Interference Scenarios and Capacity Performances for Femtocell Networks

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Abstract

In this paper, we present capacity performances of Femtocells considering different interference scenarios which are among femtocells and between femtocells and macrocell. The capacity performances are demonstrated for femtocells with both single and multiple transmit and receive antennas using Wireless Insite radio propagation software. [1]

1. Introduction

As the demand of higher data rates and the quality of service are increasing in wireless communication, the innovative approaches and solutions are being addressed nowadays. Femtocells are one of these new solutions which are planned to be used in the near future. They are small size home base stations working at low power levels which improve the indoor capacity and help to reduce the network deployment costs. However, introducing new cells to the existing cell architecture causes some important problems, such as interference, handovers, etc. To overcome these technical troubles, channel modeling is the important issue to be addressed.

Channel properties mostly depend on the physical environment. According to the environment of the radio propagation, the affecting parameters mostly have different behaviors. For instance, if the radio propagation is in a closed area such as in schools, houses, or offices, then the number of scattering, diffracting will increase due to numerous objects in the area.

In indoor applications delay dispersion is smaller due to shorter distances. Also, because of the dense multipath propagation with a much higher number of multipath components (MPC), more diffuse reflections from extended scatterers may occur [1]. Furthermore movements of the terminals are slower compared to outdoor environment. Therefore the Doppler shift is much smaller**.**

The paper is structured as follows: In Section 2, indoor channel models are investigated for femtocells with single input single output (SISO) and multiple input multiple output (MIMO) systems. In Section 3, different scenarios of the femtocellular networks are demonstrated and the impact of the interference is investigated for indoor, indoor to outdoor and outdoor to indoor environments. Th channel capacity performances are obtained by Wireless Insite radio propagation software and implemented on Matlab software.

2. Indoor channel models and their properties

Indoor MIMO channels can be categorized as physical and analytical models. While modeling indoor MIMO channels, the parameters which are path loss component, shadow fading, angle spread, Ricean K factor, path delay profile (PDF), cross polarization ratio, delay spread, angle of arrival (AoA), and angle of departure (AoD) should be considered. All these parameters should be modeled separately for line of sight (LOS) and non-line of sight (NLOS) path [1]. For more complex models, they include the incorporate polarization and time variation as an addition.

Physical indoor MIMO channel models can be categorized as deterministic models, geometry-based stochastic models, and non-geometric stochastic models. According to the complexity of a chosen model, the accuracy of radio propagation reproduction can change. Antenna configurations and the system bandwidth are not considered in physical models.

On the other hand, analytical models can be subdivided into propagation motivated models and correlation-based models. The propagation motivated subclass models the channel matrix by using the propagation parameters, such as the finite scatterer model and the maximum entropy model. The other subclass, correlation based models, defines the MIMO channel matrix statistically in terms of the correlations between the channel matrix elements [1].

In the following subsections, three different channel models are compared with each other. First one is ray tracing model which belongs to physical models. The other one is independent and identically distributed model which is a subclass of analytical channel models. The third channel model is a standard indoor model which is called IEEE802.11n.

2.1. Independent and Identically Distributed Model

Independent and identically distributed (i.i.d) model is the most primitive and simplest model of the analytical indoor models. In this model, all entries of the channel matrix, H,

$$R_H = \rho^2 I \quad (1)$$

where they are uncorrelated and have the same variance. Physically, this corresponds to a spatially white MIMO channel which occurs only in rich scattering environments characterized by independent MPCs uniformly distributed in all directions. The i.i.d. model only consists of channel power as a parameter [2].

[1] The work is supported by the Celtic HOMESNET Project.

2.2. Ray Tracing Model

Since there are several numbers of objects in indoor areas, the radio signals propagated from a constant source are reflected and distracted from lots of scatterers. Therefore, the radiated signal has lots of copy of itself. These new copies of a transmitted signal are called multipath components. These copies are lower powered, time delayed and phase shifted multipath components. The transmitted signal and its multipath components are combined in the receiver part. In ray tracing model, the number of reflections is assumed infinite with the known dielectric properties of the environment. This multipath propagation can be calculated with the very well known Maxwell equations. However, this method is not preferable because of its complexity. The methods of ray tracing usually use geometrical optic methods in order to simulate the wave surfaces as electromagnetic propagations. The most common ray tracing model demonstrates the scattered, reflected, distracted and refracted multipath components as a whole ray.

