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Research paper

Characterization of Outdoor to Indoor Propagation in Urban Area by Using A Combination of COST231 Walfisch-Ikegami and COST231 Multiwall Models in 1800 Mhz and 2100 Mhz

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Abstract

Increasing numbers of the mobile communication users in urban city; especially indoor users cause the radio coverage prediction of outdoor to indoor becoming important. Obstacles are the main problems for outdoor to indoor propagation that weaken signal level and worsen information detection. This paper proposes a combination of COST231 Walfisch-Ikegami and COST231 Multiwall to predict the received signal. By comparing the predicted and the measured signal level in the Antara building, Medan city for both 1800 MHz and 2100 MHz channels, the proposed model outperforms the compared method in predicting signal level. The proposed model is able to suppress the prediction deviation 11.035 dB lower than the compared method for Sector A and 5.98 dB lower at Sector B.

Keywords: *Path loss, propagation model, outdoor to indoor propagation, Walfish-Ikegami and Multiwall combination*

1. Introduction

Signal prediction from outdoor to indoor is important for mobile communication so that power control can be applied accordingly. As buildings dominate obstacles within urban area, modeling signal propagation is more complicated than suburban and rural area. Since minimizing repeater existence within building is preferred, indoor propagation relies on signal availability from outdoor [1]–[3].
The outdoor propagation is mostly influenced by buildings and trees density [4], while indoor propagation is affected by the density of walls, floors and furniture [5]. Propagations have been intensively studied and modeled by using mathematical equations, namely deterministic model, such as free space loss model, log distance path loss model, and log normal shadowing model or even reflecting model [6]. Some sophisticated models employ complex approaches, for instant, impulse response [7] and statistic dispersion [8]. Model is often dedicated for a specific frequency band, for instant, Paulsen model [5]. Paulsen model assumes the incident signal power arrives on the outer front wall of the building is equally strong. This model divides propagation losses into two parts: outdoor and indoor propagation losses. The formula of Paulsen model for macrocell coverage category is expressed in the Equation 1.

$$L_{Paulsen} = L(d) + L_{we}(v_i) + n_w L_{wi} - n_f G_h \quad (1)$$

L(d) is path losses in dB and defined in Equation 2. The (d) indicates distance dependence. L_{we} is external wall attenuation (dB). n_w is number of internal walls which separate transmitter and receiver. L_{wi} is internal wall attenuation (dB). G_h is height gain per floor; height gain is defined as the increase in received power when lifting the receiver to a higher floor (dB). v_i is angle of incidence. n_f is floor number; ground floor is zero. The values of L_{we} and L_{wi} depend on the content of the type of material.
L(d) is determined by using the formula of COST231 WI model for NLOS as radio waves arrive at building through reflections. Thus, the final formula is shown in Equation 2.

$$L_{Paulsen} = L_{FSPLo} + L_{rts} + L_{msd} + L_{we}(v_i) + n_{w}.L_{wi} - n_f.G_h \quad (2)$$

This paper focuses on COST231 WI but will be modified by using other propagation model to predict mobile communication signal that propagate from outdoor to indoor.

2. Proposed Propagation Model

This paper proposes a combination of outdoor an indoor propagation models: COST231 Walfisch and Ikegami (WI) and COST231 Multiwall (MW). The COST231 WI model was chosen as outdoor propagation model as it considers the average elevation of the buildings which are rapidly changing. The COST231 MW model was chosen as it does not consider the structures and types of walls, density of furniture and people density so that the model can be directly applied. In addition, it was also chosen because it is latest model obtained from Keenan-Motley model development [9].

