ENHANCED OUTDOOR-TO-INDOOR COVERAGE ESTIMATION IN MICROCELLS

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Abstract

Outdoor-to-Indoor propagation loss has been measured in four buildings in urban microcells. The results of the performed experiment as well as those of several other authors, are compared with COST231 model prediction and postulates are presented for improved coverage estimation in buildings with LOS illumination- an empirical equation for loss in the externally illuminated wall at perpendicular penetration is presented, heterogeneous building surface is fictitiously divided into multiple segments, and paths through NLOS surfaces are also considered for reception points located deep inside the building. It is shown that the proposed enhancements improve the COST231 model estimation error by approximately 3 dB.

Key word: Enhanced Outdoor: Outdoor-to-Indoor propagation, Microcells, Building penetration, Non-line of Sight (NLOS

INTRODUCTION

In• today's• sprouting• wireless• communication services a great deal of attention is paid to cover the indoor areas in buildings, shopping malls, train stations et al. Indoor radio coverage. is provided by the existing outdoor base stations or by installing exclusive indoor base stations inside the buildings. However, network providers are always interested in a cost effective approach where they can utilise the existing microcell base stations for indoor areas and avoid the cost of using additional cell sites. Thus, in order to reach sufficient indoor coverage without great expenses, it is necessary to have accurate prediction of the effective radio coverage.

A lot of research has been carried for Modeling the outdoor-to-indoor scenario and several prediction models have been proposed in this regard. Empirical models which are analytical equations designed out of extensive filed measurements require less input information and provide reasonable accuracy and computational efficiency. On the other hand deterministic models which are resulting from theory rather than experience are less computationally efficient and provide better accuracy at the cost of requiring detailed input information about the propagation environment [4][12]. Largely, among all empirical models presented in literature, the COST231 model [2] is considered to be the most accurate and widely used model for outdoor-to-indoor coverage prediction [4][5].

In this paper we present the results of field strength measurements carried in four buildings. The results are compared to the predictions of COST231 model and enhancements are suggested in COST231 model for improved coverage estimation. In section II we describe the measurement equipment and experimental procedure. Section III discusses the results and analysis of the measurement experiment. The results are compared to COST231 model estimation in section• IV• and• a• new• 'enhanced• outdoor-to-indoor• model'• is• proposed.• Finally,• the discussion is concluded in section V.

MEASUREMENT EXPERIMENT

The measurements were carried out in two tri-sector microcells with base station (BS) antenna located above rooftop level at a height of 25 m, operating at a frequency of 900 MHz. The BS antenna had a gain of 17.7 dBi, transmit power of 60 dBm and electrical downtilt of 7°. Ericsson Test Mobile System (TEMS) was used to measure the received signal strength on the downlink channel. The TEMS receiver was camped to a particular ARFCN of broadcast control channel (BCCH) and the signal strength was measured within one (51×.8) multiframe of 480 ms (sampling rate of approximately 100 samples per frame).

The measurements were taken inside and around the perimeter of four buildings in the metropolis of Karachi. The buildings included two of the campus buildings (referred to as A and B in this paper) of the Institute of Management and Computer Sciences, Bahria University and two apartment buildings (referred C and D) in the city downtown.

Building A was a three storey building of reinforced concrete with varied proportion of coated glass windows on the surface; its internal layout consisted office rooms, halls and large lobbies on each floor. Building B was a two storey (and a basement) building of reinforced concrete with uncoated glass windows; its layout consisted labs and office rooms in the basement while a cafeteria and an auditorium on the ground and first floor. Building C and D were identical nine storey apartment buildings of reinforced concrete and uncoated glass windows; internal layouts consisted five apartments (each consisting five rooms) on each floor with a corridor and an elevator channel. Building A, B and C were in line of sight (LOS) while building D was in non-line of sight (NLOS) to the transmitter

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Table I Mean RSS inside and around four buildings

Building	Mean RSS Outside [dBm]	Mean RSS Inside [dBm]	Building Loss [dB]
A	-45	-65	20
B	-45	-61	16
C	-43	-60	17
D	-47	-68	21

