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Comparison of Empirical Indoor Propagation Models for 4G Wireless Networks at 2.6 GHz

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***Abstract*— Indoor path loss models are playing an important role in the design and planning of the 4th generation of the mobile networks. Moreover, it is an important component of system level simulators used to evaluate and test the network performance before it has been established. Many propagation models were proposed for this purpose. Most of these models are for macro and micro cellular networks. Small cell which is known as femtocell has been launched for future networks and it is wildly deployed by the mobile operators around the world. The available propagation models' accuracy is at question when applied to femtocell design and engineering. This paper attempts to quantify the accuracy of these models by studying and comparing seven different propagation models for four different implementation scenarios at 2.6 GHz and for different separation distances.**

***Keywords*— Indoor propagation models, Femtocell, system level simulator, Free space loss, LTE network.**

I. INTRODUCTION

The rapid development of smartphones and tablet PCs increased the interest in indoor communication systems and femtocell technology. Femtocell which is a home access point is an important parameter in future wireless networks. Many researches are conducting annually around the world to study and investigate the challenges of deployment femtocell in the real environment. Therefore, to figure out and reduce the effects and the cost of femotcell deployment in existing wireless networks, system level simulator is necessary. The first requirement of building a system level simulator is the path loss model. It plays an important role in interference calculation. Since femtocell is installed indoor, it gained the attention to the indoor propagation models.

Many propagation models were proposed in the literature. Most of these models are for macro and microcellular networks. Propagation models that are used in microcellular are not accurate enough to be applied in femtocell propagation calculations. An accurate model that considers more specific details in addition to the direct path is required. Adding the number of floors and walls between the transmitter and the receiver is more accurate and less errors than using only the direct path [1].

The indoor propagation models that were found in literature could be divided into two main categories. The first is the general site models which are based on real measurement and not dependent on the site parameters [2-7].The second category is the site specific models which proposed based on a specific scenario and assumptions [8], [9]. The scope of this paper is the general site models. Seven of these models were studied and compared in four different scenarios.

Most of the studies recently considered the indoor to outdoor propagation [10-12]. Less attention is paid for the in building models. In [13] and [14] the cost231 multi walls multi floors model was applied for the indoor path loss calculations.

In this paper a comparison between different types of indoor propagation models has been proposed. Most of these models are suitable for three dimensional scenarios, where the number of penetrated walls and floors are considered. The path loss models were applied for four different scenarios in three story building. The frequency that assigned for LTE networks in Malaysia is 2.6 GHz. So, this frequency will be considered during the comparison process. The building consists of three floors, with three rooms each. The ceiling height is 3 m and the room dimensions are 6.5m × 5 m.

This paper is organized as follows: seven different models are presented in the next section. Section 3 shows a comparison between the available models for different scenarios. Finally, a conclusion is given in Section 4.

II. INDOOR PROPAGATION MODELS

Many studies have been conducted around the world that considered the indoor environment. Some are based on real measurements which also called general site models and others based on simulation and called site specific models. In this section, many types of indoor propagation models are presented which are WINNER II, ITU-R M2135, cost231, ITU-R P1238 and multi walls multi floors (MWMF) models. The scenario, frequency bands and the required parameters to run these models are also highlighted.

A. *WINNER II D112 V1.2 Model*

The WINNER II channel models were proposed for indoor, indoor to outdoor, outdoor to indoor, and outdoor scenarios [2]. Firstly, they were applied at 2 and 5 GHz, then they were extended over frequency range 2-6 GHz. The layout of the indoor scenario is presented in Fig. 1. Two models were proposed, line of site model (LOS), where there is no obstacles between the femtocell and subscriber user equipment (UE). The path loss is applied as in Equation (1).

$$PL = 18.7\log(d) + 46.8 + 20\log(f_c/5) \quad (1)$$

The second model is non line of site model (NLOS) as in Equation (2), where the femtocell and the UE are in different rooms. Moreover, the number of penetrated walls and floors are considered.

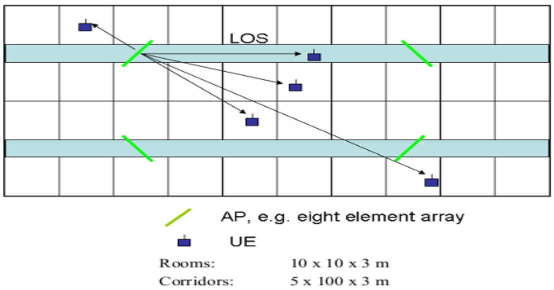

Fig. 1 Indoor scenarios layout for WINNER II model [2]

$$PL = 20\log(d) + 46.4 + 20\log(f_c/5) + 12n_W + F_L \quad (2)$$

$$F_L = 17 + 4(n_f - 1) \quad (3)$$

where f_c is the frequency in GHz, d is the distance between the femtocell and the UE in meter, n_w is number of walls, n_f is number of floors.

