Wave Propagation into Buildings

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Abstract

This paper investigates radio wave propagation into buildings illuminated from an out- door base station with an antenna above the rooftop. Field strength measurements are taken in four buildings in urban microcells. Results of our experiments as well as those of several other authors are analyzed and the important factors influencing building penetration loss have been discussed namely angle of incidence, external wall configuration, receiver height and significance of non-line-of-sight surface of the building.

Keywords: Building penetration loss, Radio wave propagation, Outdoor-to-indoor propagation, Urban microcells, Non-line-of-sight illumination

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INTRODUCTION

By the end of 2007, the global mobile base exceeded 3.25 billion connections, or over half the world's population [Green et al 2007]. With handsets and services becoming ever more affordable, the prospect of a fully connected mobile world is becoming ever more real. With present third generation telecommunication systems such as Universal Mobile Telecommunication System (UMTS), telco operators are able to provide wireless data services like Internet at data rates up to 2 Mbps in dense urban and indoor environments (Karner et al. 2006).

Since we spend considerable time inside buildings, it becomes indispensable for the network provider to cover indoor areas. Network providers, however, are always interested in a cost effective approach to utilise the existing microcell base stations to cover indoor areas. For the network provider, providing indoor coverage means additional difficulties. In addition to signal strength in urban streets, he has to predict signal losses in a completely different and complex environment. In order to accurately predict the radio wave coverage in any environment, network providers require a thorough knowledge of the channel characteristics such as the surrounding clutter, angle of arrival, frequency of operation etc. This work presented and investigates the radio propagation into buildings.

The proposed received-signal-strength estimation technique uses a topological map of the one-hop neighborhood. Each vehicle along the LOS path between the sender and the receiver is counted as a source of signal attenuation. The accumulated signal attenuation is the sum of attenuation caused by each vehicle along the LOS path. Multiple knife-edge diffraction model is used to account for the loss with each obstructing vehicle counted as a source of diffraction. The simulation results show that the attenuation strictly depends on the angle of the obstacle with the sender and the receiver nodes. A single vehicle as obstacle can cause a received signal strength drop between 2 to 20dB.

MATERIALS AND METHODS

Measurements were taken inside and around the perimeter of four buildings in the metropolis of Karachi. The buildings were typical urban structures of reinforced concrete, varying from 2 to 9 storey's in height, having coated and uncoated glass windows. 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. Measurements were taken at 900 MHz with base station (BS) antenna located above rooftop level at a height of 25 m. The BS antenna had a gain of 17.7 dBi, transmit power of 60 dBm and electrical down tilt 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).

Table 1: Rss on Each Floor of the Buildings.

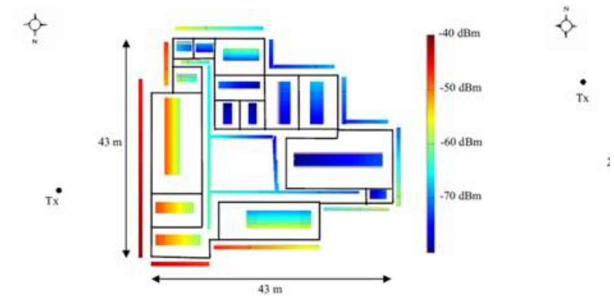
Building & Floor No	Floor Area [m^2]	Tx-Rx [m]	Mean RSS Outside [dBm]	Mean RSS Inside [dBm]	Building Loss [dB]
A f1	1386	40	-45	-69.2	19.9
A f2				-64.1	
A f3				-61.6	
B f-1	692	40	-45	-65.11	12.6
B f1				-59	
B f2				-49	
C f1	680	387	-44	-61.8	18.4
C f2				-61	
C f3				-61.6	
C f5				-63.2	
C f6				-63.2	
C f7				-63.4	
C f9				-63	
D f1	806	436	-45	-68	18.6
D f2				-65.6	
D f3				-63.8	
D f4				-62.4	
D f5				-61.2	
D f6				-61	

Floor f1 refers to ground floor while f-1 refers to basement

Building penetration loss in this work is defined as the difference between the average of local power means (in dBm) measured outside a building at street level in the adjacent streets and the average of local power means on a specific floor inside the building. The outside reference measurements were taken about 2 meters from the external wall and around two 2 meters above the ground. The measurements were taken around the complete perimeter of a given building regardless of whether the street is directly illuminated or not. The indoor measurements were taken in all the rooms inside the building. The arithmetic means were calculated over measurement lengths of 6.25λ (2m) inside the buildings. Local means were calculated as arithmetic averages within rooms.