In ray tracing algorithms, all the Tx and Rx positions are specified and then all possible paths from the Tx to the Rx are determined according to geometric considerations and the rules of geometrical optics in the ray tracing model. Usually, a maximum number N_{max} of successive refractions and diffractions is prescribed. This geometric ray tracing core is the most critical and time consuming part of the ray tracing procedure. As a result, the field vector at the Rx position is composed of the fields for each of the N_r rays.

Although this method is a complex method with lots of calculations, if the geometrical area is known, it gives much more precise results than the statistical models [3] [4].

Ray tracing based simulation programs, such as Wireless Systems Engineering Software (WISE) and Wireless Insite WI, are commonly used in both indoor and outdoor system planning.

2.3. IEEE802.11n Standard Model

IEEE 802.11n standard model is used for indoor environments in the 2GHz and 5GHz bands, with a focus on MIMO wireless local area networks (WLAN). For indoor environments such as offices, residential homes, and open spaces are considered with LOS and NLOS. This model specifies a set of six environments which are named from A to F, which mostly correspond to the single antenna WLAN channel models [5]. Environment B is implemented in this study and its parameters are given in Table 1.

Table 1. IEEE802.11n Channel Model B: T*ypical Living Environment*

Path	Average Power (dB)	Delay (ns)
1	0	0
2	-5.4287	10
3	-2.5162	20
4	-5.8905	30
5	-9.1603	40
6	-12.5105	50
7	-15.6126	60
8	-18.7147	70
9	-21.8168	80

Path loss for IEEE802.11n model can be calculated as in Equation (2):

$$L_p = 20\log_{10}\left(4\pi f_c / 3e8\right) + 20\log_{10}\left(d_{BPm}\right) + 35\log_{10}\left(d / d_{BPm}\right) \quad (2)$$

where d_{BPm} is the path loss component and it is given as 10.

3. Capacity Performances

In this section, channel capacities for different scenarios are obtained by using Wireless Insite simulator program which is based ray tracing model. In addition to these simulations, it is observed that these site specific channels of the simulated scenarios are similar to the channels obtained by implementing these scenarios for both i.i.d and IEEE802.11n model using Matlab program.

If it is investigated that the interference existing situations for SISO systems, then the signal to interference plus noise ratio (SINR) is calculated as below:

$$SINR = g_{i,j}(t)^2 / (N_0 + |I_{i,j}(t)|^2) \quad (3)$$

Here $g_{ij}(t)$ is the channel impulse response and it is shown in the Equation (7).

Then the capacity can be calculated with the very well known Shannon capacity formula as:

$$C = \log_2\left(1 + SINR\right) \quad (4)$$

The capacity formula for MIMO systems can be shown as:

$$C(SNR, H) = \log_2\left(\det\left(I_{Nr} + \frac{\mathrm{SNR}}{N_t} HH^H\right)\right) bps / Hz \quad (5)$$

Here *SNR* is the average signal to noise ratio and *H* is the channel matrix with dimension $N_t x N_r$.

The capacity in Eq. (5) is the instantaneous capacity and it is calculated for each random channel by assuming the channel information is only known at the transmitter side.

In the case of the interference, channel capacity is calculated for MIMO systems as [6]:

$$C(SINR, H, X) = \log_2(\det(I_{Nr} + \frac{SNR}{N_t} HH^H (I_{Nr} + \frac{SINR}{N_t} XX^H)^{-1})) bps / Hz \quad (6)$$

where *X* is the channel matrix between the interfered transmitter and the victim receivers with dimension $N_t x N_r$.