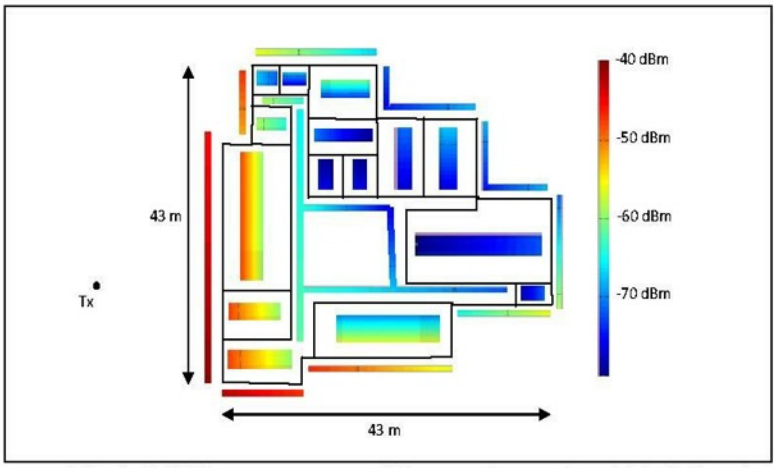

Fig. 1. RSS Layout on ground floor and street level f building A

The measurements were done by an individual carrying the receiver (in idle mode) at a height of approximately 1.5m in rooms and corridors of the buildings. The arithmetic means were calculated over measurement lengths of 6.25λ(2m) inside the buildings. Local means were calculated as arithmetic averages within rooms.

Measurement Results and Analysis

In this section we discuss the results of the measurement experiment and analyse the propagation behaviour. Table I shows the average received signal strength inside and outside the four buildings along with the corresponding mean building penetration loss values. The building penetration loss calculated here is the difference between the average of local power means in the illuminated street along the building and the average of local power means inside the building. The average building penetration loss in four buildings was found to be 18 dB which is consistent with the works of [1], [6], [7].

All the four buildings investigated had more or less a similar trend of power level inside. The received signal strength (RSS) on ground floor and outside street level of building A and C is depicted in Fig. 1 and Fig. 2, which represents the typical trend found in the experiment.

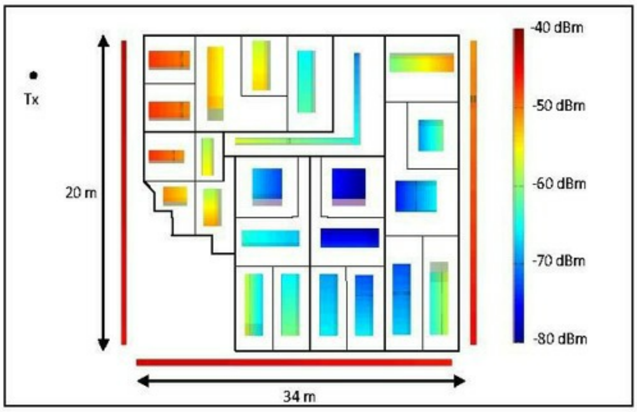

Fig. 2 RSS Layout on ground floor and street level of building C

Signal strength distribution depicted in Fig. 1 and Fig. 2 follows a plausible behaviour.
Indoor power level is high near the illuminated surface and decreases with distance and internal building partitions while moving away from the surface. However, it can be noticed that rooms located away from the illuminated surface are receiving signals from the non-line-of-sight (NLOS) surface. It is because of the strong reflections in the outdoor clutter and diffraction from the edges of the building under observation resulting in considerable coverage in NLOS streets. It can be deduced that the LOS surface may not be responsible for signal propagation into every room inside the building.

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In Fig. 2, a high variation of signal strength is observed in some cases even between adjacent rooms facing the same facet of the building. Despite the rooms being adjacent and identically oriented towards the transmitter standard deviation of as much as 12 dB was observed. This is because of the difference of window-wall arrangement in the building facet for each room. Rooms having larger proportion of windows on the building facet received higher power levels than others.

A peculiar behaviour was observed in the auditorium in building B. Penetration loss of only 2 dB was measured despite the reinforced concrete construction with no windows. Possibly, the distinct orientation of auditorium towards the transmitter was responsible; as it was illuminated on two facets as well as on the roof.

