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Analysis of Path Loss through the Partitions in Indoor Propagation

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Abstract: The indoor propagation modelling is dependent on the types of building layout designs and construction materials. The multiwall and multifloor (MWF) model operating at 2.4 GHz is applied to analyse the prediction of the received signal strength indicator (RSSI) and path loss values due to the effects of floors and walls. The experiments were measured in four corridors through multiple floors and the consecutive rooms through multiple walls with different positions of transmitter and receiver for multifloored building of Mandalay Technological University. In this research, the proposed MWF model has been evaluated based on the existing MWF model which includes the penetration loss through the brick and glass walls based on the Fresnel Transmission Coefficient (FTC). These coefficients are considered dependent on the different heights of the transmitter and receiver, the distance between the walls, the widths of the room and the types of the walls. According to the comparison of the experimental, theoretical and evaluated results, the differences of the path loss values between the evaluated and theoretical results are at least 2 dB at 5 m, 15 m and at most 7 dB at 10 m, 20 m. Therefore, the path loss values through two floors are more increased than the path loss values in other situations which are same floor and through one floor due to the partitions in multifloored building.

Keywords: Brick and Glass Walls, Indoor Propagation, Multifloored Building, Multiwall and Multifloor Model, Path Loss.

I. INTRODUCTION

Nowadays, a wide variety of radio propagation models for different wireless services with different propagation environments and operating frequency bands has become more and more popular [1]. With the increment of the implementation of indoor wireless communication, there is a great requirement for an accurate prediction model that would enable quick network planning. The complex structure of the buildings, the layout of the rooms, the types of the floors and walls (such as brick, concrete, glass, plasterboard and metal) and also many people are the main factors that control the radio wave propagation in indoor wireless network [2].

In 2009, F. I. Ismail, et. al studied the distance-dependent prediction model and Floor Attenuation Factor (FAF) path loss model [3]. In 2010, C. R. Josiane, and V. Juliana presented the Wall Factor Model (WLL) to analyse the path loss in three situations which are in an empty room without furniture, with furniture and people in the room at 1.8 GHz and 2.4 GHz bands. However, the path loss values due to the floors are not described [4]. In 2014, A. Ala, et. al discussed the one slope model, Motley Keenan model and COST-231 multi-wall model to analyze the effect of the door's state in the indoor environments [5]. In this paper, the researcher surveyed the multiwall and floor (MWF) model to express the effect of the walls and floors in Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) conditions.

The received signal strength indicator (RSSI) and path loss values are analyzed to investigate the radio wave propagation for multifloored building. There are many challenges in MWF model in indoor wireless communication. Among these challenges, the path loss values depend on the positions and the heights of Tx and Rx, the width of the rooms, the types of floors and walls which are glass and brick between Tx and Rx and the layouts of the buildings. In this research, the path loss values through the walls are analyzed based on Fresnel Transmission Coefficient (FTC) and the simulation results of the experiments, theoretical and proposed models are compared to study the difference of these results. The main purpose of the research is to evaluate the path loss values through the different types of walls which are brick and glass by considering the different heights of Tx and Rx and the types of the partitions between Tx and Rx for multifloored building in indoor wireless network.

The remainder of the paper is organized as the following scenarios. Firstly, the radio wave propagation (MWF) model is briefly presented in section II. Then, the indoor propagation model is significantly described in section III. Next, the

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experimental region and experimental procedure are explained in section IV. After that, the simulation results are expressed in section V. Finally, the conclusions are discussed in section VI.

II. MULTIWALL AND MULTIFLOOR MODEL

The different propagation models are studied to analyse the RSSI and path loss values in indoor radio propagation for the different environments. Among the indoor propagation models, the MWF model is chosen to analyze the path loss through multiple walls and floors for multifloored building [6].