3.1. System Parameters

In Table 2, the system parameters used in the simulations are summarized. For all implemented channel models, the MIMO capacity analysis is performed for narrow banded system. These results are used for analyzing the performance of the channel capacity.

Table 2. System Parameters.

Parameter Name	Parameter Value
Femtocell Power	10 dBm
Macrocell Power	40 dBm
Bandwidth	10 MHz
Carrier Frequency	2.1 GHz
Noise Power	-174 dBm/Hz
User Equipment Displacements	1-120 m, randomly
Number of Antennas (Tx, Rx)	(1, 1), (2, 2)
Distance between the Tx	4 λ
Distance between the Rx	0.5 λ
Antenna	Omnidirectional

3.2. Interference scenarios and performance results

Scenarios are implemented by using Wireless Insite (WI) radio propagation software. It is an electromagnetic modeling tool for wireless communication systems. Briefly, it models the physical characteristics of the rough terrain and building features, performs the electromagnetic calculations, and then evaluates the signal propagation characteristics.

To evaluate the capacities, WI simulation results are compared to the capacity values of i.i.d and IEEE802.11n models calculated using Matlab.

Table 3 shows a sample output from WI simulation. These results are obtained for SISO scenario and belong to the macrocell signal which is composed of 9 different multipaths. Also, during this simulation, 25 multipaths are observed for femtocell signal, because the indoor environment has more scatterers than the outdoor.

Channel impulse response is computed by using the output of WI as shown below [7]:

$$g_{ij}(t) = \frac{1}{M}\sum_{k=1}^{M}\sqrt{P_k e^{j\theta_k}}\,\delta_k(t-\tau_k) \qquad (7)$$

where P_k, θ_k, and τ_k are respectively, transmitter power of the k[th] path, phase degree and time delay. M is the total path number and δ_k is the delta impulse response. These are obtained by WI program.

Table 3. Wireless INSITE Sample Output

Path Number	Phase (deg.)	Time (s)	Power (dBm)
1	-131.441	0.311126e-06	-36.125
2	-38.026	0.364034e-06	-55.645
3	137.545	0.398609e-06	-59.897
4	-107.584	0.420452e-06	-60.249
5	161.674	0.420335e-06	-60.264
6	-60.418	0.330507e-06	-62.073
7	-139.381	0.330611e-06	-62.358
8	-6.499	0.344229e-06	-82.191
9	-132.969	0.344875e-06	-83.055

3.2.1. Scenario 1: Interference between Femtocells

Two scenarios are implemented for illustration of the interference between femtocells. The first scenario is examined two neighbor flats where the distance is very short between them. The second scenario is considered for two flats where the distance is longer than the previous scenario. The simulations are performed for SISO femtocells. The first scenario is implemented as shown in the Figure 1 with the propagation paths of the transmitted signals from femtocells. There are two flats which are neighbors and there are four randomly placed femtocell users in one flat.

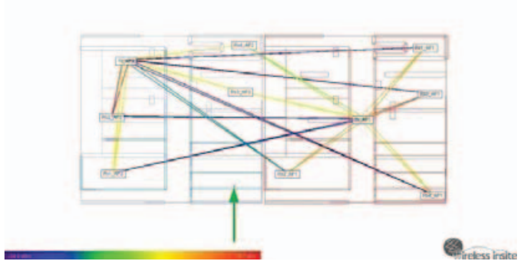

Fig. 1. Propagation paths for scenario of short-distance femtocells

The impact of the interference is drawn in Fig. 2 (for flat 1) and Fig. 3 (for flat 2).

The second scenario can be seen in the Fig. 4 with the propagation paths from the fetmocell of AP4 to fetmocell users of the AP1 femtocell. In this figure there are four flats side by side. The first (the right one called Flat1) and the last (the left one called Flat4) flat are taken into account in order to investigate the interference effect in the case of long-distance. The impact of the interference can be seen from the Fig. 5 (for flat 1) and Fig. 6 (for flat 4).

