

Estimation of Pathloss in Femtocells for Indoor Environments

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Abstract

Femtocells Access Points (FAPs) are low power base stations which improve the cellular service within indoor environments. RF propagation modeling is required to analyze the femtocell performance, power issue and the interference impact on the macro network. An indoor propagation channel is considerably more antagonistic than an outdoor channel. This paper deals with the path loss and coverage of the femtocells in indoor environments. The ability to accurately predict radio-propagation behavior for wireless systems is becoming crucial to system design. To reduce the cost of on-site measurements, propagation models have been developed. These models provide a suitable, low-cost and convenient alternative to costly on-site measurements. Lack of a LOS, heavy attenuation, diffraction by objects in the propagation path, and multipath all contribute to losses in an RF channel. RF modeling is required to predict this path loss. The path loss is associated with the design of base stations, as this tells us how much power a transmitter needs to radiate to provide coverage in the intended region. A femtocell increases overall system capacity by reducing the coverage holes and by capacity gain from higher SINR to indoor subscribers. Finally, RF modeling is carried out for indoor environments experienced in a typical femtocell.

Keywords: Femtocell, RF propagation Model, SINR and FAP.

1. Introduction

Femtocells were envisaged to improve indoor coverage for cellular networks in order to provide high quality service indoors. Femtocell networks use a local user base station and existing high bandwidth internet connection as backhaul connectivity with network operator. It forms a hierarchical cell structure with macro cells. These femtocell networks are installed at customer's premises for better voice quality and high speed data connectivity. A femtocell transceiver uses very low power. The power is intentionally kept low as it is desired that this cell should have minimum interference with the macro cell and its

range is limited to the customer's building only. Typical power level used is 0.2 Watts [1]. In order to effectively deploy a femtocell base station inside a building, a signal propagation model is required to optimize indoor coverage area. This paper is an effort to model signal propagation in an indoor environment of a femtocell.

Telecommunication industry is one of the fastest growing industries of the world. The demand for additional capacity of modern mobile telecommunication networks are increasing each year. As the prices of mobile set hardware and call rates are gradually dropping, the number of subscribers of mobile networks is growing. Users worldwide are not only using more voice call services but also consuming a larger bandwidth for data services with their cell phones. The users are getting more and more data hungry and their expectations are rising. As users are being exposed to larger bandwidth fixed internet connections, the mobile network operators are struggling to compete and match the data rate as these current fixed internet connections.

Coverage has always been an important issue in mobile telecom networks. It has traditionally been a problem in rural areas due to long distances from base stations and also in some small parts of urban areas due to wall attenuation in indoor and underground locations. The vendors have to constantly come up with solutions to make the best of the limited radio resources i.e. space and spectrum. Smaller cell sizes such as microcells and nanocells have been used to gain more capacity in urban hotspots like shopping centers and office buildings. Microcells and nanocells have also been used to improve coverage inside buildings, basements and subway tunnels. These solutions are effective but also expensive. They require capital expenditure in planning, building the sites, equipment costs and expensive backhaul connections. Also operational expenditures are substantial due to equipment

room rents, leased backhaul connections and increased electricity bills.

Femtocells offer a different approach to these problems. Femtocells are smaller than nanocells but the biggest difference is not the size of the cell. The devices are integrated to small plastic desktop or wall mount cases and are installed to the customer's premises by the customers themselves. The customer's existing internet connections are used as backhaul connections and the devices are powered from the customers' electricity sockets. As the femtocells are installed indoors they will certainly help in achieving better indoor coverage at least in their close proximity. People living in rural areas can use them in to gain better coverage. Femtocells will also give some additional network capacity due to the small cell size and reduce the load of the macrocells in urban areas. On the other hand they will also use the same radio resources as macrocells and interfere with the macro layer just as any other base stations.

