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Propagation Model for Dog-leg Staircase at 700 MHz

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Abstract: **Multi floor staircase provides a crucial vertical route during emergency events in a high rise structure. Wireless communication along the staircase is important for public safety personnel to allow them responding consistent and relay important information or data. An understanding of signal wave attenuation along the staircase is necessary to allow better wireless network planning, especially in ad hoc cases. This paper presents empirical propagation model developed for path loss prediction along dog-leg staircase. The proposed model is based on measurement at 700 MHz in 2 measurement sites. The propagation model developed shows agreeable result when validated to an actual measurement in a different staircase. The variation of staircases layout, dimensions plus their surrounding environments demonstrate the robustness of the propagation model presented.**

Keywords: **Propagation model, public safety, 700 MHz.**

I. INTRODUCTION

The public safety communication service is improving its communication network, especially in emergency situation with the introduction of incident area network (IAN) to enhance the robustness of its wireless communication link. The projected scenarios that require such deployment include indoor-to-indoor communication [1]. Considering these developments in mind, studies of interference issues that may arise between these indoor relay stations [2] are needed as deployment of aforementioned networks may be carried out in an unplanned manner. The staircase plays an essential function to allow people move about different floors in high rise buildings. It is in fact the safest route to be used in emergency situation for evacuation of building occupants or rescue operation by public safety personnel. Knowledge of how wave propagates along the staircase could act as the basis in providing seamless connectivity to public safety personnel in the given environment. The staircase's structure differs from typical indoor environments and must be treated exclusively when studying wave propagation within it [3]. This paper presents empirical wave propagation study at 700 MHz inside staircases of 2 different buildings. The operating frequency is near to dedicated public safety service communication bands [4]. The path loss and shadowing model are presented in this paper.

II. MEASUREMENT FRAMEWORK AND PROCEDURE

In this study, indoor staircase from 2 different buildings inside Universiti Teknologi Malaysia campus, have been investigated. The 2 staircase will be referred as Staircase 1 and Staircase 2. Figure 1 (a) illustrates the side cross sectional view and layout of Staircase 1 and Staircase 2. The staircases are of dog-leg type configuration that is the most common type built inside modern buildings [5], [6]. Figure 1 (a) shows the labelled back, left and right wall in this paper for reference. The dimensions as well as the floor height of both staircases are different from one another.

The stair steps, floors and half landings are made of reinforced concrete. Staircase 1 is sandwiched between a laboratory and an office and has a large opening at each floor. The back wall is a full-height aluminium alloy louver, with a horizontal reinforced concrete beam of 1.75 m above each half landing. There is a 0.9 m height metal balustrade or railing at each half landing. Both the left wall and right wall are made of plastered bricks. There is a noticeable half a metre width vertical reinforced concrete beam in the middle of the stair flight at each left and right walls. Staircase 2 resides at the edge of the building and is an enclosed stairwell that has entrance door at each floor. The walls are primarily plastered bricks but selected part of the left, back and right walls have concrete blocks arrangement that allow natural ventilation.

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The back wall also has a horizontal reinforced concrete beam 1.2 m above each half landing. It is worth mentioning that law in many nations forbid the use of combustible materials as components or finishing of staircase to provide safety passage in case of fire [7], [8].

The *Tx* was positioned on the first (ground) floor, while the *Rx* was moved along the stairwell from the first floor and reaching to the fourth floor as in Fig. 1 (c). Measurement wise, 6 stair sections denoted by S_1, until S_6 and 3 half landings were within the transmitter-to-receiver separation distance. The measurement setup consists of transmitter, *Tx*, and receiver, *Rx*, operating at 700 MHz. Larsen SPDA24700/2700 dipole antennas were used at both transmitting and receiving ends. The antennas have a maximum gain of 2 dBi and are vertically polarized. At the *Tx* side, a HP/Agilent 8657B signal generator was used with P_{tx} = 17 dBm. High transmission power was used in order to extend the dynamic measurement range. The signal generator was placed on top of an elevated stand with transmitting antenna's height being 1.25 m above the ground. The receiver end consists of a Rohde & Schwarz FSH6 handheld Spectrum Analyzer placed on a post, connected to a laptop with the FSH6 interface software installed via optic cable. The height of the *Rx*'s antenna is 1.27 m. No cable was used to connect the antennas to both the *Tx* and *Rx* setups in order to avert cable losses. At each measurement point, *Rx* was rotated 360° while recording 50 different readings which were averaged to suppress small-scale fading.