2.1 Cost231 Walfisch-Ikegami (Wi) Model

The formula of COST231 WI for non-line of sight (NLOS) condition is shown in Equation 3[9].

$$L_{NLOS} = L_{FSPLo} + L_{rts} + L_{msd} \quad (3)$$

L_{NLOS} is the total outdoor propagation losses in dB. L_{FSPLo} is outdoor free space loss (dB). L_{rts} is roof-top-to-street diffraction and scatter losses (dB). L_{msd} is multiple screen diffraction losses (dB). L_{FSPLo}, L_{rts} and L_{msd} respectively can be calculated by using Equation 4, Equation 5 and Equation 6.

$$L_{FSPLo} = 32.4 + 20\log(d_{Out}) + 20\log(f_c) \tag{4}$$

d_{Out} is distance from transmitter to receiver at outdoor areas (km) and f_c is radio waves frequency (MHz).

$$L_{rts} = -16.9 - 10\log(w) + 10\log(f_c) + 20\log(h-h_{in}) + L_{ori} \tag{5}$$

w is the road width (m), h is the average building height (m), h_m is the receiver antenna height (m) and L_{ori} is the street orientation factor to the incoming signals which is calculated by using the Equation 4[4].

$$L_{ori} = \begin{cases} -10 + 0.354 * \varphi \\ 2.5 + 0.075 * (\varphi - 35) \\ 4.0 - 0.114 * (\varphi - 55) \end{cases} \tag{6}$$

φ is the orientation angle which is formed by direct signal and road that shown in Equation 6.

$$\varphi = \operatorname{atan}^{-1}\left(\frac{h - h_m}{d_{Out}}\right) \tag{6}$$

$$L_{msd} = L_{bsh} + k_a + k_d * \log(d_{Out}) + k_f * \log(f_c) - 9 * \log(b) \tag{7}$$

L_{bsh}, k_a, k_d and k_f respectively can be calculated by using Equation 8, Equation 9, Equation 10 and Equation 11. b is the average distance between the buildings.

$$L_{bsh} = \begin{cases} -18\log[1 + (h_b - h)] & h_b > h \\ 0 & h_b \leq h \end{cases} \tag{8}$$

$$k_a = \begin{cases} 54 & h_b > h \\ 54 - 0.8(h_b - h) & h_b \leq h \text{ and } d_{out} \geq 0.5 \text{ km} \\ 54 - 0.8(h_b - h) * \frac{d_{Out}}{0.5} & h_b \leq h \text{ and } d_{out} < 0.5 \text{ km} \end{cases}) \tag{9}$$

$$k_d = \begin{cases} 18 & h_b > h \\ 18 - 15\frac{(h_b - h)}{h} & h_b \leq h \end{cases} \tag{10}$$

$$k_f = \begin{cases} -4 + 0.7\left(\frac{f_c}{925} - 1\right) & \text{For medium-sized city} \\ -4 + 1.5\left(\frac{f_c}{925} - 1\right) & \text{For metropolitan center} \end{cases} \tag{11}$$

2.2 Proposed Model

Combination COST231 WI model and COST231 MW model is realized by summing d_{Out} and d_{in} as both models have similar distance parameter. As a result, Equation 12 is expressed as:

$$L = L_{FSPL} + L_{rts} + L_{msd} + L_C + \sum_{i=1}^{I} k_{wi} L_{wi} + k_f^{\left[\frac{k_f + 2}{k_f + 1} - b\right]} \tag{12}$$

L_{FSPL} is free space loss (dB) from outdoor to indoor which is expressed in Equation 13.

$$L_{FSPL} = 32.4 + 20\log(d_{Out} + d_{In}) + 20\log(f_c) \tag{13}$$

The proposed model assumes that the signal path from transmitter to receiver is straight (penetrate wall) as shown in Figure 1.