Increase in power level of approximately 2 dB was observed on each floor while moving upward in building D. However this effect was not found in the remaining three buildings. This is because building D is in NLOS while buildings A, B and C are in LOS with the transmitter. This phenomenon is called the height gain effect, reported in most of the works on outdoor-to-indoor propagation

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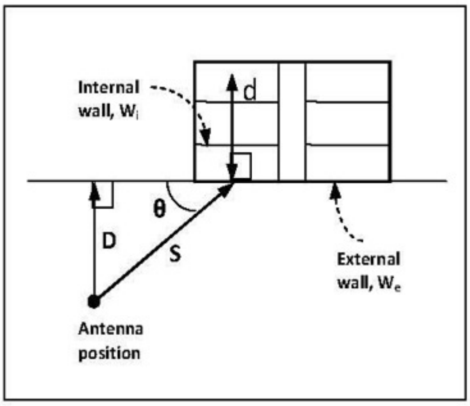


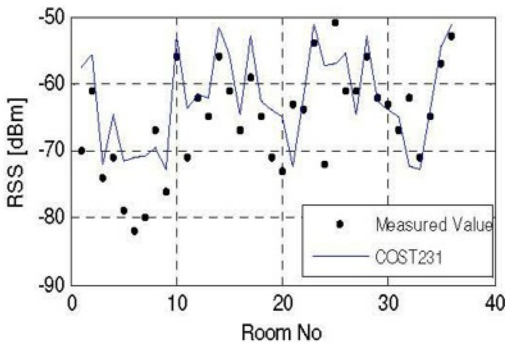


Fig. 3. Top view of the illumination of a building Fig. 4. Measured values vs. COST231 estimation

Table II COST231 parameter values and predicted & measured RSS values inside the buildings

Building	We	WGe	Wi	Predicted Mean RSS [dBm]	Measured Mean RSS [dBm]	RMSE [dB]
A	7	18	7	-59	-65	8
B	10	20	4	-64	-61	6
C	10	20	4	-65	-62	4
D	12	20	4	-68	-66	4.5

It is explained by the fact that in buildings with NLOS illumination, waves are received after reflection from the surrounding clutter. On lower floors larger number of surrounding structures is involved in the reflection mechanism while on higher floors only few surrounding structures have enough height to obstruct the line of sight.

MODELING OF OUTDOOR-TO-INDOOR COVERAGE

In this section we describe the performance and evaluation of COST231 model against the measured data, followed by postulates for enhanced outdoor-to-indoor coverage modeling.

COST231 Model

COST231 model is considered as the most accurate and widely used model for outdoor-to-indoor coverage estimation. COST231 requires relatively smaller amount of input information efficiency. The model gives the path loss between an outdoor street microcell base station antenna and a mobile in a building along the same street. The following expression gives :

$$L_{dB} = L_f(S+d)_{dB} + W_e + (1-D/S)^2 * W_{Ge} + Max(\Gamma_1, \Gamma_2) \quad (1)$$

$$\Gamma_1 = Wi * p \quad (2)$$

$$\Gamma_2 = \alpha * (d-2) * (1-D/S)^2 \quad (3)$$

The model parameters are illustrated in Fig. 3. *S* is the distance between the base station and the external wall of the building, *d* is the distance from the external wall to the mobile station, *θ*is the grazing angle of the external wall *Lf(*)* is the free space propagation loss for the distance between base-mobile station. *We* is the loss in dB of an externally illuminated wall with perpendicular penetration, θ=0°. *WGe* is the additional loss in dB in the external wall when θ=90°. *Wi* is the internal wall loss and *p* is the number of penetrated internal walls. *α*is the specific indoor attenuation constant and has NLOS version of COST231 was used for estimation in building D as it is not directly illuminated by the transmitter. Fig. 4 displays COST231 estimation against measured RSS values in building A. Table II gives the COST231 parameter values and predicted and measured RSS values inside the four buildings (*α*=0.6 dB/m). The root mean square error (RMSE) is also given to indicate the accuracy of the model.

Although COST231 gives a reasonable agreement with the measured data, however, it deviates from measured values at some

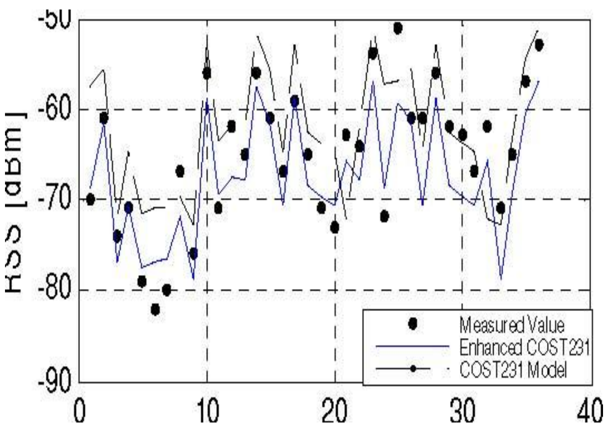
Table III Proposed model predicted RSS and measured RSS values inside the buildings