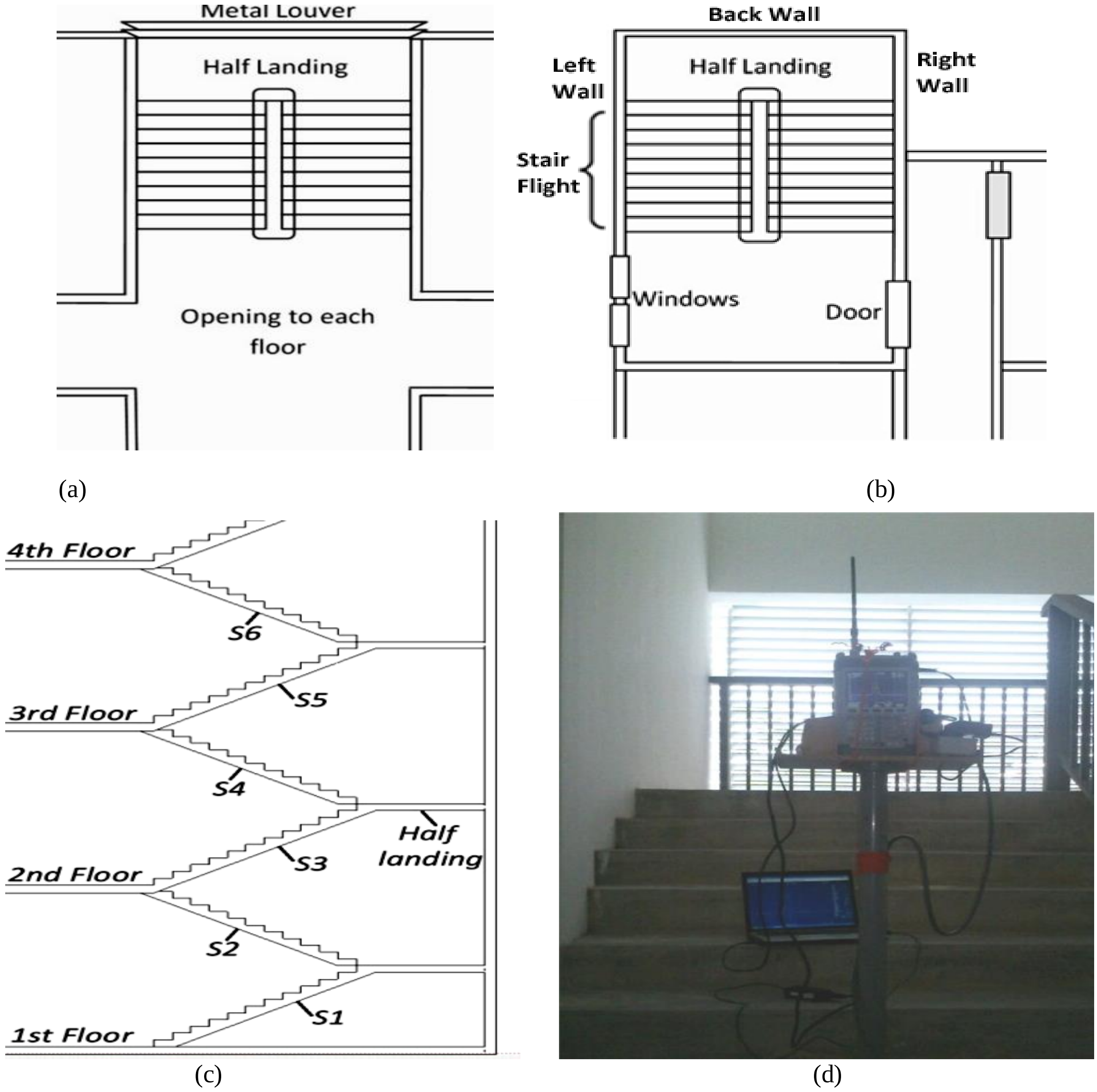

Fig. 1 (a) Layout of Staircase 1 (b) Layout of Staircase 2 (c) Cross-sectional view of investigated dog-leg staircase (d) Receiver-end setup at Staircase 1