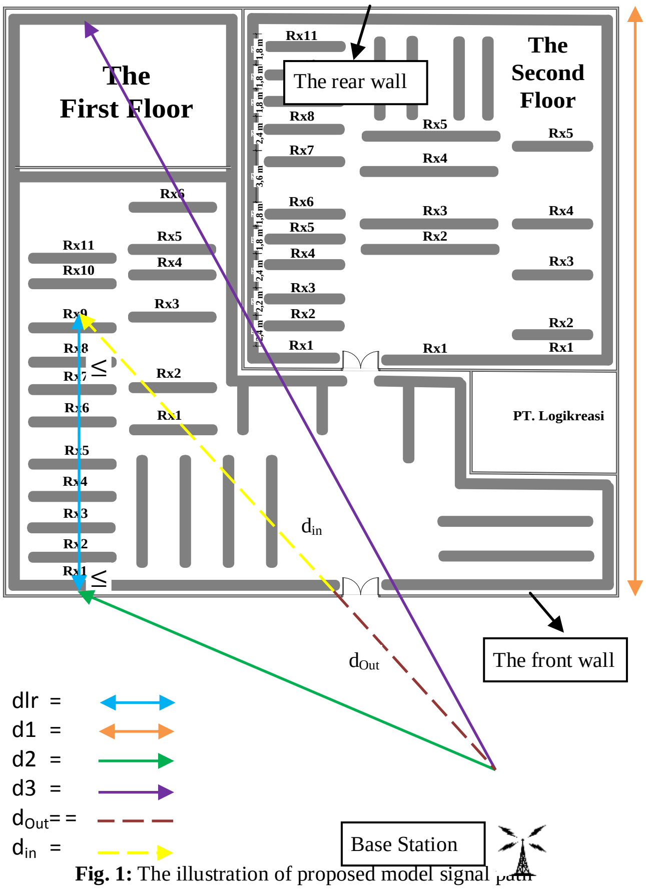

Fig. 1: The illustration of proposed model signal path

The value of d1 and dlr can be found by manual measurement. The values of d2 and d3 can be approximated by mapping application. Parameter d, d_{in} and d_{Out} can be found by using Equation 14, Equation 15 and Equation 16 [10].

$$d = \sqrt{(d2)^2 + (dlr)^2 - 2 * d2 * dlr * \cos\alpha} \tag{14}$$

Parameter d is distance between transmitter and receiver (km). d2 is distance between transmitter to the intersection point of the perpendicular line between receiver and front wall. The dlr is distance between receiver and intersection point of the perpendicular line between receiver and front wall (km). Angle α is angle of incident between d1 line and d2 line (degree). The value of $\cos\alpha$ can be found by use Equation 15 [11].

$$\cos\alpha = \frac{(d3)^2 - (d2)^2 - (d1)^2}{-2 * d2 * d1} \tag{15}$$

Distance d1 between the front wall and the rear wall which pass through receiver (km). The d3 is distance between transmitter and the rear wall which is perpendicular to the receiver line (km).

$$din = \frac{dlr}{\cos\beta} \tag{16}$$

β is angle of incident between the dlr line and d line (degree). The value of β can be found by use Equation 17.

$$\beta = \sin^{-1}\left(\left(\frac{d2}{d}\right) * \sin\alpha\right) \qquad (2 \tag{17}$$

$$dout = d - din \tag{18}$$

The d_{Out} is distance between transmitter and the front wall which is closest to transmitter that passed through the receiver line (wave radio path - km). The d_{in} is distance between receiver and the front wall which is closest to transmitter that passed through the transmitter line (wave radio path - km).

3. Measurement Method

Signal measurements were performed at the department store in the *Antara* building as shown in Figure 2. The specifications of outdoor areas are [10]:

a. Average height of building is 36 m
b. The average distance of each building is 20 m
c. The road width is 20 m
d. The outer walls were made by glass with a thickness about 2 cm.
e. Inside the *Antara* building is composed by some walls that formed by some racks that are made of metal (0.8 cm)
f. The goods can be formed as cleaning tools, cooking equipment, electronics devices, mechanical tools, electrical tools and others. Therefore, the path losses due to iron shelves wall are assumed to be identical because the iron shelves are loaded by so many goods types.

The measurements of the signal strength were performed only on the first floor of Sector A and Sector B as shown in Figure 3.

On the proposed model, the radio waves are received by the receiver which has direction as shown in Figure 3. Thus, the number of walls would be penetrated by radio waves can be determined as shown in Table 1.

