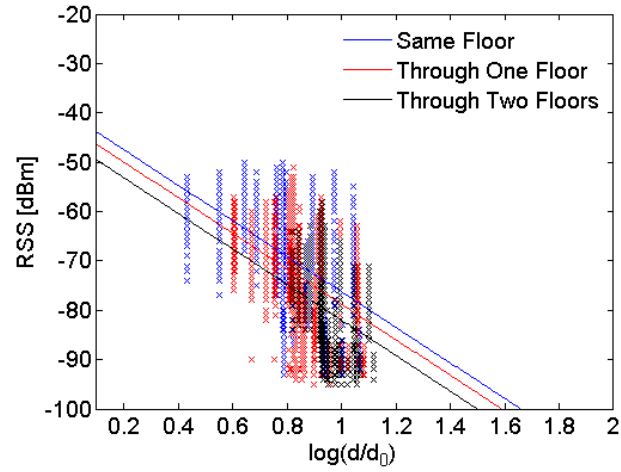


Figure 4: Path loss model of APs in Building A where (a) is the AP at Location (71.3, 37.7) in Floor 1, (b) is the AP at Location (9.4, 36.9) in Floor 3, and (c) is the AP at Location (68.4, 37.7) in Floor 4



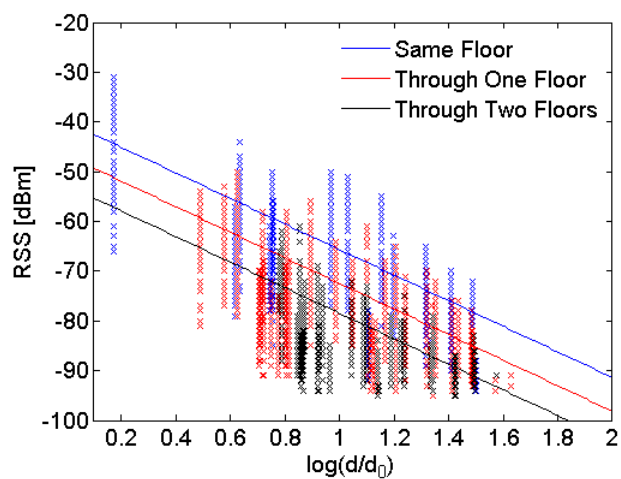


(b)

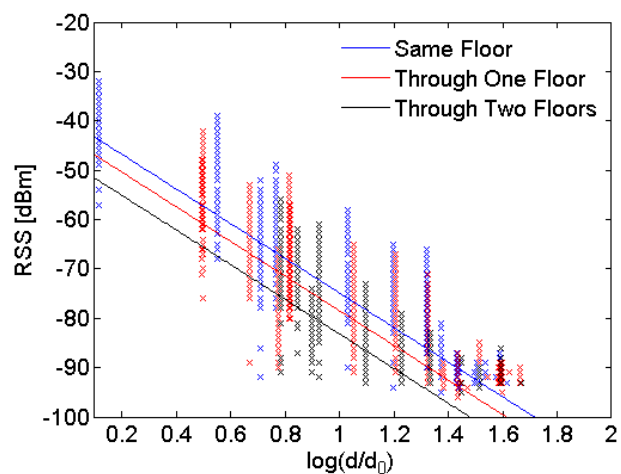


(c)

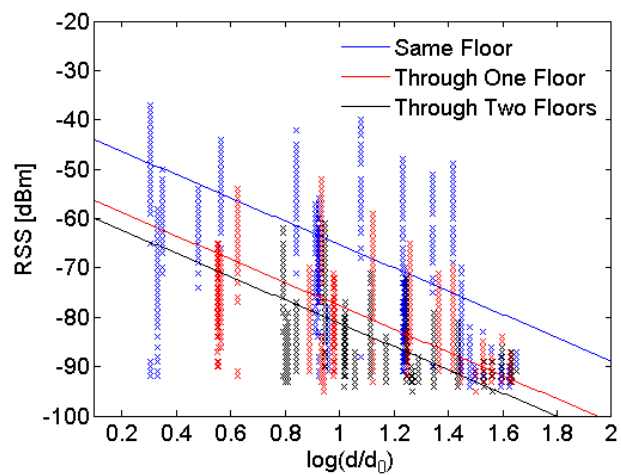
Figure 5: Path loss model of APs in Building B where (a) is the AP at Location (16.5, 5.1) in Floor 3, (b) is the AP at Location (28.3, 5.2) in Floor 3, and (c) is the AP at Location (14.6, 5.1) in Floor 4



