Indoor Optimized Propagation Model at 900 MHz and 1800 MHz

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***Abstract*—Indoor propagation environment presented new challenges such as multi-wall penetration, diffraction through corners and reflection from the walls. During the last decade, the necessity of using the same bandwidth for as many customers as possible began to force GSM providers to deploy more and more picocells into indoor environments. This development increased the importance of precise and easy-to-use propagation models. For this purpose, this study focuses on the office buildings measurements to compare our indoor optimized propagation model with the existing ones. The contribution of the model is stated with the absolute mean errors.**

Keywords—GSM frequencies; indoor propagation; modeling

I. INTRODUCTION

Wireless propagation channel places basic restrictions on the efficiency of communication systems. Wireless channels are not predictable and stationary as wired channels due to line-of-sight (LOS) and obstructions like foliage, mountains and buildings problems. Throughout the century, modeling the wireless channel has been the most popular problem [1-5].

Main concern in mobile communications is to use limited bandwidth most effectively. The demand for bandwidth increased dramatically over the last decade and it is expected to increase at an accelerated pace in the future. Data traffic caused by cell phones, personal digital assistants (PDAs) and other mobile devices forces mobile service providers to reduce cell sizes for reusing same frequency band for as many customers as possible. These cell areas are now as small as a single house.

This work focuses on developing a propagation model for a modern office building at microwave frequencies. The aim is to develop accurate propagation loss model for indoor base stations and WLAN access points. To this intent, a configurable base station is used as picocell in NETAS Main Office at Istanbul. Section 2 explains measurement procedure and relevant information. Section 3 provides our propagation model and existing picocell indoor propagation models in the literature and their experimental results. Dominant mode of propagation and contribution of each different mode for these models are analyzed. In Section 4, results are evaluated to show strengths and weaknesses of the models besides brief comparison of picocell indoor propagation models. An optimized propagation model is proposed by taking different contributions from existing picocell models and adjusting model parameters for office environment. The last section addresses several concluding remarks and some areas and suggestions for possible future works.

II. MEASUREMENT PROCEDURE

For the measurements, two floors of NETAS Office building; 3rd and 4th floors are chosen. To generate electromagnetic signals, a signal generator from 10 MHz to 20 GHz is used. Omnidirectional dual-band GSM mag-mount antenna from Pasternack is used at both transmitter and receiver sides. Specifications of the antennas are listed in Table 1.

TABLE I. SPECIFICATIONS OF THE ANTENNA USED IN THE MEASUREMENTS

Parameter	Value
Band1 Frequency	890-960 MHz
Band2 Frequency	1710-1880 MHz
Impedance	50 Ohms
Gain	3 dBi

In the first step of measurements, open-air office environment's background calibration is achieved to specify antenna gains path loss at GSM frequencies at distances of 10m, 20m and 30m. The error due to 5m long RG174/U type coaxial cable losses between the actual measurement results and free-space loss predictions are calculated. Cable losses and the attenuations are notes as 1.2 dB at 900 MHz and 2 dB at 1800 MHz, and 4.5 dB at 900 MHz and 7 dB at 1800 MHz, respectively. 70 discrete measurement locations are chosen for the measurements. The receiver position is moved around the chosen locations to obtain the accurate results [2].

III. OPTIMIZED PROPAGATION MODEL

Improved Motley-Keenan and Multi-Wall models are the best predictions for both 900 and 1800 MHz [5]. To approximate path loss shift, 2 dB and 5 dB of L_c factors are added where oats of plaster walls, glass and concrete walls are included in the test environment. It is seen that two-wall model is more accurate than one-wall Motley-Keenan model.

Considering the accuracy of the cases, 1.5 m thick steel-reinforced second floor is used for all of the models in NETAS office. Secondly, it is observed that by adding second-slope to Improved Motley-Keenan model gives more accurate predictions in the close range.

A. *Direct Propagation*

As the results obtained it is seen that following effects are suggested [5, 6].

Dual Slope: Slope change is observed at around 10 m from transmitter.

Traversing: The propagation loss for the first traversed wall is greater than the incremental attenuation caused by each additional wall. In order to model the factor, different wall loss factors are used depending on the traversing number.

Multi-Wall Types: Including different attenuation factors for different walls improved accuracy.

Angle of Incidence: Anything other than normal incidence would cause additional loss. In order to model this factor, angle of incidence between transmitter and the obstructing wall is added.

Wall Thickness: In a typical office environment, there are several different types of walls and same type of walls doesn't have same thickness all over the place. Adding thickness factor into account improves accuracy.