Fig. 2: The position of the transmitter and Antara Building (Google earth at 3°35'47.88" N 98°40'28.12" E, accessed on 02.11.2015 at 2:29 pm)

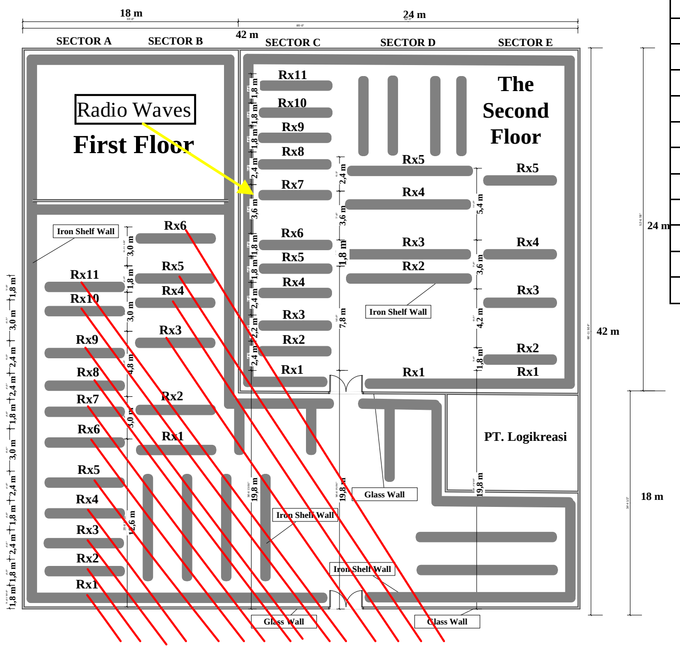

Fig.3: Prediction of radio waves path in building on the proposed model

Table.1: The penetrated walls in Sector A and Sector B

Sector A			Sector B		
Receiver	k_{w1}	k_{w2}	*Receiver*	k_{w1}	k_{w2}
Rx1	2	0	Rx1	5	0
Rx2	3	0	Rx2	6	0
Rx3	4	0	Rx3	4	0
Rx4	4	0	Rx4	6	0
Rx5	5	0	Rx5	6	2
Rx6	6	0	Rx6	7	2
Rx7	6	0	-	-	-
Rx8	7	0	-	-	-
Rx9	7	0	-	-	-
Rx10	8	0	-	-	-
Rx12	8	0	-	-	-

The specifications of the transmitter and receiver respectively are shown in the Table 2 and Table 3.

Table.2: The specification of transmitter [12]

Specifications of Transmitter	Frequency (MHz)	
	1812.5 (GSM1800)	*2140 (3G)*
High (m)	38.000	37.500
Power (dBm)	47.300	47.300
EIRP (dBm)	52.874	52.874
Gain (dB)	18.000	18.000
Loss Feeder (dBm)	42.426	42.426

Table.3: The specification of receiver [12]

Specifications of Receiver	Frequency (MHz)	
	1812.5 (GSM1800)	*2140 (3G)*
High (m)	2.0	2.0
Gain (dB)	1.5	1.5
Loss Feeder (dBm)	0	0

4. Measurement and Calculation Results

By using a mapping application, the value of d2 and d3 in Sector A are 0.187 km and 0.225 km respectively. The value of d2 and d3 in Sector B are 0.182 km and 0.221 km respectively. Based on Figure 3, the value of each of dlr on the Sector A and the Sector B respectively are calculated as shown in Table 4. The value of d1 is 0.446 km.

