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AN INDOOR TO OUTDOOR PROPAGATION MODEL AT GSM900 GSM1800 AND CDMA2100

S. Çelik[a] , O. Kurnaz [b], Y. Albayrak [c], M. Bitirgan[a], İ.B. Basyigit [e] and S. Helhel[c,d]

[a]Turkcell Telecommunication Coop., RF Planning and Optimization Department, Antalya, TURKEY.
[b] TUBITAK National Metrology Institute, Gbeze, Kocaeli, TURKEY.
[c] Akdeniz University, Electrical and Electronics Engineering Department, Antalya, TURKEY.
[d] Akdeniz U., Industrial and Medical Applications Microwave R&D Center, Antalya, TURKEY.
[e] S. Demirel University, Distance Learning Vocational School Isparta, TURKEY.

[*]Corresponding Author: selcukhelhel@akdeniz.edu.tr

Abstract

An empirical indoor to outdoor propagation model has been improved based on empirical techniques. Improved model includes building structures such as number of walls, position of windows and the affect of frequency. Proposed model is valid for GSM 900, GSM 1800 and CDMA 2100. Theory and measurements are in tracking each other at CDMA2100 and GSM frequencies by at most 6dB deviation. Generated model can easily be used for outdoor coverage predictions and interference capability based on indoor antennas, especially at CDMA.

Keywords: Propagation, propagation measurement, cellular radio, indoor propagation, gain floor height.

1. Introduction

Mobile communication has become very popular with the help of rapidly growing new wireless technologies. Due to the increasing number of the speech and data users, the wireless network operators tend to increase the number of indoor base stations and femtocells instead of macro base stations. Today, the most commonly used examples of femtocells are hotels, malls, hospitals, airport buildings, factories, etc. These new type of indoor base stations start to interfere macrocells causing overall increase in uplink interference that leads to decrease in uplink capacity in CDMA networks.

On the other hand, in city centers, increasing the number of indoor base stations leads to increase in indoor to outdoor interference as well as EMI problems [1], which must be taken into consideration when designing wireless network, especially in hotspot areas. In literature, there are studies about indoor propagation [2-4] and outdoor to indoor propagation loss calculations [5-8], but there are few studies considering about indoor to outdoor propagation [9-10].

The experimental setup of Valcarce and Zhang [9] for indoor to outdoor model was locating femto-cell transmitter next to the window which does not simulate real usage of indoor equipments. For the purpose of indoor coverage, indoor antennas are generally located in middle of buildings. In another study, P. Kyösti’s the winner project [10], the behavior of microcells were investigated by using indoor to outdoor measurement data and a new formula was suggested with the help of COST231 model [12]. However, the measurements were taken in 2-6 GHz range, so lower frequencies such as GSM900 were left out of the model

Miura et al [5], proposed outdoor-to-indoor propagation model considering the structural openings along the propagation path. They assumed that outdoor-to-indoor paths are possible only through wall openings such as doors and windows. Their result indicates that proposed model is more accurate than the COST231 model. Faisal Ahmad Katar et al [8] made path loss measurements for four different buildings, and results were compared with the Cost231 model. An empirical equation has been presented concerning both through the LOS and NLOS propagation paths. However, frequencies higher than GSM900 were not included in their formula. In [11], uplink capacity was analyzed and uplink interference avoidance strategy was presented for two-tier femtocell networks. They have demonstrated that uplink interferences to outdoor caused by indoor antennas and femtocells especially in CDMA Networks are quite important

In this study, test microcell with one indoor omni antenna was installed in the first floor of a building. An indoor to outdoor path loss was measured and calculated, and compared with theory along the outer periphery of a building at GSM900, GSM1800 and CDMA2100, respectively. Since there were not LTE and WiMAX measurement setup in our group, CDMA2100 were selected as a broadband communication system in order to investigate bandwidth affect in path loss. An indoor to outdoor empirical path loss formula has been derived from outdoor to indoor propagation model [7-8].