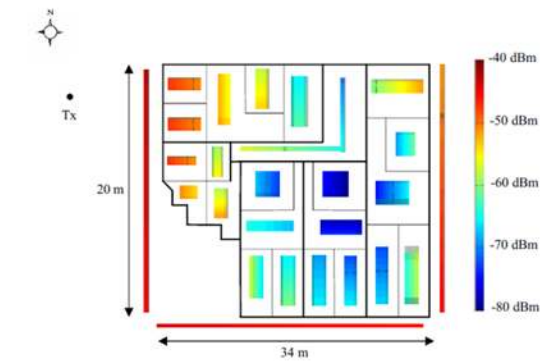
RESULTS AND DISCUSSION

Table I shows the average received signal strength on each floor inside the four buildings along with the corresponding outdoor signal strengths and the mean building penetration loss values.



(a) Building A.

Building C. Figure 1. RSS layout on ground floor and street level of buildings.



(b)

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 (Karner et al. 2006, Martijn et al. 2003 and Turkmani et al. 1991).

All the four buildings investigated had more or less a similar trend of power level inside. The building penetration loss in building B is small due to the fact that B is being illuminated on two facets as well as on the roof and also due to a relatively straight out floor plan without too many partitions. 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.

Signal strength distribution depicted follows a plausible behavior. Indoor power level is high near the illuminated surface and decreases with distance and internal building partitions while moving away from the surface. In Fig. 1 Building A is illuminated perpendicular from the front facet while it is also receiving strong reception in one side facet which is probably due to the surrounding clutter. In the figure, the three front rooms are receiving maximum reception because here the propagation is perpendicular and it is only obstructed by the external wall while there are no internal partitions.

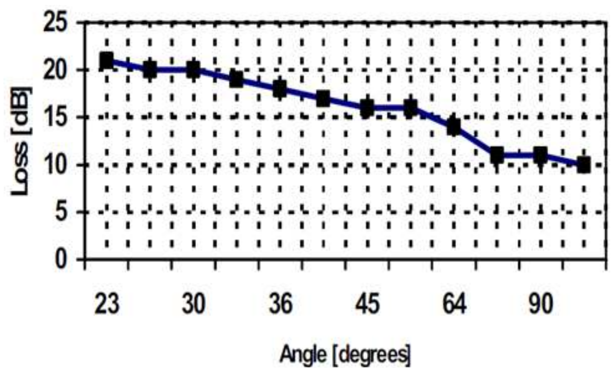
The two adjacent rooms on south have very weak reception because of the lack of wall openings. Further indoors, in the lobby the reception is nearly consistent due to uniformity of penetration channels; the penetration points are the two door openings in the front facet — one in the north and the other in the south. In the rooms deeper inside the building the reception is understandably weaker due to propagation being obstructed by a number of partitions along the way.

Fig. 2 shows the coverage in the apartment building C. The clutter here is perfect dense urban where the street is enclosed with high rise structures on either side and the transmitter is located below the mean roof top level of the buildings. The building is illuminated with one side while the surrounding dense clutter causes a good reflection mechanism, which is why strong reception can be observed at the side facets as well. However, due to the angle of incidence, the front facet can be seen as a stronger source of reception for the immediate rooms inside. Some coverage uniformity in clusters of rooms is also observable inside. It is due to the clustering of rooms in apartments, since rooms in the same apartment have fewer partitions and can therefore support easy propagation than between rooms located adjacent but in different apartments.

Factors Influencing Building Penetration Loss

Propagation into buildings involves a more complex mechanism than that of the outdoor radio channel which is dependent on path length, frequency, height of the mobile and base station and the environment local to the mobile station. In addition to these variables, indoor propagation is effected by several other variables as reported in the works of (Toledo et al. 1998, Davidson et al. 1997, Glazunov et al. 2000) such as existence of line of sight condition, building construction material, internal floor plan, floor area, antenna pattern, down tilt, cell size et al.