The multiwall and multifloor (MWF) model incorporates the path loss due to the number of penetrated walls, including a more complex term which depends on the number of penetrated floors, producing the path loss which increases more slowly as additional floors after the walls are included. The walls and floors that have to be considered are determined by the Obstructed Line-Of-Sight (OLOS) path. The model shows a nonlinear relationship between the traversed walls, floors and the penetration loss [7]. The measurement plans in multiple floors and walls for multifloored building are shown in Fig. 1 (a) and (b).

$$L_{MWF} = L_0 + 10n\log(d) + \sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk} \quad (1)$$

, where L_{MWF} means the path loss due to multiple walls and floors, L_0 is the path loss at a distance of 1 m, n is the power decay index, d means the distance between transmitter and receiver, L_{wik} is the attenuation due to wall type i and k^{th} traversed wall, L_{fjk} is the attenuation due to floor type j and k^{th} traversed floor, I is the number of wall types, J is the number of floor types, K_{wi} means the number of traversed walls of category i and K_{fj} means the number of traversed floors of category j.

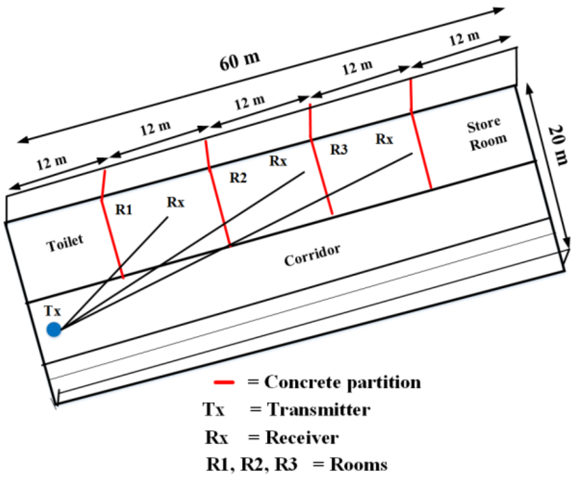

Fig. 1. (a) Measurement plan in the consecutive rooms

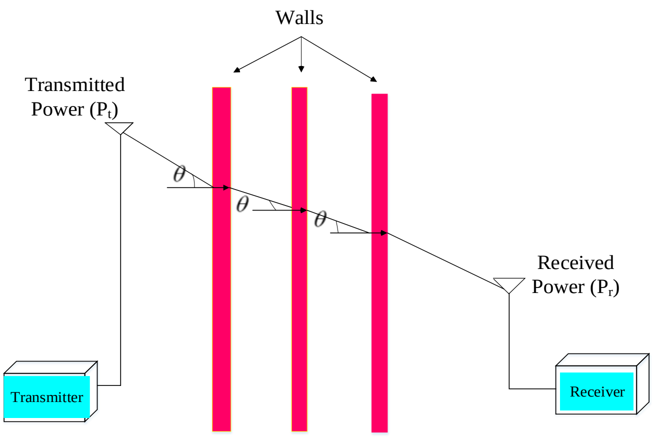

Fig. 1. (b) Side view of the measurement plan

III. EVALUATION OF MULTIWALL AND MULTIFLOOR MODEL

In this research, the RSSI and path loss values with a carrier frequency of 2.4 GHz for multifloored building in Mandalay Technological University are studied. The proposed MWF model based on the existing MWF model is evaluated to analyze the path loss through the types of wall materials which are brick and glass based on the Fresnel Transmission Coefficient (FTC).

For the proposed path loss prediction of the indoor propagation model, firstly, the experiments are measured with the specified parameters of Tx and receiver Rx for multifloored building. Next, the distance between the walls which are d_{w_1} and d_{w_2} and the number of distances between Tx and Rx which are d_t and d_r are considered. Then, the path loss due to the partitions which are brick and glass such as T_{S_1} and T_{S_2} are expressed from the experimental measurements for the optimization process. Moreover, the distances between Tx and Rx are described with meter in the experiments. After that, the experimental and the theoretical values are compared to adjust the difference of the two simulation results. In order to analyze the differences of these results and evaluate the MWF model, the penetration loss through the walls are analyzed and substituted in the path loss due to the walls which is the part of the original