Equations 2 and 3 show that the relation of penetrated obstacles is constant and linear with traversed floors and walls. It is increased by 12 dB for the wall and 4 dB for the floor.

B. *ITU-R M.2135-1/ 3GPP TR 36.814 Model*

Based on real measurement results carried out in China [15-20] the WIINER II model was modified and accepted by the ITU-R M.2135 [3] and proposed as in Equation (4) for LOS and as in Equation 5 for NLOS.

$$PL = 16.9\log(d) + 32.8 + 20\log(f_c) \quad (4)$$

$$PL = 43.3\log(d) + 11.5 + 20\log(f_c) \quad (5)$$

where f_c is the frequency in GHz, d is the distance in meter between the transmitter and the receiver.

Fig. 2 Indoor environment (one floor) for ITU-R M.2135-1/ 3GPP TR 36.814 model [3]

This model is also adopted by the 3GPP for indoor femtocell scenario [4]. The indoor scenario is presented in Fig. 2. It consists of one floor of 6 m height includes big hall and 16 rooms

C. *Cost 231 Models*

Three different types of indoor propagation models were proposed in cost231 [5] based on real measurements conducted in European cities at 900 and 1800 MHz and were scaling for other frequencies. The proposed models are as listed below:

The first is the cost231 one-slope model. This model is only considering the logarithmic distance between the transmitter and the receiver. The path loss is calculated as:

$$PL = L_0 + 10n\log(d) \quad (6)$$

Where L_0 is the path loss at 1 meter distance (dB) and it is calculated as in Equation (7), n is the power decay index, and d is the distance between femtocell and UE (m). It is clear that this model is equal to free space loss as in Equation (9) if n is equal to 2.

$$L_0 = 20\log\left(\frac{4\pi}{\lambda}\right) \quad (7)$$

The second model is cost231 linear attenuation model which indicates that the relation between the path loss and distance is linear. The path loss is expressed as:

$$PL = L_{FSL} + \alpha d \quad (8)$$

where L_{FSL} is the free space losses (dB) and it is calculated as in Equation (9), α is the attenuation coefficient (dB/m), and d is the distance between the femtocell and UE (m).

$$L_{FSL} = 32.4418 + 20\log(d) + 20\log(f) \quad (9)$$

The two previous models are very simple. They are not considering the penetrated walls and floors in the indoor environment between the transmitter and thee receiver as in the real scenarios. Therefore the third model cost231 multi walls multi floors model (Cost231 MWMF) was proposed. In this model, in addition to the free space loss, the attenuation due to walls and floors is accounted. The path loss is presented as follows:

$$PL = L_{FSL} + L_c + \sum_{i=1}^{I} K_{wi} L_{wi} + K_f^{\left[\frac{k_f+2}{k_f+1} - b\right]} L_f \quad (10)$$

where L_{FSL} is the free space loss between transmitter and receiver (dB), L_C is a constant loss which determines from measurements results and it is close to zero [5], k_{wi} and L_{wi} are the number and loss of traversed walls of type i respectively, k_f and L_f are number and loss of penetrated floors respectively, b is an empirical parameter, and I is the number of wall types.

D. ITUR P1238-7 Model

This model is based on real measurements and over frequency range 900 MHz to 100 GHz [6]. The path loss is calculated according to the following equation:

$$PL = 20\log(f) + N\log(d) + L_f(n_f) - 28 \quad (11)$$

where N is the distance power loss coefficient, f is the frequency (MHz), d is the distance between the femtocell and UE (where d >1 m), L_f is the floor penetration loss factor (dB), and n_f is the number of floors separate between the femtocell and UE.

This model is considering the number of floors only and proposed as a solution to the frequency reuse between floors.

E. The Multi Wall Multi Floor Model (MWMF)

This model is based on ray tracing simulation at 5.2GHz. It was verified using open literature results for different frequencies [7]. The path loss is computed as in Equation (12). The model shows a nonlinear relation between the traversed walls or floors and the penetration loss.

$$L_{MWF} = L_0 + 10n\log(d) + \sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk} \quad (12)$$

where L_0 is the path loss in distance of 1m (dB), n is the power decay index and it determined between 1.96 and 2.03 for the considered scenario, d is the distance between the femtocell and the UE (m), L_{wik} is the loss of k^{th} wall of type i traversed (dB), K_{wi} is number of traversed walls of category i, I is the number of wall categories, L_{fjk} is the loss of k^{th} floor of type i traversed (dB), K_{fj} is number of traversed walls of category j, and J is the number of floor categories.

