Simulator for the Analysis of the Mutual Impact Between Indoor Femtocells and Urban Macrocells

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Abstract— **The provision of broadband wireless access inside buildings is getting more and more important. In order to achieve a cost-efficient solution for the improved coverage inside buildings, the network operators expect the deployment of a large number of femtocells in the homes of their customers. However, these femtocells interact with the surrounding mobile cellular network as they operate in a licensed spectrum. Due to the mutual interference, both the performance of the regular cellular network and the indoor femtocells might be affected. Accordingly, a detailed analysis of the interference situation is required. This paper presents a simulator for the performance evaluation of LTE networks under consideration of arbitrary indoor femtocell deployments. Both, the impact of the femtocells on the macrocellular network and the impact of the macrocells on the femtocells are shown in a reference scenario.**

Keywords— **femtocell; macrocell; interference; LTE; radio network planning;**

I. INTRODUCTION

Due to the increased usage of mobile terminals inside buildings (especially for data services), the network operators are forced to improve the indoor coverage and capacity in a cost-efficient way. In order to fulfill the given requirements, the operators expect the intensive deployment of femtocells in the homes of their customers.

Femtocells are low-power wireless access points to connect standard mobile devices to a mobile operator's network using residential DSL or cable broadband connections [1; 2; 3]. This approach enables customers to use the same terminal at home, in the office or wherever they go and even allows them to obtain the same QoS. Accordingly, indoor users can be served by femtocells, increasing the number of subscribers in the mobile cellular network. However, besides the advantages in terms of improved indoor coverage and higher capacity, the deployment of indoor femtocells has also an impact on the surrounding cellular network [4; 5]. Due to the mutual interference, the performance of the outdoor network and the indoor femtocells might be affected, especially for LTE networks with a typical frequency reuse factor of one. Therefore, a detailed analysis of the interference situation is required.

In this paper, a network planning tool is presented which allows the performance evaluation of LTE networks in urban and indoor environments. The paper is organized as follows: Section II describes the simulation methodology for the interference analysis between the indoor femtocells and the urban macrocellular network including a brief introduction for a special measurement campaign. In section III, the investigated reference scenario is presented. Section IV shows the simulation results and section V draws some conclusions on the interference impact in both transmission directions.

II. SIMULATION METHODOLOGY

A. *Coverage Prediction Model*

The basis for any radio network planning simulation is a wave propagation model which predicts the signal and interference contributions based on the defined network configuration. For the analysis of the femtocell impact on the macrocells and vice versa the different propagation model approaches for outdoor and indoor scenarios need to be combined. This implies the integration of the indoor building data (with possibly multiple floors and individual materials for the different walls and subdivisions like doors and windows) and the outdoor environment where the buildings are described as polygonal cylinders superposed to topographical pixel data.

An example for such a combined environmental database including indoor building vector data, urban building vector data and topographical pixel data is shown in Figure 1.

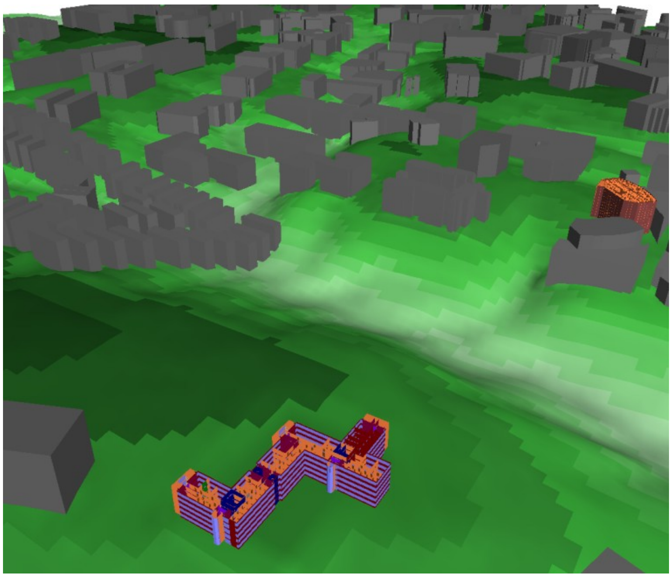

Figure 1: Combined 3D urban and indoor building database superposed to topographical pixel data

In order to combine the different environments (outdoor and indoor) an appropriate interface needs to be defined. For this purpose the polygonal cylinder surrounding the indoor building database is used. For outdoor propagations the polygonal cylinder is considered only, while for the indoor propagation modeling the individual outer and inner walls of the building are taken into account. Another important issue is the support of different prediction resolutions for the outdoor and indoor domain, typically 5 to 10 m for urban scenarios and 1 m for indoor scenarios are used. Furthermore different prediction heights need to be considered, typically 1.5 m for outdoor scenarios and additional heights according to the given multi-floor structure of the considered building.