Table.4: The value of dlr on the Sector A and Sector B

Sector A		Sector B	
Receiver	*dlr (m)*	*Receiver*	*dlr (m)*
Rx1	1.80	Rx1	12.6
Rx2	3.60	Rx2	15.6
Rx3	6.00	Rx3	20.4
Rx4	7.80	Rx4	23.4
Rx5	10.2	Rx5	25.2
Rx6	13.2	Rx6	28.2
Rx7	15.0	-	-
Rx8	17.4	-	-
Rx9	19.8	-	-
Rx10	22.8	-	-
Rx12	24.6	-	-

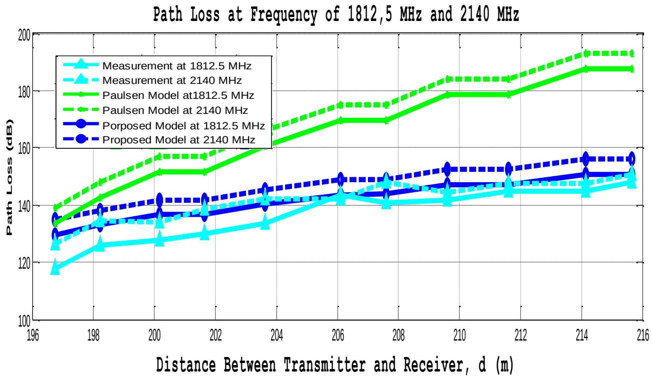

Fig.4: The results of path losses from measurement and calculation in the Sector A

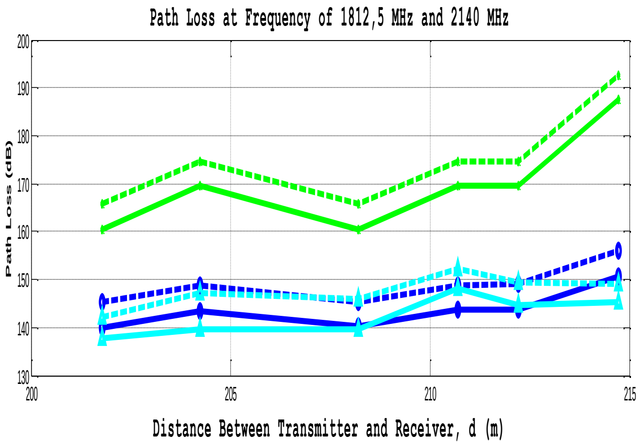

Fig. 5: The results of path losses from measurement and calculation in the Sector B

Figure 4 and 5 shows the measurement and model calculations for both Sector A and Sector B. These figures show that the proposed model predicts signal closer than Paulsen model. The reading of the graph scan is made easier by using a regression method on each of graphs. The type of regression method is used in this paper namely polynomial regression quadratic which is expressed in Equation 19 [13].

$$Y = a + b * X + c * X^2 \quad (19)$$

The variables of a, b and c can be obtained by using the Equation 20, Equation 21 and Equation 22.

$$\sum(Y) = n * a + b * \sum(X) + c * \sum(X^2) \quad (20)$$

$$\sum(XY) = a * \sum(X) + b * \sum(X^2) + c * \sum(X^3) \quad (21)$$

$$\sum(X^2Y) = a * \sum(X^2) + b * \sum(X^3) + c * \sum(X^4) \quad (22)$$

The regression results from each of graphs respectively shown in Figure 6 and Figure 7.

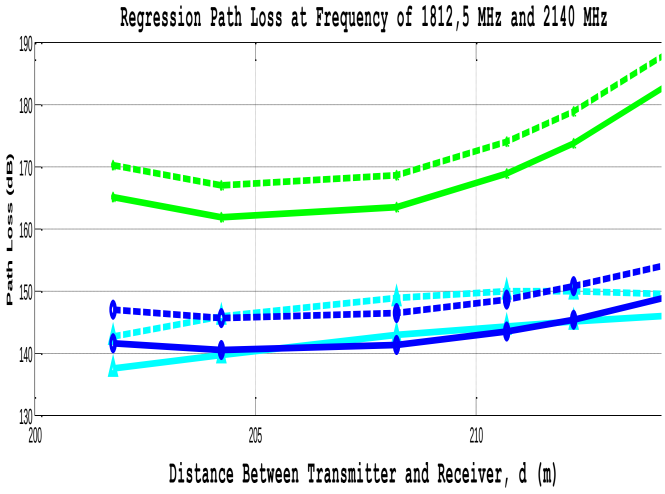

Fig.6: The results of path losses regression from measurement and calculation in the Sector A