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theoretical equation in MWF model. The evaluated path loss equation for the indoor propagation is described as follows:

$$\sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} = \left[\sum_{r=1}^{m}\left(\frac{d_t+d_{w_1}+d_{w_2}+d_r}{d_t+d_{w_1}+d_{w_2}}\right)^2 \times \left(\frac{1}{T_{S_1}{}^2}+\frac{1}{T_{S_2}{}^2}\right)\right] \quad (2)$$

The proportion of the path loss through the walls is substituted in the original equation of the MWF model. Therefore, the evaluated equation becomes as follows:

$$L_{MWF} = L_0 + 10n\log(d) + \left[\sum_{r=1}^{m}\left(\frac{d_t+d_{w_1}+d_{w_2}+d_r}{d_t+d_{w_1}+d_{w_2}}\right)^2 \times \left(\frac{1}{T_{S_1}{}^2}+\frac{1}{T_{S_2}{}^2}\right)\right] + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk} \quad (3)$$

, where d_{w_1} is the distance between first wall and second wall, d_{w_2} is the distance between second wall and third wall, m is the number of distances between Tx and Rx, T_{S_1} is the path loss due to window, T_{S_2} is the path loss due to wall.

IV. EXPERIMENTAL REGION AND PROCEDURES

Firstly, all the experiments are measured in four corridors and consecutive rooms at the main building of MTU. It is constituted with the concrete floors, brick walls and glass windows with wood frame doors. After that, the various types of experiments with different heights of Tx and Rx are also quantified along the corridors through multiple floors and walls by placing Tx and Rx in various positions. There are three floors of 3 corridors and two floors of 1 corridor in MTU. These corridors are denominated as corridor 1, corridor 2, corridor 3 and corridor 4 as illustrated in Fig. 2. The height between two floors is 4 m and the width of corridor 1, 2 and 3 is 2.67 m and the length of corridor 4 is 3 m.

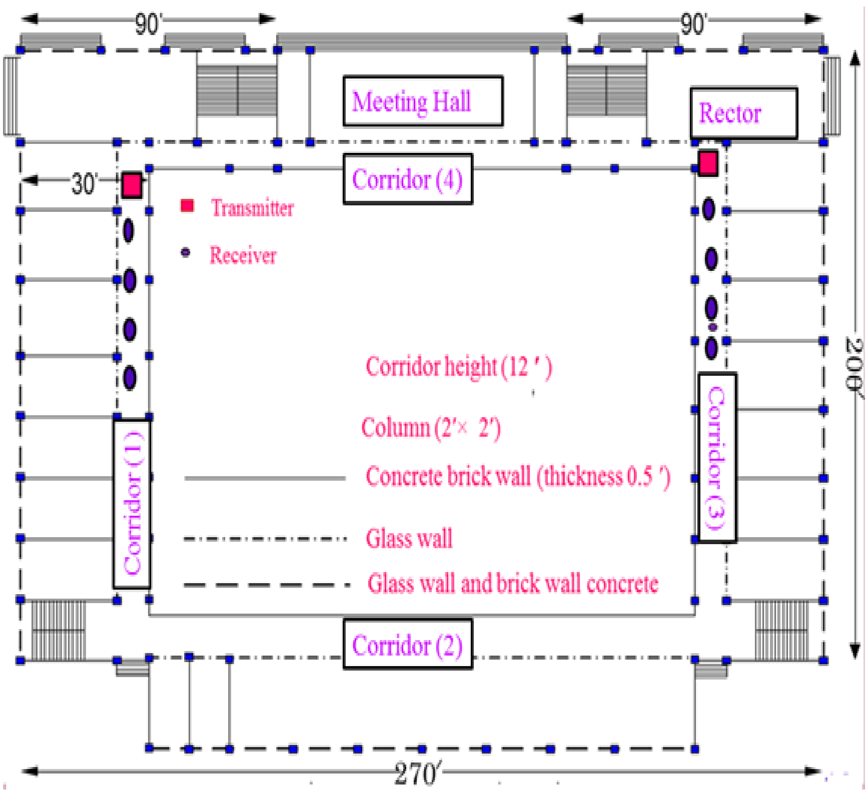

Fig. 2. Building layout of the experimental region

The Rohde&Schwarz SMBV100A Vector Signal Generator as transmitter (Tx) and Rohde&Schwarz EMIESL Test Receiver (Rx) as receiver and 3 dBi omnidirectional antennas are used for collection of experimental data. Firstly, Tx is