2. RF Propagation in Outdoor and Indoor Environments

With the growth in the capacity of mobile communications, the size of a cell is becoming smaller and smaller: from macrocell to microcell, and then to picocell. The service environments include both outdoor and indoor areas. When propagation is considered in an outdoor environment, three things should be taken into consideration i.e. urban, suburban, and rural areas. The terrain profile of a particular area also needs to be addressed. The terrain profile may vary from a simple, curved earth to a highly mountainous region. The presence

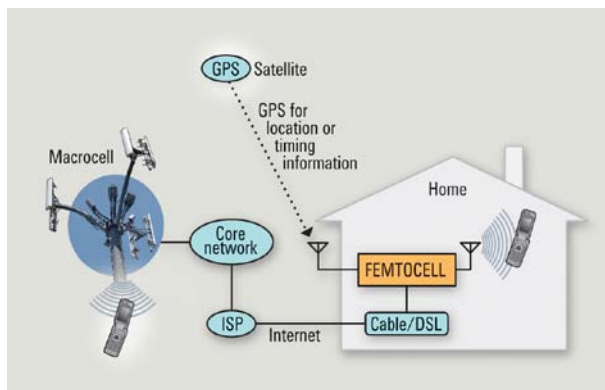


Figure 1: Typical Overview of Femtocells

of trees, buildings, moving cars, and other obstacles must also be considered. The direct path, reflections from the ground and buildings, diffraction from the corners and roofs of buildings are the main contributions to the total field generated at a receiver due to radio-wave propagation. With the advent of Personal Communication Systems

(PCS), there is also a great deal of interest in characterizing radio propagation inside buildings. The indoor radio channel differs from the traditional outdoor mobile radio channel in two aspects: the distance covered is much smaller, and the variability of the environment is much greater for a much smaller range of transmitter and receiver separation distances [2]. Propagation into and inside buildings has, to some extent, a more complex multipath structure than an outdoor propagation environment. This is mainly because of the nature of the structures used for the buildings, the layout of rooms and, most importantly, the type of construction materials used in the buildings [4].

3. Problem Statement and Main Contribution

Our research question is to find out the path loss which will analyze the effect of femtocell in an indoor environment. Femtocell is used in indoor surroundings or buildings. The main problem is to check and analyze the performance of femtocell users and indoor environment losses due to obstacle within the building.

We will make analysis of the performance of femtocell users and find out the path loss that is best suitable in the building or office. To estimate the propagation characteristics, path loss have been measured in the indoor environment by analyzing the performance of the users in different rooms of the office.

4. Indoor RF Propagation Model

Generally wireless communication systems depend on the radio wave transmission path between the transmitter and receiver. Radio channels are extremely random and they differ from the wired channels. Moreover, electromagnetic wave propagation characteristics vary significantly over different frequency bands.

Indoor coverage of a typical isolated femtocell is a few hundred square meters. Usually the cell radius varies between 30 m and 200 m depending on the propagation characteristics in the femtocell's environment. In principle, both isolated femtocell coverage and multiple femtocell coverage can be implemented. In the future, we can also expect that femtocell use scenarios in outdoor and mixed indoor/outdoor environments, with limited mobility conditions but in the presence of large volumes of aggregated traffic (e.g., in malls, airports, railway stations, pedestrian areas) and also when the end user requires high-capacity.

A phenomenal growth has been witnessed in the wireless communication over the last decade. Indoor radio

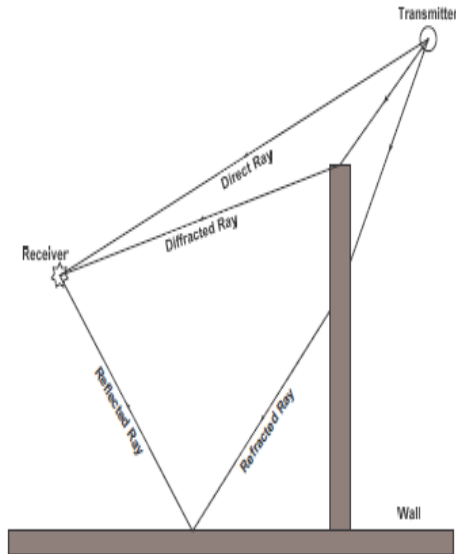


Figure 2: A typical indoor radio environment with different types of rays.

propagation is not influenced by weather conditions like rain snow or clouds as compared to outdoor propagation, However it can be affected by the layout of a building and building material. The transmitted signal often reaches the receiver through more than one path resulting in a phenomenon called multi-path fading. Figure 2 shows four main types of rays from the transmitter to receiver. The mechanism behind electromagnetic wave propagation are diverse, however they can generally be attributed to reflection, diffraction and scattering.