The dominant propagation phenomena in urban and indoor scenarios are shadowing behind obstacles, reflection from the walls of buildings, wave-guiding effects in street canyons or corridors (due to multiple reflections) and diffraction at vertical and horizontal wedges. The dominant path model (DPM) used for the deterministic prediction of the radio coverage is fully three dimensional and based on the evaluation of 3D building vector, vegetation and topographical data representing the evaluated scenario [6]. The DPM combines short computation times with a high accuracy and has been evaluated with numerous measurement campaigns in different scenarios. The high flexibility of the DPM allows the prediction of the outdoor coverage as well as the coverage inside buildings on various floors, both for outdoor and indoor transmitters.

B. *Propagation Measurements*

In order to capture the propagation phenomena between outdoor and indoor environments in both directions properly, a special measurement campaign has been carried out. Therefore, a large number of different positions on the inside and outside of a variety of buildings has been analyzed.

The first step has been, to verify and extend existing models which describe the propagation from base stations on the outside to mobile stations on the inside [7]. Followed by the second step, to gain in-depth knowledge of the conditions under which the signals of a femtocell penetrate from the inside to the outside [8]. And last but not least, the propagation of signals from femtocells within the indoor environment has been another issue. Figure 2 exemplarily shows the measurement of a femtocell on the second floor inside the building and its coverage on the outside.

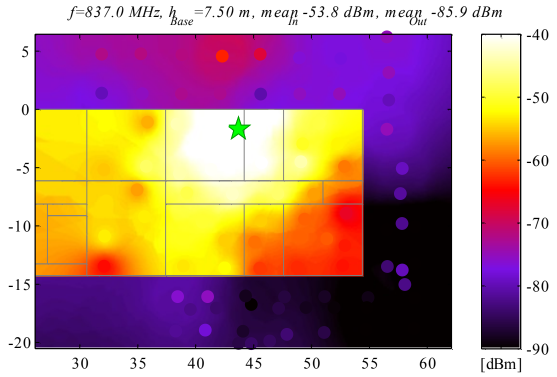

Figure 2: Measurement of a femtocell on the second floor inside the building and at ground level on the outside in the 800 MHz band

Since fast fading effects are a serious problem for static measurements [9], a linear translation stage has been used to continuously move the measurement antenna. The received samples got averaged along the length of the linear translation stage. Thus, the influence of multipath propagation leading to destructive or constructive interference has been reduced.

C. *LTE Network Simulation*

Generally, the performance of a mobile cellular network in terms of coverage and throughput depends on the available Rx power and the given signal-to-noise-plus-interference ratio (SNIR). Besides the Tx power, the given SNIR is mainly affected by the interference originating from neighboring base stations.

While the OFDM multiple access scheme which is used in the LTE air interface avoids the interference among users served in the same cell, the scarce number of frequency carriers and the resulting frequency reuse factor of one put the emphasis on the interference originating from neighboring cells. The instantaneous interference depends on the individual cell load of the neighboring cells, i.e. how many resources are currently used. Therefore, it is important to consider the cell load in the network simulation.

The planning tool allows the configuration of the load for each cell individually depending on the corresponding traffic demand. The cell load can be used to control the transmit power in downlink or the number of used sub-carriers (similar to fractional frequency reuse). Furthermore, the network simulator allows a detailed configuration of the LTE air interface including bandwidth, the distribution of resources among data, pilot- and reference signals (see Figure 3) and the definition of various transmission modes including QPSK, 16QAM, and 64QAM schemes.

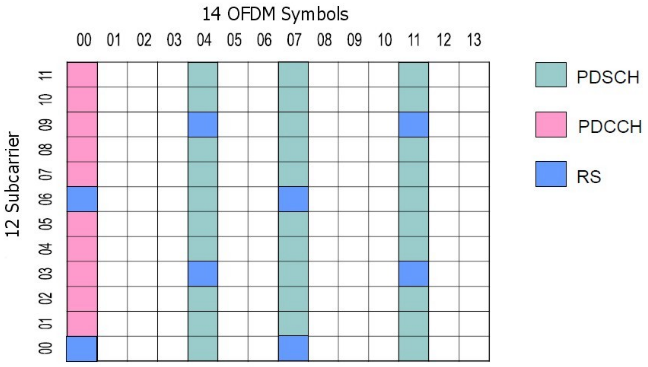

Figure 3: Distribution of LTE resource elements among data, pilot- and reference signals

Based on this approach various LTE air interface configurations can be analyzed (also for the individual frequency bands used in different regions). In case of fully loaded cells all resources in time and frequency domain are occupied corresponding to a worst case assumption.