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III. MEASUREMENT RESULTS AND PROPAGATION MODEL DEVELOPMENT

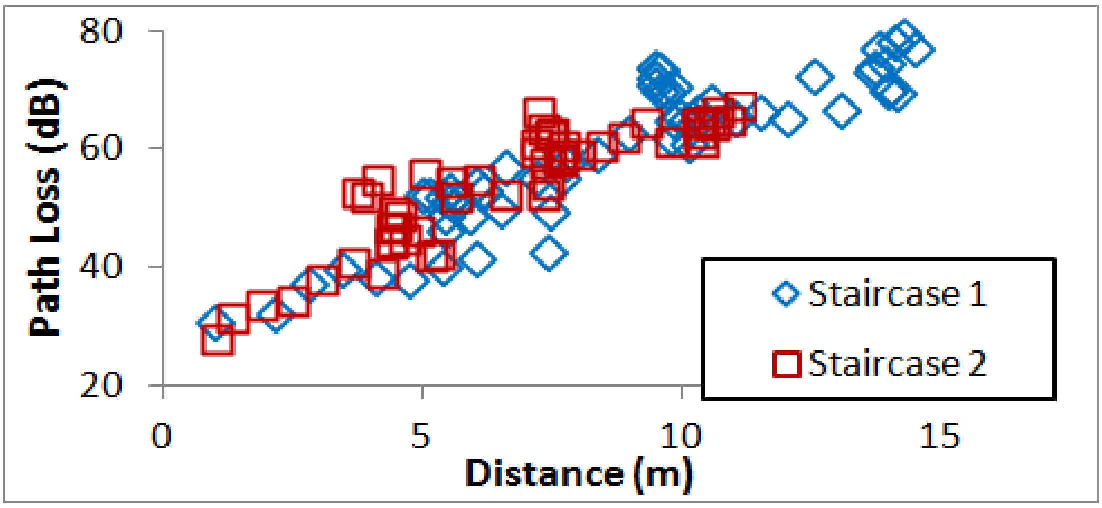
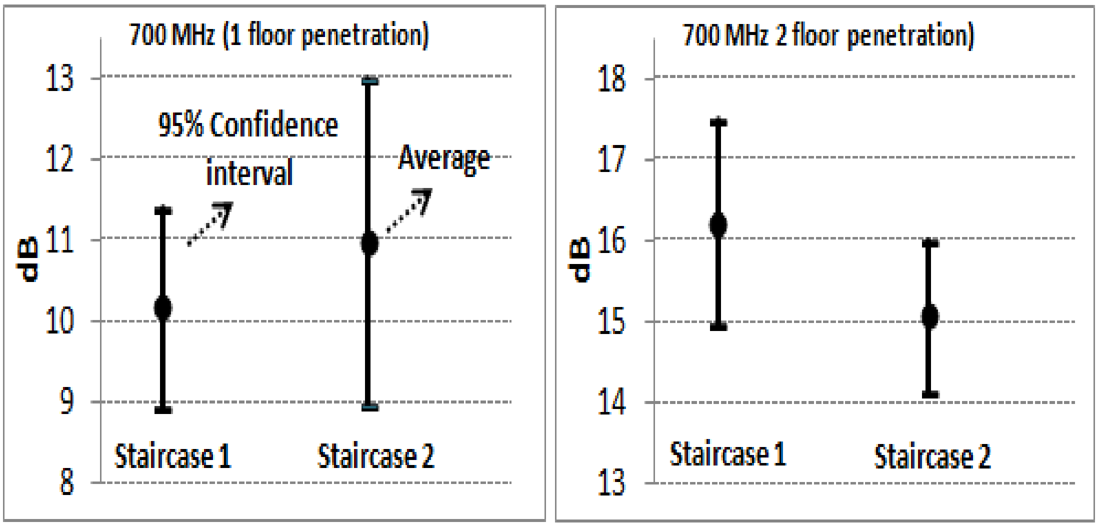