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placed in a fixed center position of corridor 1 and Rx is also moved 1 meter (m) distance from the fixed point of the transmitter in free space position to predict the RSSI values in same floor. Next, the placement of transmitter is fixed and the heights of transmitter and receiver are 0.6 m and 0.4 m from the ground.
After that, the transmitter is placed 15 m from the side wall of corridor 2 of the second floor, and then, the receiver is also placed 15 m from the wall of the ground floor to predict RSSI through one floor between Tx and Rx. Moreover, the receiver is also moved on the ground floor as the same placement as the transmitter on the third floor to predict RSSI through two floors. In the next situation, to calculate the path loss through one, two and three wall partitions, the transmitter is positioned along the corridor and the receiver is placed in the consecutive rooms of MTU. The experimental parameters of the experiments are described in Table 1.

TABLE I. PARAMETERS OF EXPERIMENT

Parameters	Values
Frequency (f)	2.4 GHz
Transmitter height (h_t)	0.6 m
Receiver height (h_r)	0.4 m
Resolution Bandwidth (RBW)	30 kHz
Video Bandwidth (VBW)	30 kHz
Frequency Span	1.5 MHz
Transmitted power (P_t)	10 dBm
Transmitter gain (G_t)	3 dBi
Receiver gain (G_r)	3 dBi
Sweep Time	2.5 ms

V. RESULTS AND DISCUSSION

RSSI values are obtained from the experimental measurements. The path loss values are inversely proportional to RSSI values and these values are also predicted. The RSSI and path loss values of the theoretical model, proposed model and the experiments are compared by applying the scatter plots for all measured locations in the corridors of the multifloored building.

V - A. RSSI Identification in Same Floor, through One Floor and through Two Floors
The comparisons of the RSSI calculations in same floor, through one floor and two floors versus the distance in the range of 30 m are displayed in Fig. 3, Fig. 4 and Fig. 5. The RSSI values at the distances of 10 m, 20 m and 30 m are marginally more decreased than that values at the other distances in same floor due to the wall partitions as shown in Fig. 3. According to the figure of RSSI versus distance in same floor, the maximum differences of the proposed method and existing method are at most -7 dBm at 10 m and at least -2 dBm at 5 m.