The MIMO technology for achieving higher data rates and interference reduction can be considered as well [10].

III. REFERENCE SCENARIO

The urban simulation scenario is shown in Figure 4 with the prediction of the reference signal received power (RSRP) for 3 LTE macrocells (3 sectors each with an antenna gain of 18 dBi and 3 dB beam width of 65 degrees). The building which includes the indoor femtocells is marked within the blue ellipse. One of the macrocells is located closely to the femtocell building with about 300 m distance, the other two macrocells are further away in southern and eastern direction, respectively, and thus have reduced impact.

Figure 4: Prediction of the RSRP for 3 deployed macrocells (3 sectors each) and indoor femtocells (blue ellipse) based on a 3D urban vector database

Figure 5 depicts the considered building with the locations of the 14 femtocells distributed on 5 floors. The deployment of this large amount of femtocells in a single building ensures a homogeneous coverage on all floors. Both, the macrocells and the femtocells transmit the same LTE carrier (5 MHz bandwidth) in the 800 MHz band. While the LTE macrocells typically use a Tx power of about 43 dBm plus the gain of the sector antenna, the femtocells transmit 13 dBm each by using omni-directional antennas. In order to analyze the worst case scenario, the assumption of fully loaded macrocells is considered, i.e. radiation with maximum Tx power at all the time.

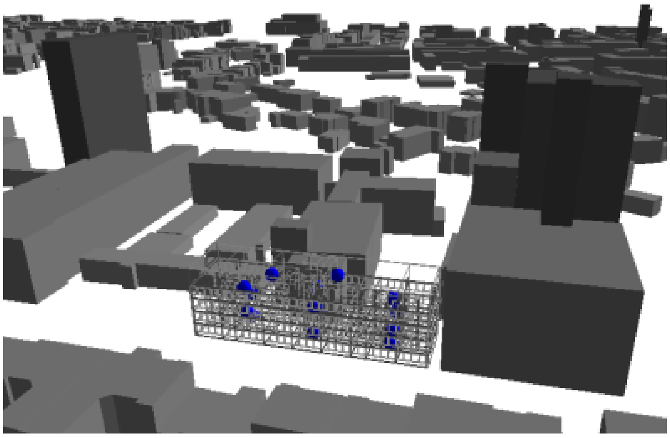

Figure 5: Reference scenario with 14 femtocells inside the building on 5 floors. The selected building has an approximate size of 55 m by 15 m and 18 m height

IV. INTERFERENCE ANALYSIS

The mutual interference between the indoor femtocells and the urban macrocells has different impacts on the coverage situation. While the macrocellular outdoor coverage is affected mainly by the femtocells in lower floors, the femtocell indoor coverage suffers even more in the highly elevated floors due to the impinging macrocellular interference. Both types of impact for the evaluated reference scenario are presented in more detail in the following subchapters. At first, the impact of the femtocell interference on the outdoor macrocellular coverage will be discussed. Secondly, the impact of the macrocellular interference on the indoor femtocell coverage is subject of the analysis.

A. *Impact on outdoor macrocellular coverage*

Figure 6 shows the SNIR conditions in a scenario without femtocell interference. The blue ellipse in the center of the image points to an area with good SNIR that surrounds the building. Figure 7 illustrates the impact of the femtocells on the macrocellular coverage (SNIR degradation in the same area). As it can clearly be seen, the deployed femtocells strongly affect the macrocellular coverage. Due to the additional interference originating from the femtocells, the SNIR performance in the vicinity of the building is reduced, especially in front of the building where the femtocell signals are shadowed by the outer wall respectively the window only. In this region the SNIR of the macrocellular network is reduced by up to 13 dB.

The SNIR reduction affects the maximum data rate which can be provided to a single user as well as the maximum throughput which is offered at a specific location (to be shared by different users). For the given reference scenario the SNIR reduction is limited to the vicinity of the building due to the densely built-up neighborhood, e.g. for a region of about 100 m in the corresponding street canyon. In case of massive femtocell deployments and/or more rural scenarios larger interference regions can be expected.