3.2.2. Scenario 2: Interference from Macro to Femtocell

Interference from macrocell to femtocell users can be seen from the Fig. 7. In this scenario there are 5 femtocell users. As shown in this figure, EU_{f1} user is outside the house in the garden. Other four femtocell users which are randomly placed are inside the house. Due to the macrocell is 100 m away from the femtocell, macrocell is not shown in Fig. 7.

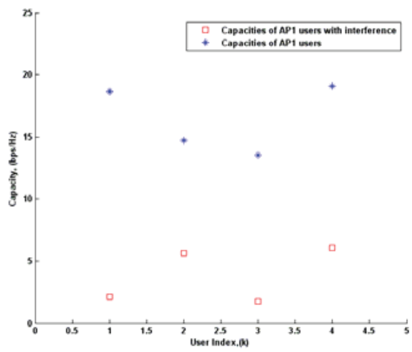

Fig. 2. The Impact of the femtocell interference from Flat2 to Flat1

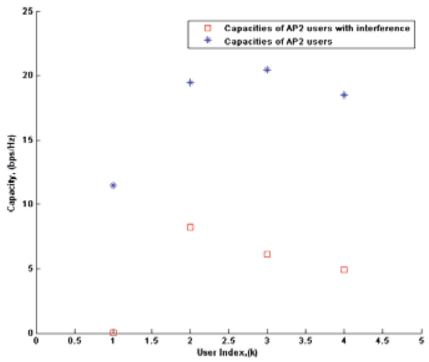

Fig. 3. The Impact of the femtocell interference from Flat1 to Flat2

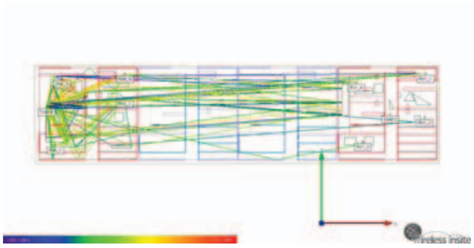

Fig. 4. Propagation paths for scenario of long-distance

Indoor channel models are demonstrated in Fig. 8 and Fig. 9 for SISO and MIMO systems, respectively. The receivers, femtocell users, are placed in the same coordinates for both systems to make the comparison precisely. One can see the advantage of the MIMO systems over SISO in terms of the capacity improvement.

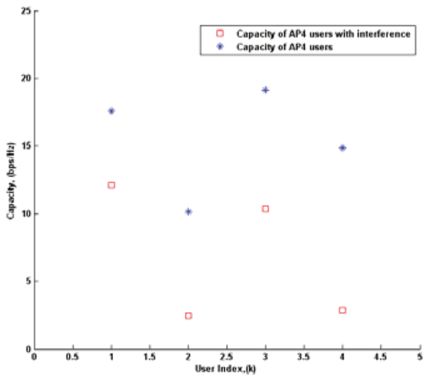

Fig. 5. The Impact of the femtocell interference from Flat 1 to Flat 4

Interference impact of the macrocell on the femtocell users for SISO systems is shown in Fig. 10.

The impact of the macrocell interference on femtocell users for MIMO systems can be seen in Fig. 11. Computation of the interference is achieved by using the Equation (5).