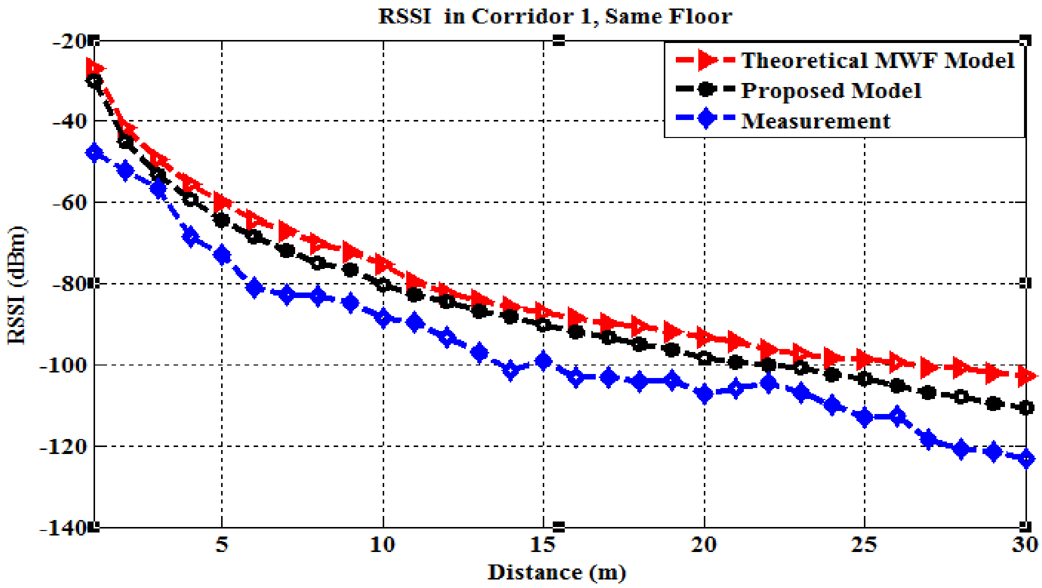

Fig. 3. RSSI versus distance in corridor 1, same floor

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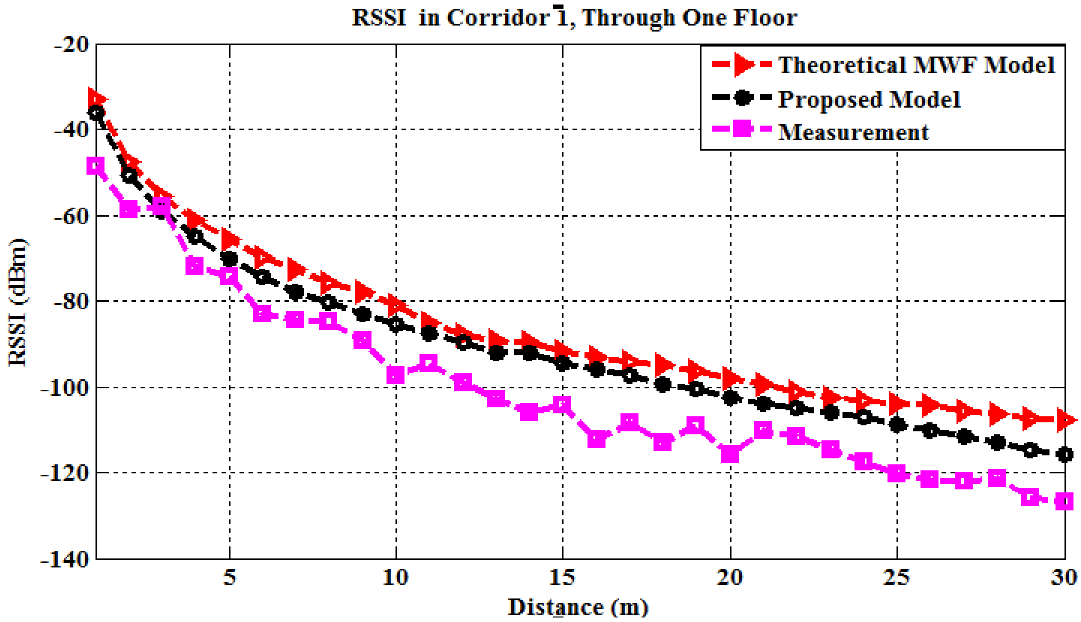

Fig. 4. RSSI versus distance in corridor 1, through one floor

Moreover, the comparisons of the RSSI calculations through one floor, versus the theoretical and the experimental values of the distance in the range of 30 m are plotted in Fig. 4. The RSSI values at the distance of 10 m are in the range between -80 dBm and -100 dBm. Furthermore, these values at 20 m are in the range between -100 dBm and -120 dBm. Similarly, these values at 30 m are significantly more decreased than those values at the other distances. According to the comparison results, the RSSI values through one floor are considerably more and more decreased than the values in same floor due to the wall partitions between Tx and Rx as shown in Fig. 4.