To sum up, all of the previous models could be applied for three dimensional indoor environments. Therefore, next section is presenting a comparison between the previous models for four different indoor scenarios.

III. Comparison of Indoor Models

The indoor models which considered in this paper were proposed for different frequency bands and for different scenarios. This section is presenting a comparison between these different models for the same frequency and the same scenario to check the capability of these models. Four indoor scenarios are considered in this paper A, B, C, and D. The layout of the proposed scenarios is as shown in Fig. 3. The building consists of three floors, with three rooms each. The floor height is 3 m and the room dimensions are 6.5 X 5 m. The applied frequency is 2.6 GHz, since it is the frequency assigned for LTE networks by Malaysian mobile operators.

The first scenario is A, where is the femtocell and the UE are in the same room and LOS connection. The maximum distance is the length of the room which is 6.5m. f is 2.6 GHz. n in equations (6) and (12) is 4 [5]. N in Equation (11) is 28 [6]. α in Equation (8) is 0.62 [5]. The comparison is as in Fig. 4. Notice that the cost231 MWMF model in Equation (10) is same to FSL as in Equation (9), and the MWMF model Equation (12) is same as the one slope model Equation (6).

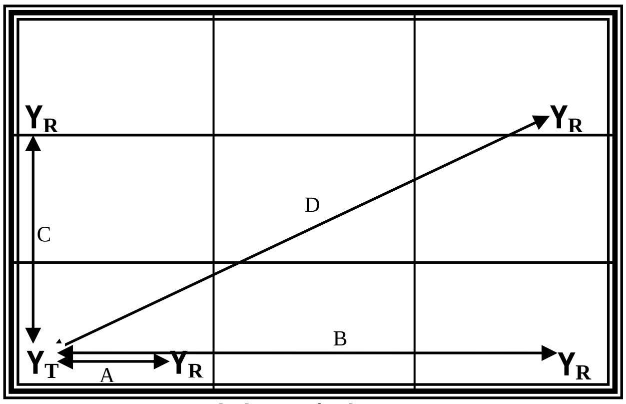

Fig. 3 The layout of indoor scenarios

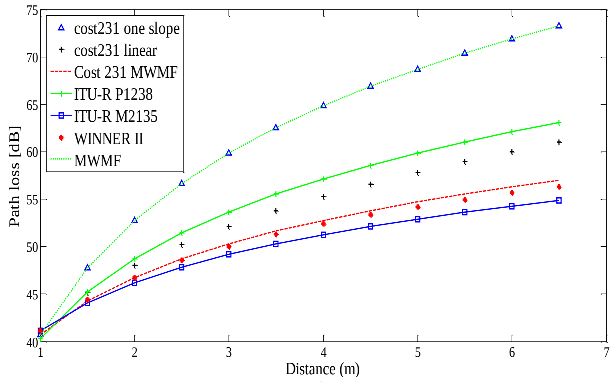

Fig. 4 Path loss for scenario A

Fig. 4 shows that the cost231 one slope and MWMF models close to each other and expecting path loss range of 75 dB for 6.5 meters distance, while the path loss is 30 dB better for cost231 MWMF, WINNER II and ITUR M2135. The ITU-R P1238 and cost231 the linear models are predicting 63 dB in between.

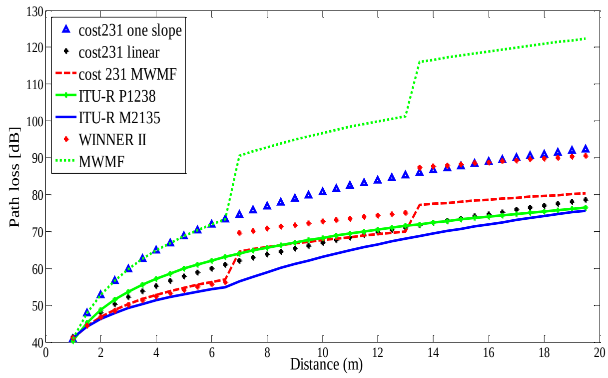

Fig. 5 Path loss for scenario B

In the second scenario (B), the femtocell and the UE are in the same floor but in different rooms. The maximum distance is the length of the floor which is 19.5m. f is 2.6 GHz. n, N

and α are same as in scenario A. L_w for cost231 MWMF model is 6.9 dB [5]. L_{w11}, and L_{w12} in the MWMF model are 16 and 14 dB respectively [7]. Comparison between the seven models is shown in Fig. 5. In this scenario the effect of walls is considered.