Building	Predicted Mean RSS [dBm]	Measured Mean RSS [dBm]	RMSE [dB]
A	-67	-65	4
B	-62	-61	3.4
C	-63	-62	3.3

The parameter *We* (perpendicular penetration loss in the external wall) is a major contributor in calculating the overall outdoor-to-indoor loss. COST231 merely suggests a range 4-10 dB (concrete with normal window size 7 dB, wood 4 dB) for *We* without providing details for different scenarios. However, in our experiment as well as in the works of [2][3][4] better estimation is observed by using values considerably higher than the suggested range. Additionally, the choice of *We* value for a specific window wall arrangement becomes difficult as there is no detailed definition of *We* given against specific wall properties. Also, COST231 assumes only the external wall that is in direct view (line of sight) of the base station as responsible for penetration. However, in a cluttered surrounding, as in our experiment, non-line-of-sight facet can be a dominant signal source for rooms located away from the LOS surface.

Proposed 'Enhanced Outdoor-to--Indoor Coverage Model'

Based on the observations of this investigation we propose the following postulates for the COST231 model for the case when there exists LOS between the building and the base station:
The building surface should be divided into a number of characteristic segments representing specific window-wall arrangements. Each segment is assigned its own perpendicular penetration loss (*We*) depending upon its surface properties. The individual rooms located inside are awarded their corresponding



For the calculation of perpendicular penetration loss (*We*) an empirical model is developed which eliminates the uncertainty in choosing a value for specific wall properties. Backward

Table I VVariables and values for different instances for eqe (4)

f	In MHz
Wpr	In percentage %
Wt	Uncoated glass 1 Coated glass 2 Double glazed 3 Wire reinforced 3
Wmat	Brick 1 Cinder block 1 Concrete block 2 Reinforced concrete 3

segments. Thus instead of considering a uniform surface for every room, we consider the actual surface of a room by assigning it a semi-generic surface profile in the form of surface segment.
At least two propagation paths should be considered in calculating the signal level for every location inside the building; one through the LOS surface of the building and the other through the side facet closest to the mobile station. This would improve the accuracy particularly in the rooms located away from the LOS surface where the NLOS facet can be a dominant source of propagation Room No

Fig. 5. Proposed model and COST231 estimation vs Measured values

multiple regression technique was employed and the data gathered in this experiment and from the works of [9], [10], [15] was used for the formulation of the following empirical expression:

$$W_e = 15.53 + 10.143 * \log_{10}(f) - 0.158 * W_{pr} - 0.3549 * W_t + 3.439 * W_{mat} \quad (4)$$

where *We* gives the perpendicular penetration loss, f is the operational frequency in MHz, *Wpr* represents the proportion of windows in the external wall, *Wt* represents window type and *Wmat* represents the material type of the external wall. Table IV lists the values of each variable for different instances.

The proposed enhancements show a reasonable improvement in the COST231 model estimation. Fig. 5 plots the proposed model and COST231 estimation against measured RSS values in building A. From Fig. 5 it is obvious that the enhanced model improves coverage prediction in room 8, 18, 20, 21, 29, 32 which, contrary to COST231 assumption, are receiving coverage from the NLOS facet. Similarly, room 1, 10, 11, 16, 24, 36 and 37 all have varying window sizes and exterior properties, therefore the improvement is due to our proposed surface segmentation and the We calculation formula.

Table IV shows the mean predicted and measured RSS values inside the three LOS buildings and the respective RMSE. It can be noticed that the enhancements improve the RMSE in building A by 4 dB, in building B by more than 2 dB and by more than 1 dB in building C as well.

The proposed model suggests three enhancements that promise improved coverage estimation when incorporated in the COST231 model. We have suggested an equation—an accurate and effortless method—for calculating the perpendicular penetration loss, a suggestion of fictitiously dividing the external surface into segments and also proposed that at least two propagation paths i.e. both through the LOS and NLOS facets should be considered for every indoor location.

CONCLUSION

We have proposed a new model for outdoor-to-indoor coverage estimation in microcells. Results of field strength measurements performed in and around four buildings are presented. The results are compared to the well known COST231 model and a new model is proposed for improved coverage estimation. The proposed model incorporates three postulates in the COST231 model and improves coverage estimation by several dB. It is proposed that instead of considering a uniform external building surface for every location inside, the surface should be divided into multiple segments and individual rooms inside should be assigned its corresponding surface segment, at least two paths should be considered for every indoor location including both through the LOS and NLOS facets. Subsequently an empirical equation is presented to accurately calculate the perpendicular penetration loss.