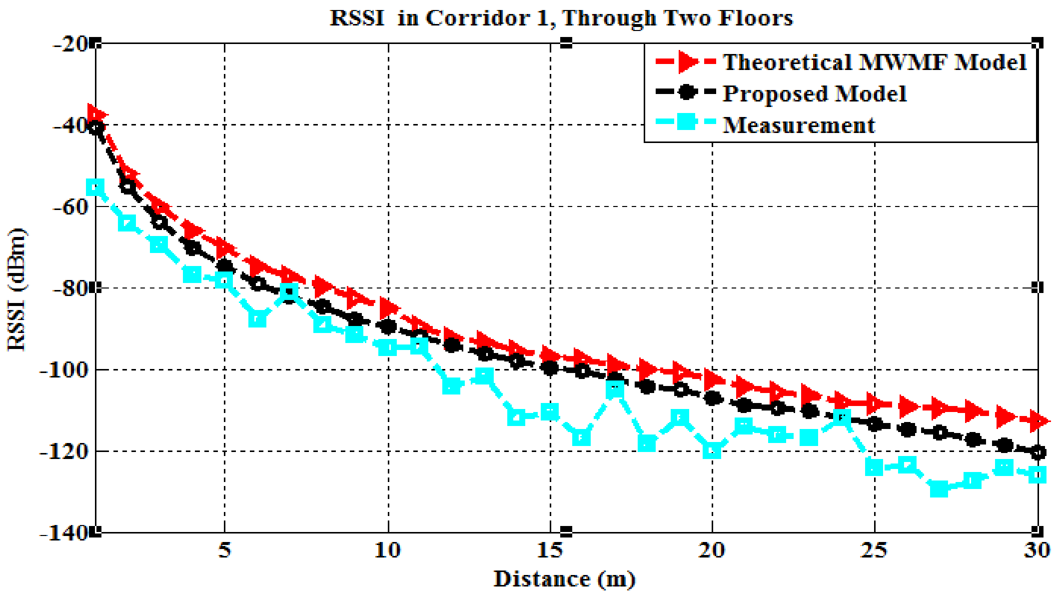

Fig. 5. RSSI versus distance in corridor 1, through two floors

Moreover, the comparisons of the RSSI values through two floors for all measured locations in the corridors of the multifloored building are also scattered in Fig. 5. The RSSI values of the theoretical model are between -40 dBm and -115 dBm and the RSSI values of the proposed model are between -40 dBm and -120 dBm. The RSSI values of the theoretical, proposed models and the experiments are more and more decreased when the distance between Tx and Rx are increased.

V - B. Path Loss Identification in Same Floor, through One Floor and through Two Floors

The path loss values in indoor radio propagation can be calculated by the following equation.

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$$PL(\text{dB}) = P_t + G_t + G_r - P_r \tag{4}$$

, where PL means the predicted path loss values, P_t is the transmitted power, G_t means the transmitter gain, G_r is the receiver gain and P_r is the RSSI values. According to Fig. 6 of path loss versus distance in same floor, the path loss values are more increased at the distances of 10 m, 20 m and 30 m due to the wall partitions. These values are steadily increased from the distance of Tx of in the range of path loss between 40 dB and 60 dB to the highest values between 100 dB and 140 dB.