4.1 Propagation Models

There are two scales on which propagation effects are examined, large scale and small scale. The model which predicts the mean signal strength for an arbitrary transmitter-receiver separation distance is referred to as large-scale propagation models. Such model helps in estimation of radio coverage area. On the other hand, a model that characterize the rapid fluctuations of received signal strengths over the very short distances or short time durations are called small-scale fading models.

4.2 Free Space Propagation

This is the most basic type of propagation model. Free space propagation model is used to predict the received signal strength when the transmitter and receiver have a clear line of sight between them. The free space model predicts that the received power decays as a function of the transmitter-receiver separation distance raised to some power. The free space power received by a receiver antenna is given by eq. (1).

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (1)$$

Where as

P_t is the transmitted power.

$P_r(d)$ is the received power which is a function of Transmitter-Receiver separation.

G_t is transmitter antenna gain.

G_r is the receiver antenna gain and d is the Transmitter-Receiver separation distance in meters.

L is the system loss factor not related to the propagation and λ is the wavelength of carrier.

4.2 Log-distance Path Loss Model

In reality, indoor radio propagation rarely follows free space propagation. Some classical propagation models have emerged which are very useful to predict the large-scale coverage for mobile communication systems design. A simple path loss model which determines the average large scale attenuation for any arbitrary Transmitter-Receiver separation can be expressed as a function of distance by using a path loss exponent of eq. (2).

$$\overline{PL}(d) \propto \left[\frac{d}{d_o} \right]^n \quad (2)$$

Where PL is the mean path loss and n is the mean path loss exponent that indicates how fast the path loss increases with the distance, d_o is the reference distance and d is the T-R separation distance [2].

4.3 Empirical Model for Femtocells

Empirical models are based on statistics and measurements. Therefore they do not require the knowledge of geometry of environment. In this approach only distance between emitter and receiver is taken into account. Empirical models are relatively easy to implement. It has advantage of being very fast because only one path is computed at each receiving point. However they suffer from a low accuracy because obstacles are not taken into account.

On the other hand when high accuracy is required deterministic models are the best option to consider. However this cannot be done without a complexity cost. Generally most complex models are more accurate [3].

4.4 Empirical narrow-band Models

A couple of empirical indoor models have been investigated here. The one slope model (ISM) shows a linear dependence between the path loss (dB) and the logarithmic distance is given by eq. (3).

$$L = L_o + 10n \cdot \log(d) \quad (3)$$

Where as

L_o is the path loss at 1 meter distance

n is the power decay index,

d is the distance between transmitter and receiver in meters

As the distance between transmitter and receiver appears as an input parameter so this model is easy to implement.

Multi-wall model gives the path loss as the free space loss added with losses introduced by the walls and floors penetrated by the direct path between the transmitter and the receiver. It can be observed that the total floor loss is a non-linear function of the number of penetrated floors. This is achieved by introducing an empirical factor b . Multi-wall model is express by eq. (4).

$$L = L_{FS} + L_C + \sum_{i=1}^l k_{wi} L_{wi} + k_f \left[\frac{k_f + 2}{k_f + 1} b \right] L_f \quad (4)$$

Where [5]

L_{FS} is free space loss between transmitter and receiver

L_c is constant loss

k_{wi} is number of penetrated walls of type i

L_{wi} is loss of wall type i

k_f is number of penetrated floors

L_f is loss between adjacent floors

b is empirical factor

It is important here to see that loss factors in eq. (4) are not physical wall losses but model coefficients which are optimized along with the measured path loss data.

Table 1: Wall Type Description

Wall Type	Description
Light wall(L_{w1})	A wall that is not bearing load e.g plasterboard, particle board or thin(<10cm)
Heavy wall (L_{w2})	A load-bearing wall or other thick (>10cm) wall, made of e.g. concrete or brick.