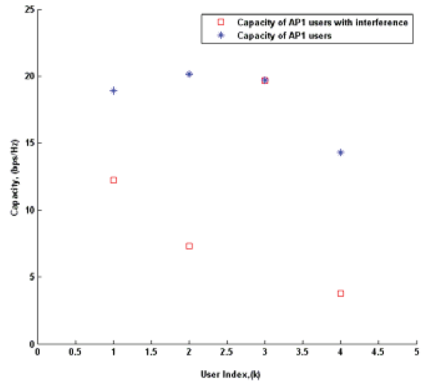

Fig. 6. The Impact of the femtocell interference from Flat4 to Flat1

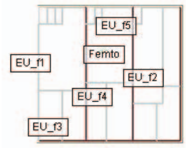

Fig. 7. Placement of the Femtocell Users and the Femtocell

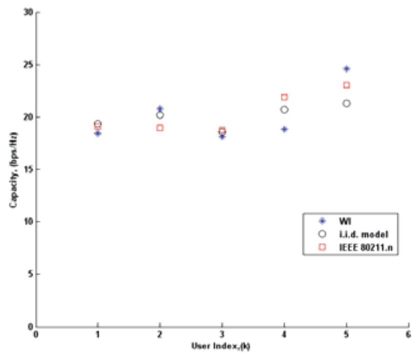

Fig. 8. SISO channel indoor models for femtocell

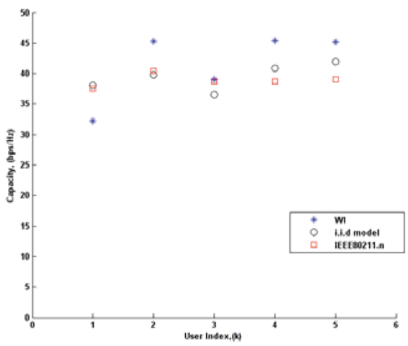

Fig. 9. 2X2 MIMO channel indoor models for femtocell

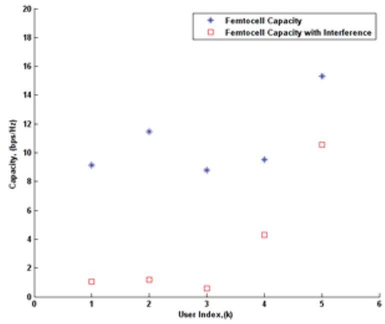

Fig. 10. The impact of the macrocell interference on femtocell users (SISO system)

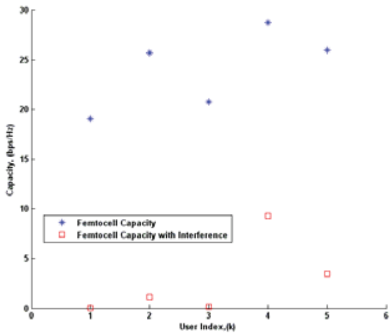

Fig. 11. The impact of the macrocell interference on femtocell users (MIMO system)

3.2.3. Scenario 3: Interference from Femto to Macro

Fig. 12. Propagation paths of the indoor-outdoor environment scenario

This scenario can be seen from the Fig. 12. In the scenario there are 5 femtocell users. As shown in the figure, EU_{f1}, EU_{f2}, EU_{f5} user is outside the house. Other femtocell users are inside which are randomly placed.

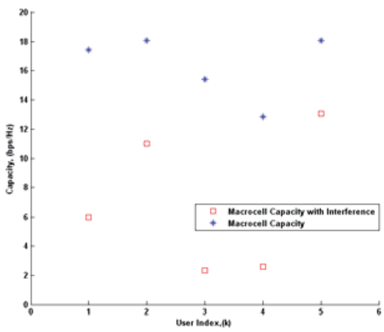

Fig. 13. The impact of the femtocell interference on macrocell users (SISO system)

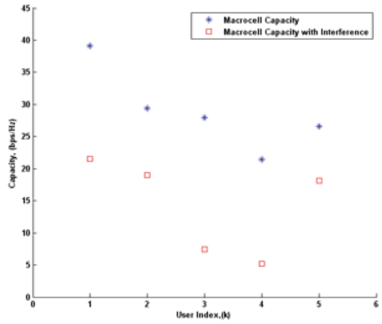

Fig. 14. The impact of the femtocell interference on macrocell users (MIMO system)

The opposite condition of the Scenario 2 is shown for both SISO and MIMO systems respectively in Fig. 13 and Fig. 14.

4. Conclusions

In this paper, the evaluation of the channel capacities according to different indoor channel models has been illustrated. We have focused on interference scenarios for wireless networks based on femtocells. The impact of interference on the capacity performances for the macrocell-femtocell and femtocell-femtocell has been shown for MIMO and SISO systems.

It has been shown that the interference has a strong effect on capacity performance. Therefore, the interference avoidance and cancellation techniques must be implemented in the femtocell deployments. The future studies will mainly focus on the solutions to mitigate the interference in these scenarios.

5. References

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