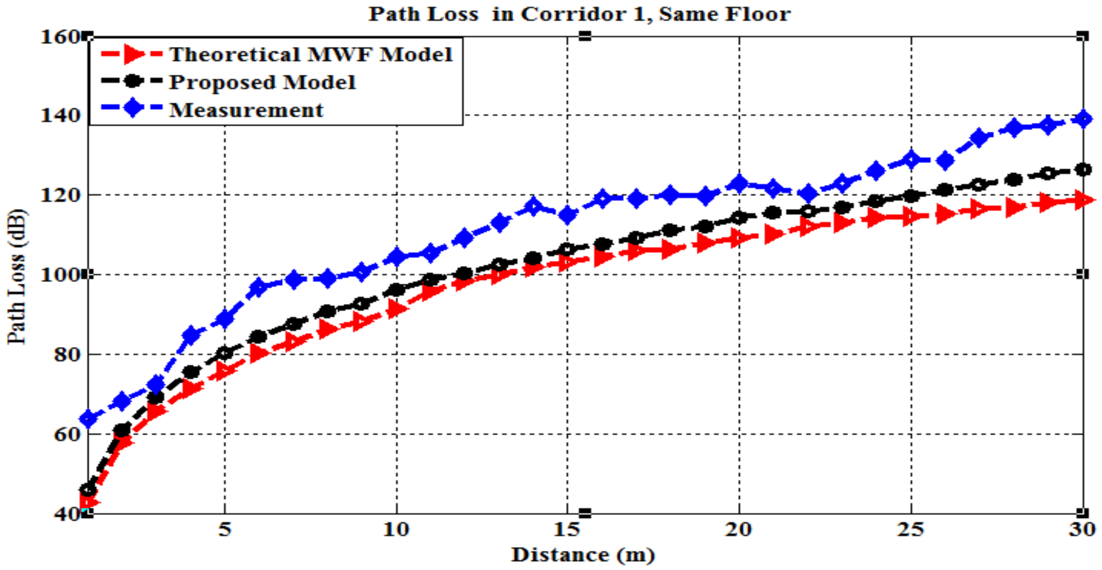

Fig. 6. Path loss versus distance in corridor 1, same floor

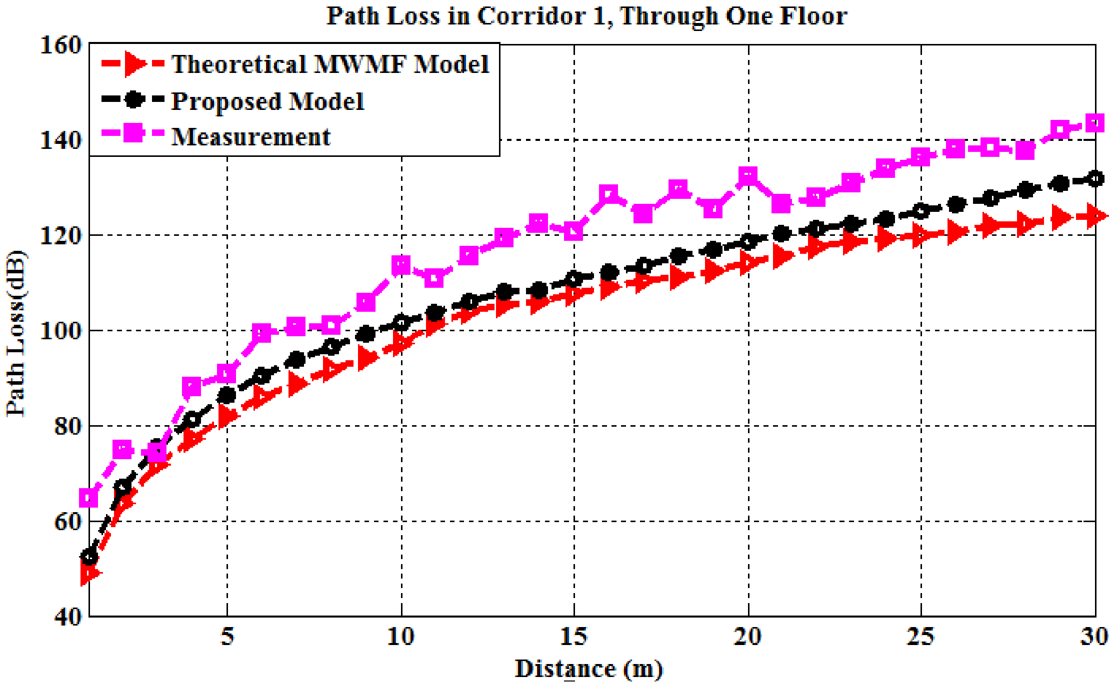

Fig. 7. Path loss versus distance in corridor 1, through one floor

As shown in Fig. 7, the path loss values are slowly increased and started the path loss values between 50 dB and 80 dB at 1 m and to the highest values between 100 dB and 144 dB at 30 m. The most differences of the theoretical, proposed methods and experiments are at most 7 dB and at least approximately 1 dB. The path loss values through one floor are more increased than those values in same floor.

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The path loss values through two floors started in the range between 55 dB and 80 dB and marginally increased to the highest values between 120 dB and 145 dB according to figure 8. The path loss values at a distance of 10 m are 100 dB and 120 dB, these values at 20 m are between 120 dB and 140 dB and that values at 30 m are between 120 dB and 145 dB. The path loss values through two floors are more than those values in same floor and through one floor when the distances between Tx and Rx are increased.