2. MATERIALS AND METHODS

Radio waves transmitted by indoor microcell propagate inside the building, penetrate the building external wall, and reach to the receiver, respectively. The propagation loss formula for NLOS propagation model has been given as below

$$\Delta L = L_{in} - L_{out} \tag{1}$$

Where ΔL ,L_{in} and L_{out} are path loss difference, the propagation loss between the Base Station(BS) and the receiver inside the building, and Loss(out) is the propagation loss between the BS and the receiver outside the building [7]. A modified COST231 path loss formula for indoor-to-outdoor propagation is given below

$$\Delta L = W_e + W_{ge} + \max(\Gamma_1, \Gamma_3) + G_{FH} + \log(f) \tag{2}$$

Where W_e, W_{ge}, and f are perpendicular penetration loss at an external wall having a value of 4-10 dB (7 dB for concrete with normal-size window; 4 dB for wood), external wall loss (angle-dependent) [6-10], frequency in MHz, respectively. $\Gamma_1$and Γ_3 are defined as below

$$\Gamma_1 = W_i.p \tag{3}$$

$$\Gamma_3 = \alpha.d \tag{4}$$

Where W_i, p, α and d are the internal wall loss having a value of 4-10 dB (7 dB for concrete with normal-size window and 4 dB for wood), number of penetrated walls, penetration coefficient (taken as 0.6 dB/m), and penetration distance respectively. All doors of offices were closed during measurements, and p and d parameters were decided based on straight line between transmitter and receiver. Floor height gain (G_{FH}) is defined as

$$G_{FH} = n.G_n = h.G_h \quad (5)$$

Where n, G_n, h and G_h are number of floors, nth floor gain (4-7 dB/floor when the floor height is 4-5 m [6]), floor height and height gain (1.1-1.6 dB/m when the story height is 4-5 m), respectively. The term "n" is chosen as zero for the ground floor. The term "h" is the height above the ground level [7].W_e, α, and W_i are determined by the structural characteristic of the building. All the parameter values used in this study are presented in Table1. In order to take into consideration the contribution of frequency to the propagation model, Matlab curve fitting tools were used, and a term "log(f)" has been added. In the study, four set of measurements have been used. The model is generated from the first set, and then three more measurement sets have been used for control purposes.

Table 1. Parameter values used in calculations (Okamoto et all [7])

W_e	BW			α	W_{ge}	W_i	G_{FH}
	GSM 900	GSM 1800	CDMA 2100				
7 dB	0.2 MHz	0.2 MHz	3.84 MHz	0.6 dB/m	5 dB	7 dB	5 dB

3. TEST SETUP AND MEASUREMENTS

The transmitter (brand name is Andrew) holding a CELLMAX-O-25 omni-directional antenna operating between 806 MHz and 2100 MHz was used as part of measurement setup. Channel utilization bandwidth of 0.2 MHz for both GSM900 and GSM1800 and 3.84 MHz for CDMA2100 were chosen. Transmitting antenna was located at the first floor and having an output power of 21 dBm. Nemo-Handy software loaded Nokia N95 mobile phone was used as a radio receiver as well as GPS receiver, and the transmitter setup is shown in Fig. 1. Because of selection of safe frequencies, there was no additional communication traffic in the system that may affect the propagation mechanisms.

Figure 1: Transmitter setup

Measurements were made by using Nokia N95 Nemo Test telephone which has similar capabilities with Ericsson TEMS mobile telephone[2]. It was at idle mode, and transmitting antenna was placed at one ceiling of the building. The Test Mobile System was used to measure the normalized received signal power given by Martijin et al. [6] and Helhel [2] is shown below

$$Rx_{lev} = \Pr(dBm) + 110dB \tag{6}$$

where Rx_{lev} and Pr are measured average received signal power level and received signal power level, respectively. The accuracy of Nemo test telephone measured RxLev is ±1(dB), and the received signal measurement range is from 0dBm down to -110dBm, where -110dBm is the noise floor. P_r is the average received signal power measured within one slow associated control channel (SACCH) multi-frame of approximately 480 ms. In total approximately 100 samples are taken within one SACCH multi-frame [2, 6]. Since the receiver equipment was in movement, it can be assumed that small-scale fading affects were removed from recorded data. The transmitter and receiver heights, floor height and output power of transmitter are shown in Table 2.

Table 2. Transmitter Properties

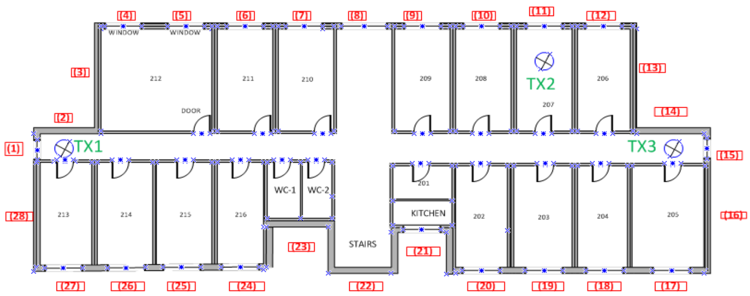
Used Frequencies	900, 1800 and 2100 MHz
Power	+21 dBm
Transmitter antenna height	2 m (from the first floor)
Receiver antenna height	1.5 m (from the ground)
Floor height	4.5 m

The construction material for the measured building is concrete. All the window panes are double-glazed window. The average number of windows per room is approximately 1. The windows have average width of 2.3 m and average height of 2 m.