Fig. 2 Plotted path loss for at 700 MHz for Staircase 1 and Staircase 2

Fig. 2 shows the path loss plots for both investigated staircases. It can be clearly seen that even though measurement was conducted covering from the first floor and reaching up to the fourth floor in both measurement sites, the maximum distance in metre is different due to the difference in dimensions and floor height. Nevertheless, both plots of path losses show very similar path loss-to-distance relation despite the differences previously stated and diverse staircase's layout. To develop the empirical propagation model, the standard path loss model as in equation (1) is used as the basis for the model. In equation (1), *PL* is the path loss for a specific distance, *d*, in metre. *PL(d0)* is the path loss at reference distance, *d0*, which is at 1 metre, and *n* is the path loss exponent that shows the degree of signal wave attenuation for a specific environment. The *n* value is obtained through regression analysis of plotted PL on a log-scale graph [9]. *PL(d0)* and $n_{first\ floor}$ are presented in Table 1.

$$PL(d) = PL(d_0) + 10n_{first\ floor}Log_{10}(d)\ dB \qquad (1)$$

To predict *PL* at different floor, the floor penetration factor, *FPF*, need to be added to (1). Based on equation (1), predicted *PL* is first computed for the second and third floors. The differences between computed and actual measured *PL* at each floor is then obtained. Fig. 3 shows the average and the 95 % confidence interval for differences between the computed and measured *PL* at Staircase 1 and Staircase 2.



(a) (b)

Fig. 3 Floor Penetration Factor: (a) 1–floor penetration (b) 2–floor penetration

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It is observed that the average between both staircases is very close and the range of the 95 % confidence interval overlaps one another. As such, it can be said that both staircases depict consistent penetration characteristics. The average value of differences between computed and measured *PL* for the 2 staircases are then averaged to give value for *FPF*. In the same manner, the value of *PL(d0)* and $n_{first\ floor}$ were also averaged given that the values have only small variation. The approximated values proposed for FPF, PL(d0) and nfirst floor are presented in Table 1.

TABLE I: PATH LOSS (1 METRE), PL_{D0}, AND PATH LOSS EXPONENT, *n*

Site	Path loss at 1m, PL_{d0} (dB)		Path loss exponent, $n_{first\ floor}$		1-floor penetration factor, $FPF_{1\text{-floor}}$ (dB)		2-floor penetration factor, $FPF_{2\text{-floor}}$ (dB)	
	Meas.	Avg.	Meas.	Avg.	Meas.	Avg.	Meas.	Avg.
Staircase 1	30.71	29.2	2.61	2.66	10.17	10.58	16.22	15.65
Staircase 2	27.69		2.70		10.98		15.08	

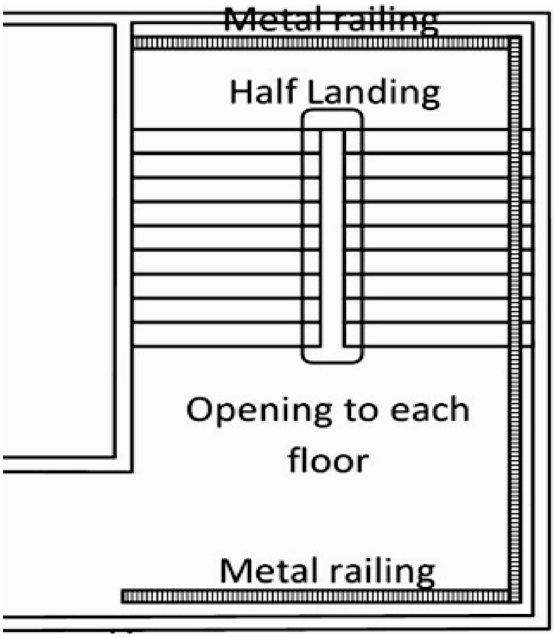
Based on the findings via measurement and the analysis of *FPF* earlier, the proposed empirical propagation model for the staircase environment at 700 MHz is given as the following equation.