In Fig. 5 it is clear that cost231 linear, cost231 MWMF, ITU-R P1238 and ITU-R M2135 models are close to each other and predicting 80 dB losses for the two walls. The path loss is increased to 10 dB for the cost231 one slope and WINNER II models. Moreover, the path loss is worse and up to 120 dB by using the MWMF model.

In the third scenario (C), three floors are considered. However, the UE in the third floor is exactly above the femotcell. It is one meter above the ground. Therefore, only two penetrated floors are accounted and the distance is 7 m. The following parameters are considered: n for two floors is 5.2 [5], N is 28, α is 2.8, L_f in cost231 MWMF model is 18.3 dB, L_{f11} and L_{f12} in the MWMF model are 19 and 15.2 dB respectively [7].

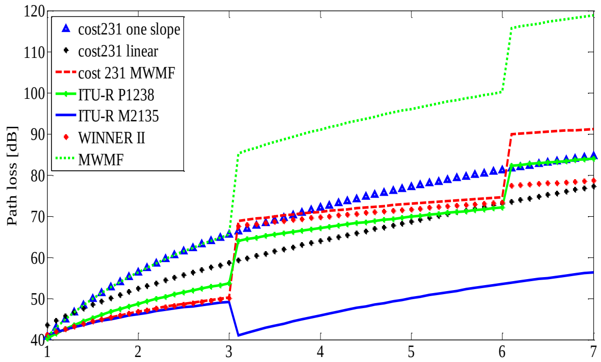

Fig. 6 Path loss for scenario C

Five of the models show almost the same performance with some difference as shown in Fig. 6. The path loss was 78 dB for the linear model, while the cost 231 MWMF was 13 dB worse and pointed at 81 dB. In addition, the MWMF model shows over estimated result with 120 dB loss. Finally, the performance of the ITU-R 2135 was not stabile because the distance is less than ten meters, hence the NLOS part of the model was proposed for distance more than 10 meters. Normally the distance between floors in the residential departments is around 3 meters. So the NLOS part of the model will not be suitable to estimate the penetration losses of floors even though it was proposed by the 3GPP for femtocell scenarios.

The last scenario considered the diagonal distance between femtocell installed in the left side of the first floor and UE in the right side of the third floor as in D. In this scenario the effects of walls and floors are studied. Models parameters are same as in scenarios B and C.

Fig. 7 shows that four of the models are close to each other especially for the NLOS with path loss around 110 dB. However, The ITU-R models predicted less loss with 100 dB for the ITU-R P1238 and 80 dB ITU-R M2135. Lastly, the expected loss using the MWMF model was very high with 175 dB.

IV. Conclusions

Seven different indoor propagation models available in the literature for 4G femtocell frequencies was studied and compared in four different scenarios. In LOS scenarios like scenario A, the minimum path loss is 55 dB and it is increased to 75 dB for the cost231 one slope and MWMF models. In addition, for the NLOS and same floor scenario, the loss is 80dB for most of the models except the MWMF model where the loss is around 120 dB.

The third scenario considered the floors penetration only. The path loss is 90 dB for five of the models and 120 for the MWMF model. The ITUR M2135 has limitations in this scenario since the minimum distance assumed for NLOS in this model is 10 m. Finally, in the last scenario, walls and floor are accounted. The path loss is below 120 dB for six models while it is 175 dB for the MWMF model. The overestimation of the MWMF model might be due to the value used for the path loss exponent which is between 1.96 and 2.01 while for other models it is considered between 4 and 5.2.

As a future works, real measurement will be conducted and compared with the previous models to check the best reflected model.

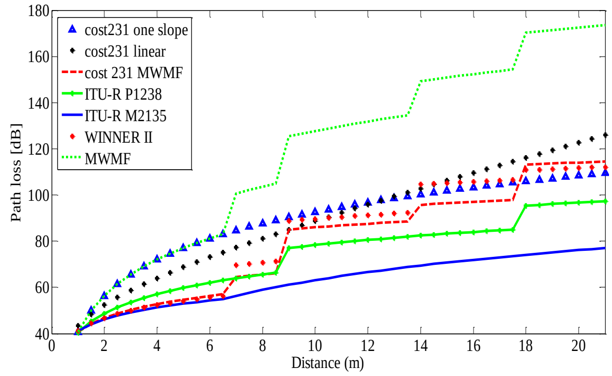

Fig. 7 Path loss for scenario D

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