Improved Motley-Keenan model introduced wall thickness into equation and the results show that considerable increase in accuracy is achieved over standard model with this approach. Improved Motley-Keenan approach requires the knowledge of attenuation and thickness value for some reference obstructions.On the other hand, standard Motley-Keenan model requires the assumption of some reference attenuation values for the walls.

B. *Diffraction*

Diffraction approach in uniform theory of diffraction (UTD) indoor model is implemented to the optimized model for the one corner only. Luebber [9] has suggested a modified heuristic diffraction coefficient (LHDC) to improve UTD equations in a limited location sizes, however the drawbacks of the theorem are overcome with New heuristic diffraction coefficient (NHDC) equations by H. El-Sallabi et al. [10]. In optimized model, UTD equations for wedges are used and the diffracted electric field is given in [11].

C. *Waveguide Propagation*

For long hallways, direct propagation calculations predict higher path loss than actual value. This is due to wave guiding effect of corridors. Waveguide model for corridors are suggested in [1] to calculate path loss in hallways. In these works, hallways are considered as slab waveguides. The path loss for hallway is then given in [5, 12], parameters for the model are given in Table 2.

TABLE II. MODEL COEFFICIENTS FOR OPTIMIZED MODEL

Frequency	**N_1**	**N_2**	**L_0[dB]**	**L_f[dB]**	**db_p[m]**
900 MHz	20	30	30	40	10
1800 MHz	20	30	38	40	10

For wall losses, the values found in previous Section are used with the addition of traversing effect. Reference wall losses at 900 MHz and 1800 MHz are given in Table 3 and Table 4.

TABLE III. REFERENCE WALL LOSSES AT 900 MHZ

Wall Type	**Thickness[cm]**	**j=1**	**j=2**
Glass	1	2	-
Plaster Wall	12	2.5	1.5
Concrete Wall	15	8	7

TABLE IV. REFERENCE WALL LOSSES AT 1800 MHZ

Wall Type	**Thickness[cm]**	**j=1**	**j=2**
Glass	1	2	-
Plaster Wall	12	3.5	2.5
Concrete Wall	15	9	8

Direct propagation is characterized by path loss along the direct route between transmitter and receiver, where d is the direct distance between transmitter and receiver, d_c is the distance between diffracting corner and receiver, ϕ_c is the angle between diffracting corner and transmitter, $D(d_c, \phi_c, d'_c, \phi'_c)$ is diffraction parameter, L(d) is path loss formula for direct path, h is the height of corridor, k is wave number, n is the number of reflections, $p_n^{(0)} = \sqrt{k^2 + (\pi n/h)^2}$ and R_n is the reflection coefficient of each wall. In the proposed Optimized Model, it is denoted as L(d) and is given by (2) as follows:

$$L_F(d) = \begin{cases} L(d) & \text{Direct,} \\ -10log[l(d_c)l(d_{c'}) \times |D(d_c,\phi_c,d'_c,\phi'_c|^2 + l(d)] & \text{Direct+Diffraction,} \\ 32.1 - 20log|R_n| - 20log\left[\frac{1-[R_n]^2}{1+[R_n]^2}\right] + 17.8logd + 8.6\left[-ln|R_n|\left(\frac{\pi n}{h}\right)\frac{d}{p_n^{(0)}h}\right] & \text{Waveguide,} \end{cases}$$

(1)

$$L(d) = L_0 + \sum_{i=1}^{I}\sum_{l=1}^{L_i} L_{0ij} 2^{\log_3 \frac{e_{il}}{e_{0i}}} / \cos\theta_l + k_f L_f + \begin{cases} N_1 \log_{10} d & 1m < d \le d_{bp} \\ N_1 \log_{10} d_{bp} + N_2 \log_{10}(\frac{d}{d_{bp}}) & d > d_{bp} \end{cases}$$

(2)

where L_0 is the loss at 1m, d is distance, d_{bp} is break-point distance, L_i is number of type i walls, I is number of wall types, L_{0ij} is the penetration loss in type I reference wall for j-th traversed wall, e_{0i} is the thickness of I reference wall, e_{il} is the thickness of the l-th wall of type i, k_f is the number of floors, L_f is floor attenuation factor, θ_t is angle of incidence between l-th wall and direct path between transmitter and receiver, N_1 is path loss exponent for LOS region and N_2 is path loss exponent for NLOS region.

IV. DISCUSSION OF MODELS

The formulations of each model with the model parameters are simulated in Matlab. Determined input values consist of number of corners, walls, floors and types of walls, thickness of walls and etc. For various scenarios, to evaluate optimized model's efficiency mean absolute errors of all models are calculated for single-floor, multi-floor, LOS, light obstruction by plaster walls and heavy obstruction by concrete walls scenarios separately. Measured values of transmission coefficients and attenuation losses in dB for different obstructions are shown in Tables 5 and 6.