$$PL(d) = 29.2 + 26.6Log_{10}(d) + FPF\ dB \quad (2)$$

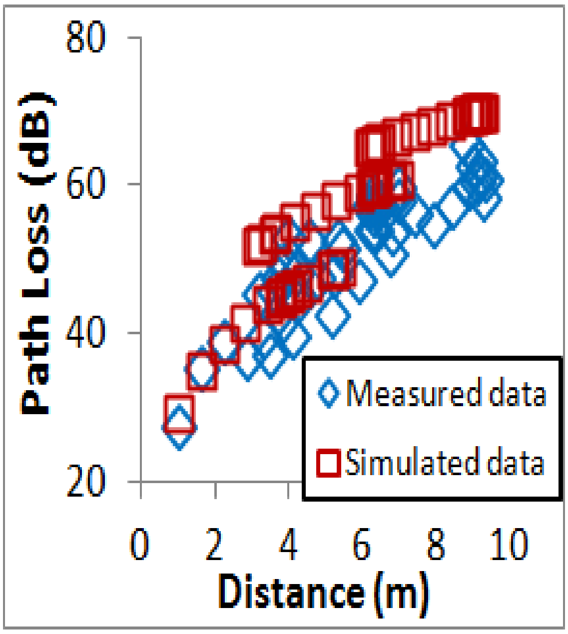
$$FPF = \begin{cases} 10.58\ dB\ for\ 1\ floor\ penetration \\ 15.65\ dB\ for\ 2\ floor\ penetration \end{cases}$$

IV. VALIDATION OF PATH LOSS MODEL

To observe the precision of the model, the model is tested against actual measurement at another staircase, which will be referred as staircase 3 in this paper. The layout of staircase 3 is illustrated in Fig. 4 (a). Staircase 3 is an open staircase that resides at the side of the building. The left wall is a plastered brick wall while all the other sides are open with metal railing. It is worth noting also that the floor height of staircase 1 and 2 are 4.5 m and 3.5 m. On the other hand, the floor height of staircase 3 is 2.9 m, which is smaller relative to staircase 1 and 2. Floor penetration factor)



(a)



(b)

Fig. 4 a) Layout of Staircase 3 (b) Comparison of measured and predicted path loss

Fig. 4 (b) shows that the staircase empirical propagation model developed predicts *PL* at staircase 3 with standard deviation of 4.94 dB. Given that the layout and dimensions of staircase 3 are considerably different from staircase 1 and staircase 2, the results demonstrate that the empirical propagation model developed and proposed in this paper is quite robust pertaining to different dimensions and staircase's layout.

V. CONCLUSION

This paper presents measured path loss, *PL*, for several staircases at 700 MHz. An empirical propagation model for multi floor building's staircase is proposed based on the measurement campaign conducted. The propagation model incorporates findings of floor penetration factors, *FPF*, up to 2 floors penetration. The proposed model is expected to provide easy planning of ad hoc wireless network along multi floor stairwell. The investigated frequency is also allocated for Long Term Evolution (LTE) air interface, hence, aiding in the design of LTE small cells network for wireless coverage along the stairwell should it be required for public safety purpose. Predicted *PL* from the model may help in forecasting the optimum quantity of signal transmitters, access points or relays when establishing wireless coverage along the required stairwell extent of a high rise building. Since the mathematical expression of the model is straightforward and is developed based on measurement studies, it can directly be applied in propagation simulation tools and serve as comparison to other site-specific type models.

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