4.5 Linear attenuation Model

Linear Attenuation Model (LAM) given in eq. (5) assumes that the excess path loss (dB) is linearly dependent on the distance where α (dB/m) is the attenuation coefficient.

$$L = L_{FS} + \alpha d \quad (5)$$

5. Design Scenario

To simulate RF propagation in indoor environment, an office building layout is assumed. In an indoor environment, multipath propagation cannot be estimated accurately because it involves a number of factors like furniture, room layout, personnel present, curtains etc. These are such variables that either change continuously or vary from building to building. Therefore keeping this in mind, this simulation is simplistic, that means it does not account for the multipath propagation. Following is the layout of the building under consideration. The black lines are light walls and the red and black line indicates a heavy wall. Heavy wall is assumed to provide double the attenuation than the light wall. The position of antenna is also indicated with an inverted red triangle. The attenuation is calculated beyond 1 m from the antenna. A Cartesian coordinate system is assumed keeping the antenna at the origin.

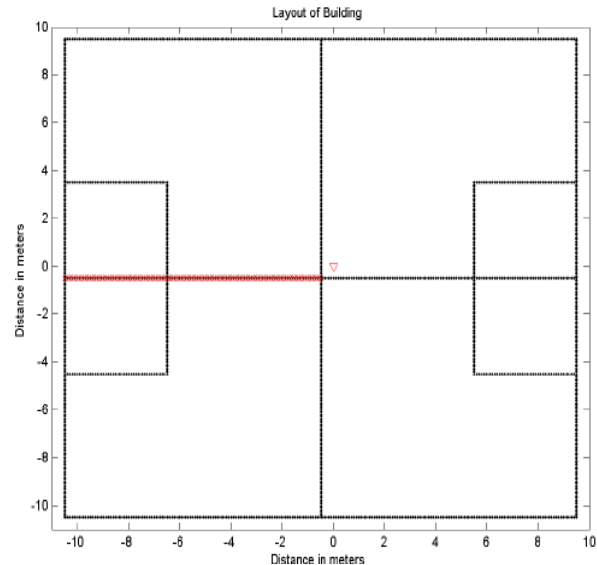


Figure 3: The Building Under Consideration

The simulation uses the multiwall model with a simplification. Here only one floor is assumed. The

Table 2: Color Coding for Signal Strength.

Colour	Path Loss
Green	0 – 37 dB
Cyan	37 – 47 dB
Yellow	57 – 63 dB
Magenta	63 – 68 dB
Blue	68 – 73 dB
Red	73 – 83 dB
White	83 dB +

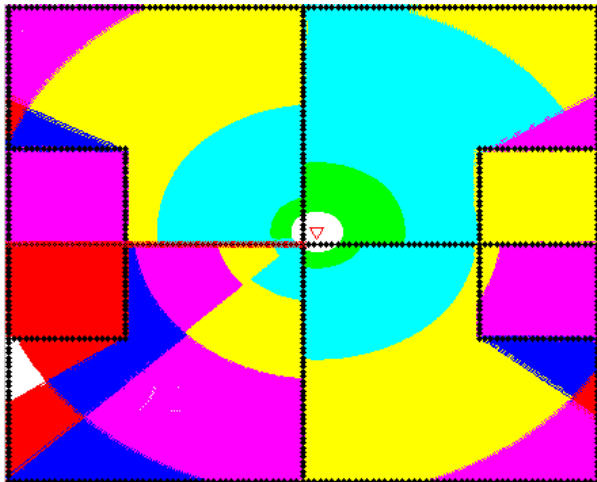


Figure 4: Simulation Results

simulation results are as shown in the Figure 4. The colour coding is as per the Table 2. The simulation results show that for the building under consideration, most of the indoor area faces a path loss less than 83 dB. For a receiver sensitivity of -73 dB_m , a transmitter with a power of 10 dB_m would be enough. Typical femtocell transmitter power can be as high as 23 dB_m that can easily provide coverage to the whole building. Going forward with the discussion, consider the same building design again as depicted in Figure 5. It shows four marked locations A, B, C and D. Assume that four different users are present at these locations and connected to the network through femtocell. These locations are randomly selected. The intention is to determine the path loss at these selected locations.