Generally the network operator should optimize the macrocellular network by taking the interference originating from the femtocells into account, while the femtocells are typically deployed by the users in their apartments. Especially the femtocells on the lower floors have a significant impact on the outdoor coverage in the surrounding as provided by the macrocells.

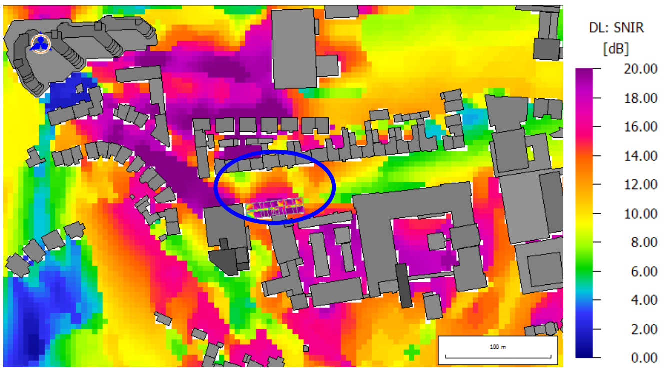

Figure 6: SNIR conditions in a scenario without femtocell interference

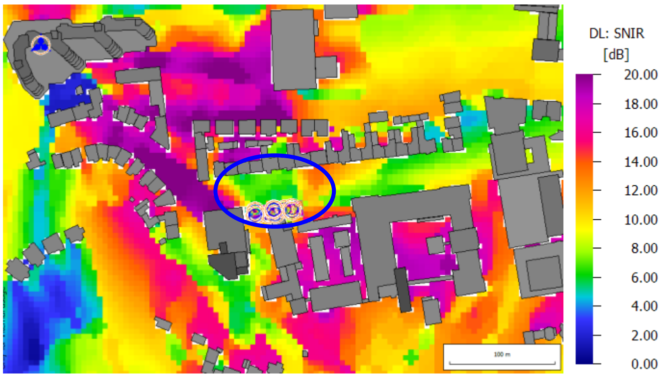

Figure 7: SNIR degradation due to femtocell interference

B. *Impact on indoor femtocell coverage*

Inside the building, the situation strongly depends on the floor level and the corresponding visibility relation (and distance) to the macrocellular sites. Another important impact is given by the material properties of the construction materials used for the considered building.

Figure 8 shows the coverage situation by femtocells on the highest floor of the building without interference from the macrocells. On top, the best server areas are shown. In the image below, the SNIR plot is given. The two deployed femtocells on this floor almost provide coverage on the whole floor (except for a minor area between the two femtocells which is served by a third femtocell one floor below) with SNIR values for large parts of the area of above 10 dB.

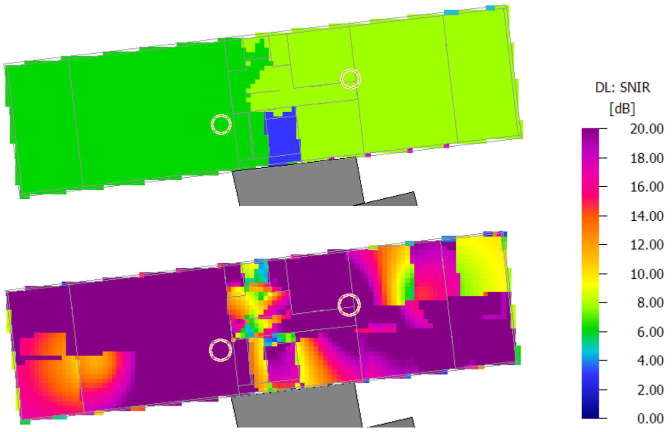

Figure 8: Best server map (above) and SNIR map (below) for the highest floor in a scenario without macrocellular interference

When the macrocellular interference is included in this scenario, the coverage situation on the highest floor changes drastically, as illustrated in Figure 9. Due to the limited distance and the direct visibility to the macrocellular sectors in the north-west and in the south, most parts of this floor are now dominated by the macrocellular coverage (see best server map), while the femtocells serve only a limited part of this floor. Furthermore, there is a severe SNIR degradation of the femtocell signals due to the high interference received from the macrocells (and vice versa).