Continuous measurements were obtained around the building of Industrial and Medical Based Microwave Research Center located in Akdeniz University campus. Four different transmitter locations were selected on the basement and first floors of the building in order to simulate different scenarios. In each scenario, transmitter was located inside the building. On the other hand, receiver was outside the building and on the ground. There was no line of sight (LOS) between the transmitter and the receiver. In order to remove fading effect, the antenna moved continuously and average values are used in the study.

Three positions, one end of hallway (Tx1), the other end of hallway (Tx2) and inside one of the rooms (Tx3) on first floor, and also one end of ground floor's hallway (Tx4), which is in same alignment with Tx1 when looking from top, were selected as transmitting locations. All the measurements were repeated for each location.

For each measurement set, the receiver started to move around the building in clockwise direction and completed one tour, beginning from the nearest wall to the transmitter location and ending at the same position. For locations on the first floor; the tours start from point 1 and end at point 28, from point 15 and end at point 14, and from point 11 and end at point 10 for Tx1, Tx2 and Tx3, respectively. The measured data were recorded approximately 1 m away from the outer wall of the building. Top view of the first floor, transmitter locations and calculation points (1-28) are all shown in Fig. 2. For transmitter location on the ground (Tx4); the tour starts from point 1 and end at point 28. Similarly, measured data were recorded approximately 1 m away from the outer wall of the building. Top view of the ground floor, transmitter location and calculation points (1-28) are all shown in Fig. 3.



: Top view of first floor of the building. **2 Figure**

The red numbers (1-28) show calculation points, namely, the points where the model is applied. All points are 1 m away from the external walls of the building

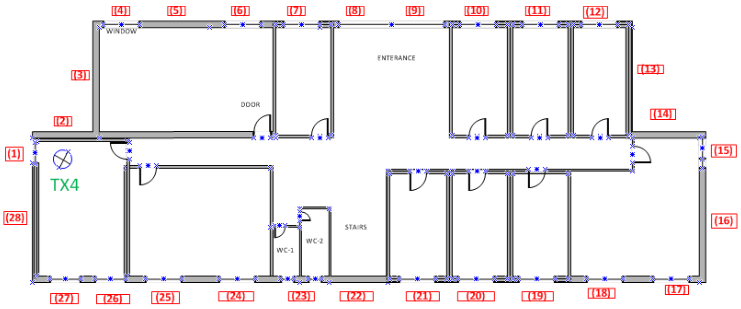


Figure 3: Top view of ground floor of the building

In theoretical calculations, for each point, the number of penetrated walls, p, in Eq. 3 was chosen such that nearest wall openings, such as windows or doors were considered, as Miura et al [5] suggested.

4. RESULTS

For each point around the building (1-28), the derived model is applied and result is compared with the averaged measurement value at that point. Results represent that theory and measurements are good in track of each other.

Fig. 4a, Fig.4b and Fig.4c are demonstrating measurement results and theoretical calculations for transmitter location TX1 for GSM900, GSM1800 and CDMA2100, respectively. Results indicate that theory and practical measurements are good in track of each other, except for some regions. A deviation between theory and measurements could be a result of office design such that some offices have roof shelves, and those shelves may cause additional attenuations which should be taken into account for further studies.

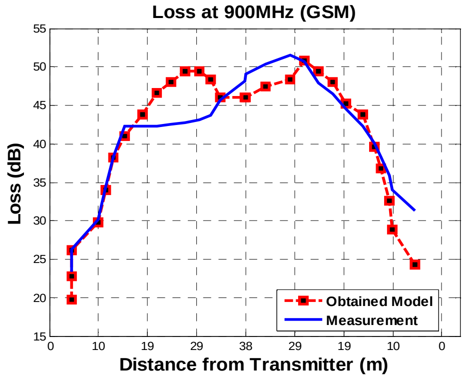


Fig 4a.GSM900 for transmitter location 1 (Tx1)

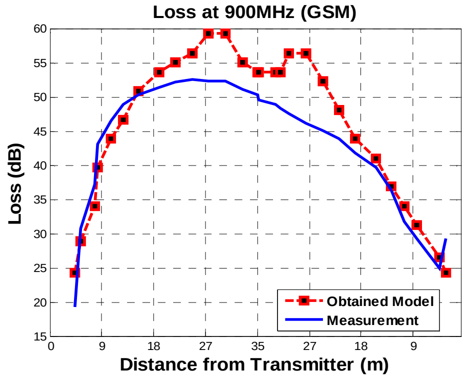


Fig 5a. GSM900 for transmitter location 2 (Tx2).