(a)



(b)



(c)

Figure 6: Path loss model of APs in Building C where (a) is the AP at Location (5.3, 13.6) in Floor 5, (b) is the AP at Location (32.6, 47.1) in Floor 6, and (c) is the AP at Location (5.9, 18.7) in Floor 7

For multi-floor signal propagation, floor attenuation factor (FAF) is calculated. According to [3], the FAF is computed based on the average of the difference between predicted RSS by path loss model (blue line) plotted in Figure 4 to 6 and the mean measured RSS value on the multi-floor locations. The value of calculated FAF is tabulated in column 7 and 9 of Table 1 for one and two floor difference respectively. The trends of FAF on increasing floor for all buildings are similar where the higher the floor the higher the FAF as mentioned in [3]. The results of FAF for Building A are almost similar as reported in [3] for Office Building 2 environment i.e. the value of FAF though one and two floors of Building A between 13.7 to 14.8 and 20.0 and 24.8, are close to 16.2 and 27.5 of Office Building 2. The value of FAF depends on structures within the building which affect the attenuation of the signal. The FAF values in Building A increase higher compared to Building B and C because the environment is closed-space compared to the other two buildings which the floor structures are partly open e.g. Building B has hollows between floors and ceilings and Building C has hollows between walls. The multi-floor path loss model as defined in Equation 2 is plotted in Figure 4 to 6 for though one floor (red line) and two floors (blue line) path loss. The model shows good agreement with the measured RSS value of the fingerprints.

The plotted single-floor and multi-floor path loss model show that RSS value of a specific AP changes at different fingerprint locations according to propagation rule. This means a fingerprint location could be uniquely characterised by RSS value of AP.

CONCLUSION

The 2.4GHz WLAN radio wave proportionally propagates according to log distance separation of the transmitter and the receiver in various multi-floor environments which follows Seidel's model. The path loss exponent increases when there are increment of measurement signal in NLOS locations. The FAF also accordingly increases as the floor increases. The value of FAF decreases if open-space between floors of the building increases. The low value of standard deviation shows the good fit of the model with measured signals. The variation of signal strength across location and floor are feasible for indoor localisation application.

REFERENCES

- [1]. C. Oestges, D. Vanhoenacker-janvier, and B. Clerckx, *IEEE Trans. Antennas Propag.*, **54** (11) 3143–3150 (2006)
- [2]. F. S. De Adana, *IEEE Trans. Veh. Technol.*, **49** (6) 2105–2112 (2000)
- [3]. S. Y. Seidel and T. S. Rappaport, *IEEE Trans. Antennas Propag.*, **40** (2) 207–

- 217 (1992)
- [4]. B. R. Jadhavar and T. R. Sontakke, *Int. J. Soft Comput. Eng.*, (3) 108–113 (2012)
 - [5]. E. S. Lohan, J. Talvitie, P. Figueiredo e Silva, H. Nurminen, S. Ali-Loytty, and R. Piche, “Received signal strength models for WLAN and BLE-based indoor positioning in multi-floor buildings,” in *2015 International Conference on Location and GNSS (ICL-GNSS)*, 2015, 1–6.
 - [6]. J. Zhang, L. Xin, and F. Zhang, *Phys. Commun.*, **9** 246–256 (2013)
 - [7]. T. S. Rappaport, *Wireless communications: principles and practice*, Vol. 2. Prentice Hall PTR New Jersey, 1996.
 - [8]. C. Laoudias, G. Constantinou, M. Constantinides, S. Nicolaou, D. Zeinalipour-Yazti, and C. G. Panayiotou, “Demo: the airplace indoor positioning platform,” *Proc. 10th Int. Conf. Mob. Syst. Appl. Serv. - MobiSys '12*, p. 467, 2012.
 - [9]. R. G. Akl, D. Tummala, and X. Li, “Indoor propagation modeling at 2.4 GHz for IEEE 802.11 networks,” in *The Sixth IASTED International Multi-Conference on Wireless and Optical Communications*, 2006.