TABLE V. TRANSMISSION COEFFICIENTS FOR INTERNAL WALLS IN NETAS OFFICE

Wall Type	Thickness[cm]	900 MHz	1800 MHz
Glass	1	0.8	0.8
Plaster Wall	12	0.75	0.67
Concrete Wall	15	0.4	0.35

Comparisons between Optimized model and picocell propagation models for different models are shown in Table 7, Table 8, Table 9, Table 10 and Table 11.

TABLE VI. WALL LOSSES IN DB FOR INTERNAL WALLS IN NETAS OFFICE

1800 MHz	Thickness[cm]	900 MHz	1800 MHz
Glass	1	2	
Plaster Wall	12	2.5	3.5
Concrete Wall	15	8	9

TABLE VII. COMPARISON OF MODELS FOR SINGLE-FLOOR CASES

Model	Mean Error (900 MHz)	Mean Error (1800 MHz)
Single-Slope	5.8	5.4
Dual-Slope	10.2	11.0
ITU-R Model	7.7	7.0
Motley-Keenan	5.9	5.7
Improved Motley-Keenan	4.2	4.9
Akerberg	7.8	7.3
Multi-Wall	4.1	5.2
Winner II	-	6.5
Lecours	5.0	-
UTD Indoor	4.9	-
Optimized	3.2	4.3

TABLE VIII. COMPARISON OF MODELS FOR MULTI-FLOOR CASES

Model	Mean Error (900 MHz)	Mean Error (1800 MHz)
Single-Slope	9.2	8.9
Dual-Slope	44.3	43.8
ITU-R	14.6	13.9
Motley-Keenan	5.0	7.2
Improved Motley-Keenan	4.3	6.8
Akerberg	36.2	35.2
Multi-Wall	5.0	3.4
Winner II	-	15.1
Lecours	4.5	-
UTD Indoor	4.4	-
Optimized	4.1	5.1

As it is seen obviously, optimized model have the optimum results with parameter optimization and the addition of second-slope. Marginal improvement is achieved for heavily-obstructed cases at 900 MHz and the same results are obtained for 1800 MHz.

TABLE IX. COMPARISON OF MODELS FOR LOS CASES

Model	Mean Error (900 MHz)	Mean Error (1800 MHz)
Single-Slope	4.3	3.1
Dual-Slope	2.7	3.2
ITU-R	12.5	11.2
Motley-Keenan	2.7	4.0
Improved Motley-Keenan	2.7	4.0
Akerberg	9.5	8.5
Multi-Wall	3.5	3.2
Winner II	-	5.7
Lecours	2.5	-
UTD Indoor	2.2	-
Optimized	2.4	3.0

TABLE X. COMPARISON OF MODELS FOR LIGHT OBSTRUCTION CASES

Model	Mean Error (900 MHz)	Mean Error (1800 MHz)
Single-Slope	8.4	6.5
Dual-Slope	6.3	10.9
ITU-R	6.8	3.7
Motley-Keenan	8.2	5.9
Improved Motley-Keenan	5.9	8.5
Akerberg	7.0	6.2
Multi-Wall	4.0	8.4
Winner II	-	6.2
Lecours	5.7	-
UTD Indoor	3.5	-
Optimized	3.5	5.1

TABLE XI. COMPARISON OF MODELS FOR HEAVY OBSTRUCTION CASES

Model	Mean Error (900 MHz)	Mean Error (1800 MHz)
Single-Slope	5.6	6.1
Dual-Slope	14.5	14.2
ITU-R	5.9	6.2
Motley-Keenan	6.6	6.4
Improved Motley-Keenan	4.3	4.2
Akerberg	7.3	7.1
Multi-Wall	4.4	5.1
Winner II	-	6.9
Lecours	5.8	-
UTD Indoor	6.5	-
Optimized	3.4	4.6

V. CONCLUSION

It has been observed that addition of several wall types and thickness information into propagation formula significantly improves the accuracy of the models. Different path loss patterns in the near zone of the antenna were observed during measurements.

Effects like diffraction, traversing and angle of incidence were also observed to make positive contributions in measurement cases that suit them. Using the performances of the existing models as a base, this study suggests an optimized model for an office environment. Input parameters were also revised to obtain best predictions.

The main contribution of this work is the derivation of an office-optimized indoor propagation model. The model is quick and easy to use and gives good predictions in our measurement site. Once a site-map is obtained, the model could be used to make quick signal level estimations. Multi-wall effects, wall thickness effects, floor attenuation, diffraction, traversing, angle of incidence and dual-slope effects are evaluated in the model.

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