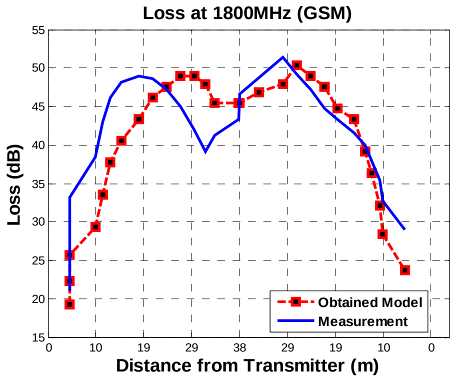


Fig 4b. GSM1800 for transmitter location 1 (Tx1).

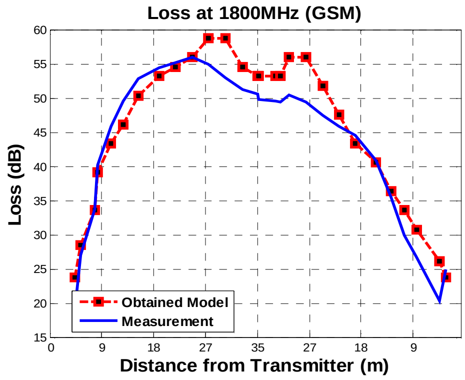


Fig 5b.GSM1800 for transmitter location 2 (Tx2).

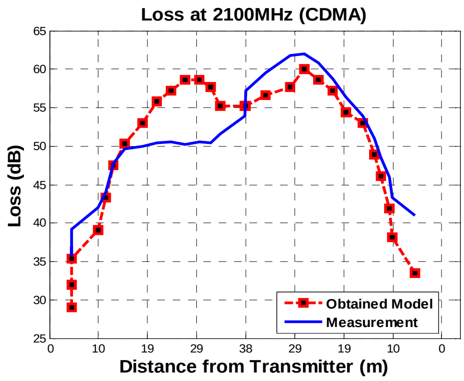


Fig 4c. CDMA 2100 for transmitter location 1 (Tx1).

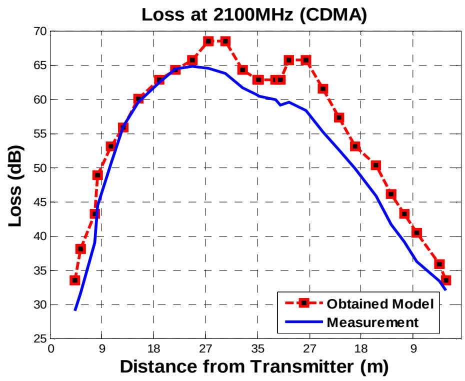


Fig. 5c. CDMA 2100 for transmitter location 2 (Tx2).

Average deviations of model predictions from measurements are about 5dB. A smoothing process of MATLAB using moving average filter has been applied to both measured and calculated data. Fig.5a, Fig.5b and Fig.5c are demonstrating measurement results and theoretical calculations at transmitter location TX2 for GSM900, GSM1800 and CDMA2100, respectively. The theoretical and practical measurements are good in track of each other. Maximum deviation is obtained at around longest distance where p =0 in the formula.

Fig. 6a, Fig. 6b and Fig. 6c are demonstrating measurement results and theoretical calculations at transmitter location TX3 for GSM900, GSM1800 and CDMA2100, respectively. The model and practical measurements are deviating from each other in the case of direct ray dominant, and at this location p=0.

In figures belonging to TX3, it is seen that the distance steadily increases up to 6th point. But, it starts to decrease up to 9th point, and then starts to increase again up to the maximum distance. If top view of the first floor (Fig. 2) is examined again, it is seen that this strange behavior is a result of the building construction.

Fig. 7a, Fig. 7b and Fig. 7c are demonstrating measurement results and theoretical calculations at transmitter location TX4 for GSM900, GSM1800 and CDMA2100, respectively. It can be observed from the figures that the model and measurements are deviating from each other between the points 3 and 10. This could be a result of the fact that the rooms near the points from 3 to 10 contain lots of metal components inside.