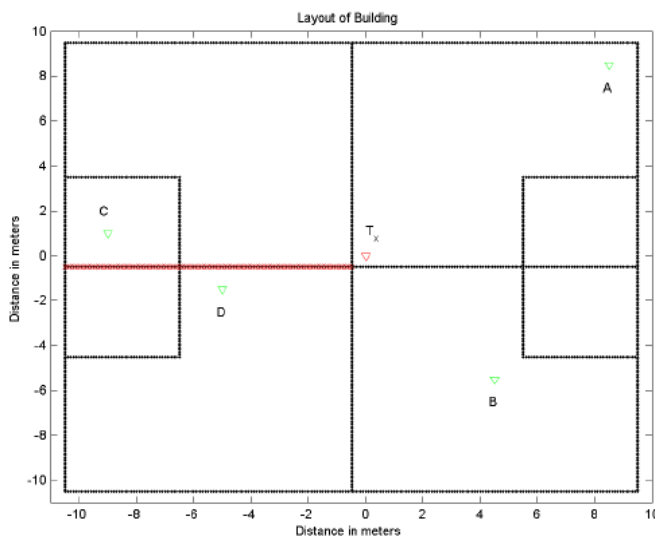


Figure 5: Assumed User Locations in Building under Consideration

The path loss graph is depicted in Figure 6 that is based on the distance of the location from the transmitter and the

number of walls that obstruct the path as shown in Table 3. The location 'A' is in line of sight of the transmitter at a distance of 12m. The path loss at this location is 58.6 dB. The user at location 'B' is behind one wall. Its distance from the transmitter is 7m but the path loss is 59 dB. The user at location 'C' is behind two walls. The path loss here is 66.14 dB. The user at location 'D' is obstructed by two walls. One is a heavy wall while the other is light wall. The overall impact is assumed to be that of three lighter walls. The path loss here is 66.35 dB.

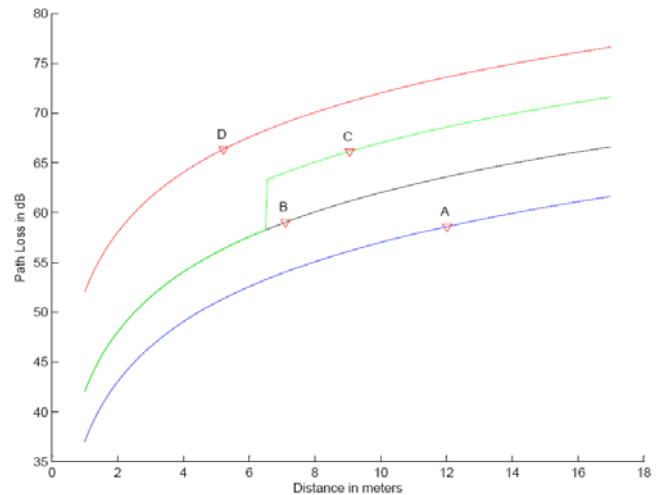


Figure 6: Graph for Calculated Path Loss for Four Users
 The user location with respect to distance is calculated the path loss as per the Table 3.

Table 3: Calculated Path Loss for Four Users

Location	Distance	No of Walls	Path Loss
A	12.02	0	58.6
B	7.11	1	59.03
C	9.06	2	66.14
D	5.22	1 x 2 + 1	66.35

6. CONCLUSION

In this paper an effort has been done to make some sense out of the mysteries of radio propagation within building. Different path loss models are discussed. One of these models is used to carry out a simulation. We have assumed a simple building layout and shown that a typical femtocell can be used to provide coverage to every part in the building under consideration. To verify this, four different users were considered and path loss was calculated at their locations. It was determined that the path loss for all four users present at different locations inside the building was within the acceptable limit. Similar analysis can be carried out for any real building to estimate the path loss and predict the femtocell coverage in the building. Although the simulation carried out is simplistic, it is a very quick and in-expensive means to carry out a reasonable accurate analysis.

7. References

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