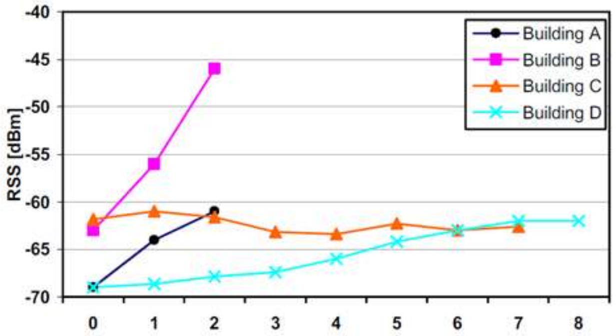
Here we discuss only the most influential factors affecting the building penetration loss observed in the experimental study.



(a) Mean penetration loss against the angle of incidence

Angle of Incidence

To cover indoor areas, buildings are illuminated under different incident angles from the outdoor base stations; The effect of the angle of incidence is something that has to be accounted for. Certain models (Toledo et al. 1998,Glazunov et al. 2000) include in their formulation the effect of this angle where an extra loss factor is added to the loss under. A steady variation of signal strength with increasing angle of incidence on the illuminated surface can be noticed in Fig. 3. As the angle of incidence on the surface increases the difference of outdoor-to-indoor power levels decreases. Angle of incidence



(b) Mean RSS for all floors of the incidence

Exterior Wall Configuration

The most important factor influencing penetration loss is the external interface i.e. the external wall of the building. Among important parameters of the external interface like the width of the wall and wall material, the defining parameter is the configuration of the external interface. The configuration (arrangement) of windows and wall in the interface effects the overall propagation into building. In our experimental study a high variation of signal strength was observed in some cases even between adjacent rooms facing the same facet of the building. Adjacent rooms, despite being identically oriented towards the transmitter, showed standard deviation of as much as 12 dB. 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 receive higher power levels than others.Most of the outdoor-to-indoor coverage estimation models consider a fixed value to account for the external interface loss. However, it is observed that not all rooms inside the building have uniform external interface i.e. some rooms may have a larger portion of windows and therefore can receive higher field strength than others and therefore can receive higher field strength than others with less or no windows (Kakar et al., 2008).

Receiver Height Inside the Building

As shown in Fig. 4, among the four buildings a steady increase in power level with receiver height in building D is of interest. An increase of approximately 1.5 dB was observed on each floor while moving upward in building D. However this effect is not found in the remaining three buildings.

The ascendancy in building A and B is because of the antenna pattern; both the buildings are situated very close to the 25m high transmitter and the lower floors unlike the upper floors do not receive the direct antenna beam. The effect in building D, however, is because of the phenomenon called the height gain effect, reported in most of the works on outdoor-to- indoor propagation. It is explained by the fact that in buildings with NLOS illumination, waves are received after reflection from the surrounding clutter. On lower floors a larger number of surrounding structures are involved in the reflection mechanism while on higher floors only few surrounding structures have enough height to obstruct the line of sight.

Non-line of Sight Facade

Signal strength distribution depicted in Fig. 1 and Fig. 2 follows a reasonable behaviour. Indoor power level 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 a considerable coverage in NLOS streets. It can be deduced that the LOS surface may not always be responsible for signal propagation into every room inside the building.

The hitherto outdoor-to-indoor coverage estimation models consider the LOS surface to be always responsible for indoor coverage from an outdoor transmitter (Kakar et al., 2008). However, improved prediction accuracy can be experienced if at least two propagation paths are 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. The prediction would be improved particularly in the rooms located away from the LOS surface where the NLOS facet can be a dominant source of propagation.

CONCLUSION

We presented field strength measurements carried in four buildings. Typical coverage patterns on different floors of the buildings are shown. The average building penetration loss in four buildings was found to be 18 dB. The signal propagation behavior in each of the four buildings is discussed and the results of the performed experiment are analyzed. The effect of angle of incidence on building penetration loss is reported. The influence of the external interface of the building on propagation loss is also observed. Height gain effect observed in the measurement is examined. It is also noticed that a reasonable amount of penetration occurs from the non-line-of-sight (NLOS) facet of the building, suggesting that the LOS surface may not be always responsible for outdoor- to-indoor propagation in rooms located deep inside the building.

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