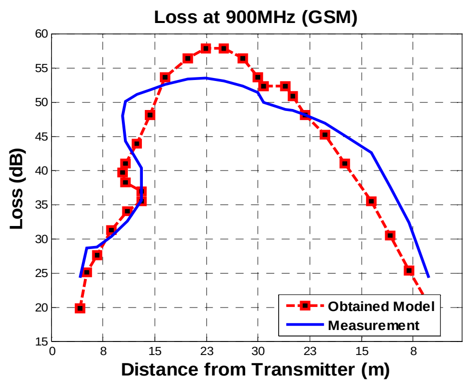


Fig. 6a. GSM900 for transmitter location 3 (Tx3).

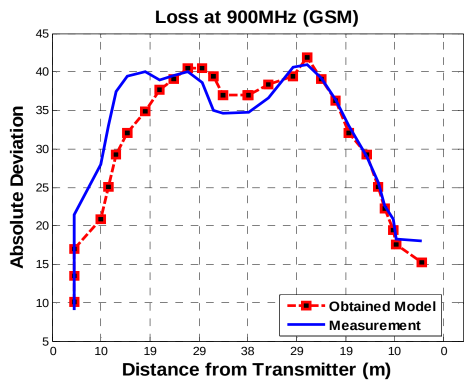


Fig. 7a. GSM900 for transmitter location 4 (Tx4).

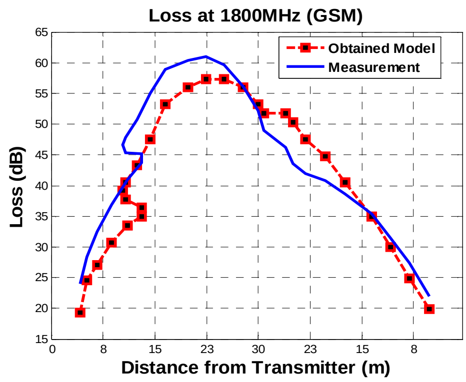


Fig. 6b. GSM1800 for transmitter location 3 (Tx3).

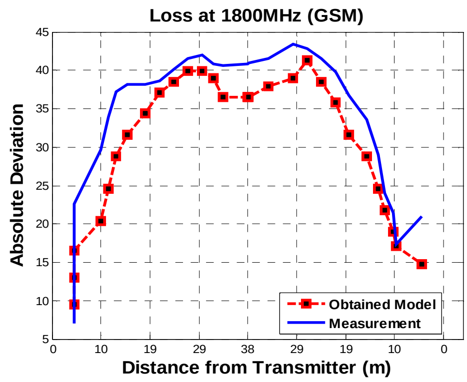


Fig. 7b. GSM1800 for transmitter location 4 (Tx4).

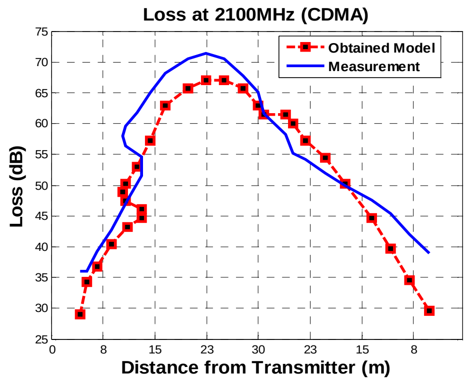


Fig. 6c. CDMA 2100 for transmitter location 3 (Tx3).

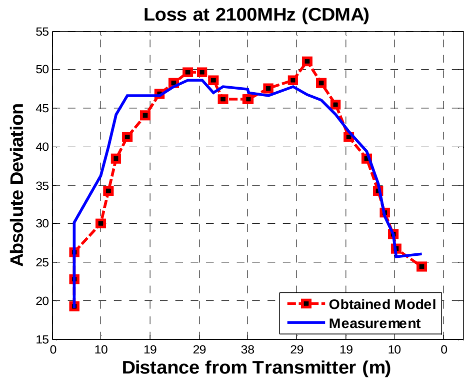


Fig. 7c. CDMA 2100 for transmitter location 4 (Tx4).

5. CONCLUSİONS

This study presented a modified indoor to outdoor propagation model, derived from outdoor to indoor empirical model [7,13]. Presented model also includes bandwidth effect of utilization channel. Generated model includes building structures such as the number of walls, position of windows and other scatters. It is valid for GSM900, GSM1800 and CDMA 2100. Maximum deviation between theory and measurement is obtained in the case of p=0 (there is only a window between Tx and Rx) that this scenario should be taken into account by further studies.

VI. ACKNOWLEDGEMENTS

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