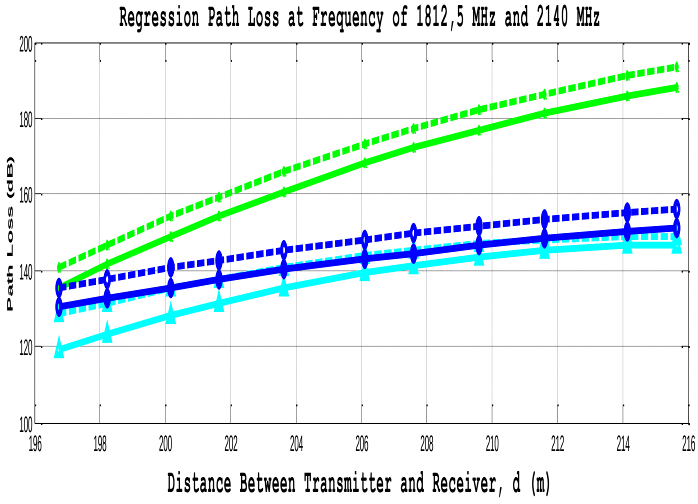

Fig. 7: The results of path losses regression from measurement and calculation in the Sector B

Based on the Figure 6 and Figure 7, the proposed method charts are closer to the measurement charts than of Paulsen model. Based on the results of the propagation losses calculations and measurements from outdoor to indoor on each of sectors inside the Antara Building, the values of mean error and standard deviation can be obtained by using the Equation 23 and Equation 24[13].

$$\text{Mean error}(\text{dB}) = \frac{1}{n} * \sum(P_{Lmi} - P_{Li}) \quad (23)$$

$$\text{Standarddeviation } (\sigma) = \sqrt{\frac{1}{q-1} * \sum_{i=1}^{q}(P_{Li} - \bar{P}_L)^2} \quad (24)$$

q is number of the measurements data of losses. P_{Lmi} is the values of measurements. $P_{Li}$is the value of calculations. $\bar{P}_L$ is the mean of calculations value. The results of the calculations of mean error and standard deviation on each of the sectors and frequency are shown in Table 5 and Table 6.

Table.5: The results of calculation and measurement for propagation losses at Sector A

Frequency (MHz)	Models	Standard Deviation (dB)	Mean Error (dB)
1812.5 (GSM1800)	Paulsen Model	18.163	28.577
	Proposed Model	7.128	5.488
2140.0 (3G)	Paulsen Model	18.163	28.660
	Proposed Model	7.128	5.570

Table.6: The results of calculation and measurement for propagation losses at Sector B

Frequency (MHz)	Models	Standard Deviation (dB)	Mean Error (dB)
1812.5 (GSM1800)	Paulsen Model	9.8590	26.946
	Proposed Model	3.8747	1.0841
2140.0 (3G)	Paulsen Model	9.8590	26.986
	Proposed Model	3.8747	1.1241

5. Conclusion

The paper has proposed a model to predict outdoor to indoor propagation. The measurement and calculation results show that the combination COST231 Walfisch and Ikegami (WI) and

COST231 Multiwall (MW) is able to predict the received signal without changing the numbers and types of walls.

The proposed model outperforms Paulsen model by achieving prediction deviation 11.035 dB lower than the compared method for Sector A and 5.98 dB lower at Sector B. The mean error and standard deviation in the Sector A for GSM1800 and 3G are 7.128 dB and mean errors are respectively 5.488 dB and 5.570 dB. In the Sector B, standard deviation for GSM1800 and 3G are 3.874dB and mean errors are 1.084 dB and 1.124 dB respectively. It means the proposed model is closer to the measurement result.

Finally, the proposed model fulfills ITU standard with deviation less than 10 dB. The proposed model is suitable applied in the urban areas at the frequency of 1812.5 MHz and 2140 MHz

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