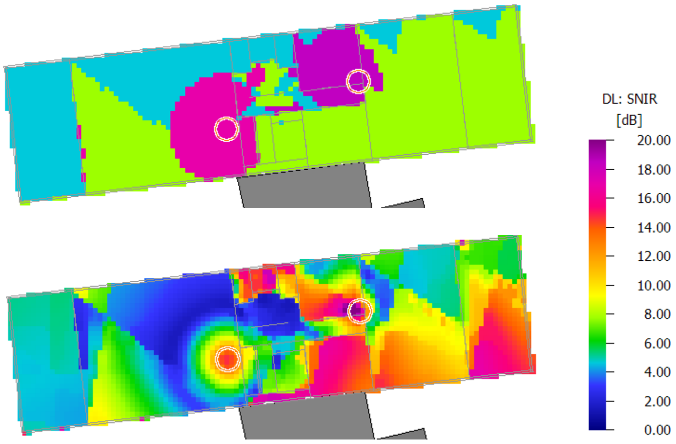

Figure 9: Best server map (above) and SNIR map (below) for the highest floor in a scenario with macrocellular interference

Again, without consideration of the macrocells, Figure 10 shows the coverage situation on the ground floor (best server map and SNIR map). The three femtocells deployed on this floor provide almost full coverage (except for two rooms which are served by femtocells of the floor above with rather low SNIR values).

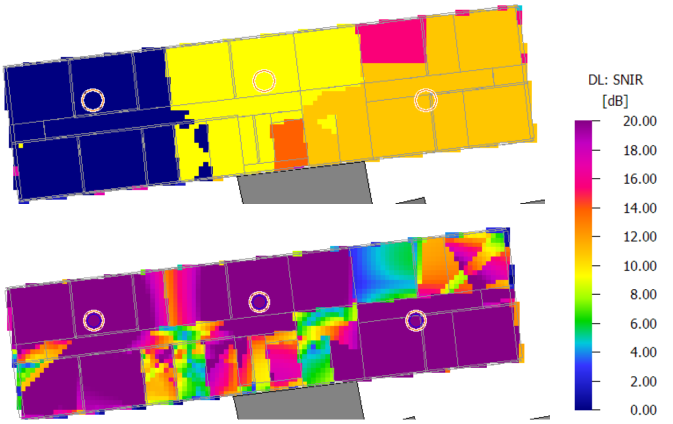

Figure 10: Best server map (above) and SNIR map (below) for the ground floor in a scenario without macrocellular interference

The same floor experiences a far different coverage, when the impact of the macrocellular interference is taken into account. Figure 11 visualizes the reduced femtocell area (see best server map) and accordingly the SNIR performance on the ground floor, which is significantly reduced.

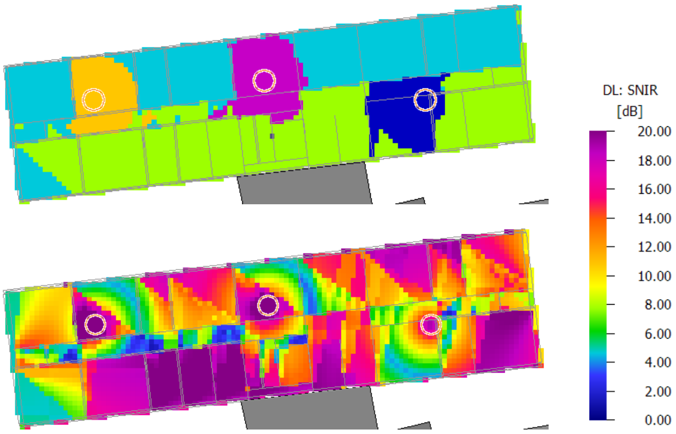

Figure 11: Best server map (above) and SNIR map (below) for the ground floor in a scenario with macrocellular interference

V. CONCLUSIONS

In order to improve the indoor coverage in a cost-efficient way, massive deployment of femtocells in the homes of the users has to be expected. By serving the indoor users in a direct way, femtocells allow to increase the number of subscribers in the mobile cellular network. However, any indoor femtocell generates mutual interference with the macrocellular network.

In the presented reference scenario the SNIR of the macrocellular network is reduced by up to 13 dB due to the interference from the deployed femtocells. Hereby femtocells on the lower floors have a dominant impact on the macrocellular outdoor coverage. The impact of the macrocellular interference on the femtocell coverage is equally critical. Besides the shrinking of the femtocell areas, the SNIR performance is significantly reduced, partly up to 20 dB. Therefore, a detailed analysis of the interference situation is required.

The herein presented network planning tool allows the performance evaluation of LTE networks considering the mutual impact between indoor femtocells and urban macrocells [11].

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