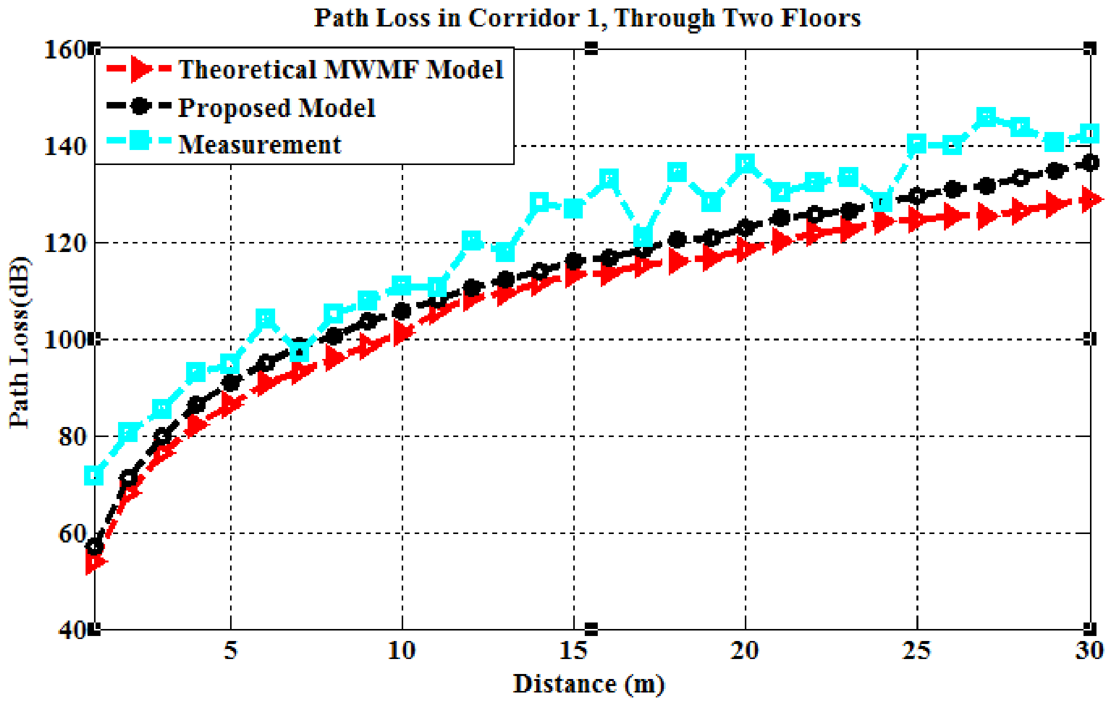

Fig. 8. Path loss versus distance in corridor 1, through two floors

VI. CONCLUSION

The evaluated model based on the empirical multiwall and multifloor model operating at 2.4 GHz are presented for the multifloored building. In this paper, all of the path loss due to multiple walls and floors in Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) are studied. According to the measurement results, the simulation results of the existing MWF and the proposed models, the RSSI values are decreased after penetrating through the walls. The proposed MWF model for the indoor wireless scenarios is evaluated based on the path loss values of the different types of the penetrated walls with the Fresnel Transmission Coefficient (FTC).

In this proposed model, the different heights of Tx, Rx, the width of the room and the distance between the walls which are brick and glass are considered. The path loss values of the measurement, the theoretical MWF model and proposed method of MWF model are more increased at 10 m, 20 m and 30 m due to the wall partitions. When analyzing the proposed MWF model, the difference of the path loss values for the experiment and the predictive data for the evaluated and existing models are at least 1 dB at 5 m, 15 m and 25 m and the highest differences are at 7 dB at 10 m, 20 m and 30 m. Similarly, the path loss through one floor and two floors are more increased than the path loss in same floor due to the partitions between Tx and Rx. Moreover, the path loss estimation with the help of the evaluated MWF model will be a useful tool for the multistoried building in indoor environment.

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BIOGRAPHY

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