We have also demonstrated that the proposed model provides improved accuracy over the COST231 model by 2 to 4 dB.

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REFERENCES

- **J. M. Durante**, "Building Penetration Loss at 900 MHz," Proc. IEEE Trans. Veh. Technol, pp 1-7, 1973.
- **J.E. Berg**,•"Building•Penetration,"•in•Digital•Mobile•Radio•Toward•Future•Generation Systems (COST 231 Final Report), Brussels, Belgium: COST Telecom Secretariat, CEC, sec. 4.6, pp. 167–174, 1999.
- T**. Kuerner, A. Meier**, P rediction of u tdoor and u tdoor-to-Indoor Coverage in Urban Areas at 1.8 H z, e lected Areas in Communications, IEEE Journal on, vol. 20, no. 3, pp. 4965 06, April 2002.
- **W. Karner, A Paier, M Rupp**, I ndoor Coverage Prediction and p timization for UMT Macro Cells, IEEE Advanced Information Networi ng and Applications, AINA, vol 2, pp 626-632, April 2006.
- **Y. Miura, Y. Oda , T. Taga**,•"Outdoor-to-Indoor Propagation Modeling with the Identification of Path•Passing•through•Wall•Openings,"•IEEE•PIMRC,•vol•1,•pp•130-134, 2002.
- **Martijn, E.F.T. and Herben, M.H.A.J**., C haracterization of radio wave propagation into buildings at 1800 MHz, Antennas and i reless Propagation Letters, Vol. 2, Iss. 9, pp. 122-125, 2003.
- **M. D. Turkmani and A. F. de Toledo**, a dio transmission at 1800 MHz into and within multistory buildings, Inst. Elect. Eng. Proc.-I, vol. 138, no. 6, 1991.
- **F. de Toledo, A. M. D. Turkmani, and J. D. Parsons**, Estimating coverage of radio transmission into and within buildings at 900, 1800, and 2300 MHz, in IEEE Personal Commun., vol. 5, pp. 404 7, Apr. 1998.
- **P. Backman, S. Lidbrink , T. Ljunggren**, B uilding Penetration Loss Measurements at 1.7 H z in Microcellular Environments, CT 231, TD9 01 21, Darmstadt, Dec, 1990.
- **R. Gahleitner**, a dio a ve Propagation In and Into Urban Buildings, Ph. D. Thesis, Technical University of Vienna, 1994.
- **Davidson and C. Hill**, M easurement of building penetration intomedium. buildings at 900 and 1500 MHz, IEEE Trans. Veh. Technol., Vol. 46, pp 161-167, 1997.
- **K. Cheung, J. Sau, and R.D.Murch**, A new empirical model indoor propagation prediction, IEEE Trans. Vehic. Tech., 1997.
- **W. J. Tanis and G. J. Pilato**, B uilding penetration characteristics of 880 MHz and. 1922 MHz radio waves, 43. rd. IEEE Veh. Technol Conf. Proc., 1993.
- **S. Aguirre, L.H. Loew, and Y. Lo**,•"Radio•Propagation•into•Buildings•at•912,•1920,•and•5990. MHz Using Microcells". Proceedings of 3rd IEEE ICUPC. , pp. 129-134, Oct 1994
- **M. Sanden**, B uilding Penetration Loss Environment, CT 231, TD9 01 22, Darmstadt, Dec, 1990.
- **Y.L.C. de Jong, M. Koelen and M.H.A.J. Herben**, "A Building-Transmission Model for Improved Propagation Prediction in Urban Microcells", IEEE Trans. Veh. Technol, vol 53, 2004.
- **COST 231**, "Digital• Mobile• Radio• Toward• Future• Generation• Systems,"• Final• report• COST Telecom Secretariat, European Commission, Brussels, Belgium, 1999.
- **J. Horikoshi, K. Tanaka, and T. Morinaga**, 1 .2 H z band wave propagation measurements in concrete building for indoor radio communications, *IEEE Trans. Veh. Technol.*, vol. VT-35, pp. 1461 52, Nov. 1986.
- **Alayon Glazunov, L. Hamberg, J. Medbo**, "Building shielding loss measurements and modeling at the 5GHz band in office building areas", Proceedings of IEEE VTC, 2000.
- **Alayon Glazunov, J-E Berg**, "Building shielding loss modeling", Proceedings of IEEE VTC 2000.