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Numerical Modeling of the Effect of the Built Environment and Usages on Downlink EMF Exposure Induced by MU-MIMO 5G Antennas

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Abstract

In this paper we use numerical modeling to assess exposure to a MU-MIMO 5G antenna in different built environments. First, users are randomly distributed inside and outside buildings, and the channel between the antenna elements and the users is computed using ray-tracing. Second, beamforming is computed using zero-forcing method to maximize the throughput to serve users. The process is iterated until all users have been served. By taking into account usages, this leads to a time dependant radiation pattern of the antenna. This pattern is used to compute exposure maps with a ray-tracing method. These maps can be averaged over time to outline the influence of the environment on the spatial distribution of the electric field level.

1 Introduction

There are several techniques to forecast downlink EMF exposure in urban environments. Some rely on measurements to feed numerical or statistical models. Therefore, they are not suitable for not fully deployed networks such as MU-MIMO 5G.

Numerical simulation of the downlink exposure is then a good alternative. EMF exposure to smart antennas has initially be approached from the point of view of dimensioning security perimeters around antennas [1, 2, 3, 4]. The goal was to get distribution functions of the effective maximum gain of the antenna. In [5] a numerical method simulating beamforming exposure in deterministic built environments was introduced, to compare the overall electric field distribution to other methods. In this paper we use and expand this method to take into account usages and to be able to analyze the influence of the built environment on the spatial distribution of the electric field.

This paper is organized as follows: section 2 details the simulation method (antenna model, channel computation, beamforming and scenarios) and section 3 shows the results obtained for two test environments. We finally conclude in section 4 and introduce future works in section 5.

2 Simulation method

2.1 Antenna model

The antenna used is this study is a Uniform Planar Array antenna in the 3.5 GHz band. Its base element is a 3GPP model [6] with a 8.9 dBi gain, a 80° horizontal and a 65° vertical aperture. The antenna itself is an 8x8 array of base elements with 0.6 λ horizontal spacing and 0.9 λ vertical spacing, and the beams can be steered from -60° to +60° horizontally and -20° to 20° vertically by relative phase-shifting between elements. Beams steered toward a single direction are illustrated on figure 1. The maximum gain of a beam is then 27 dBi = 8.9 dBi + 10 $\log(8 \times 8)$, with a 12° horizontal and a 8° vertical aperture.

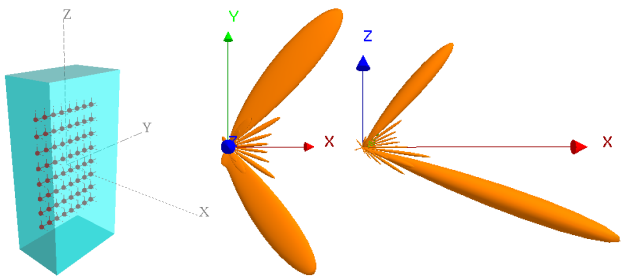

Figure 1. 8x8 antenna (left) with beams steered to horizontally to azimuth 60° (middle) and vertically to tilt 20° (right), linear scale

2.2 Users

User equipments (UEs) are randomly distributed on the ground (20%) and inside the buildings (80%). There are more UEs than real users, in order to represent moving UEs and changing receiving conditions which could alter the channel. In this study we generate 1280 UEs per environment, to be treated as 20 batches of 64.

2.3 Channel computation

The channel between each antenna element and each UE is computed with ray-tracing, to take into account reflection, transmission and diffraction effects, as illustrated on figure

2. Each channel is then the result of multiple paths contributions, and a channel matrix is computed for each set of 64 UEs.

2.4 Beamforming

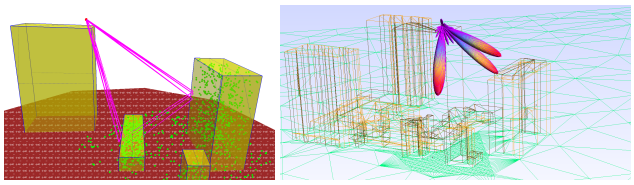

Figure 2. Channel computation for a UE with multipath ray-tracing (left) and beamforming for K=3 UEs (right)

In this study we use zero-forcing beamforming [8]. It aims at maximizing the SINR (signal to interference and noise ratio) to serve a given number of UEs simultaneously. The beamforming weights applied to each sub-element are obtained by computing the pseudo-inverse of the channel matrix (between the 64 sub-elements of the antenna and the selected users).

A greedy user selection algorithm is used to find the number K of UEs that can be served simultaneously amongst the 64 UEs with the overall higher throughput rate with a given noise. Power allocation between users is then done with a water-filling method.

2.5 Scenarios

Two scenarios are tested. First, a constant drop duration scenario, then a more elaborated one.

2.5.1 Constant drop duration scenario

In this scenario the antenna serves users for fixed duration $D = 1$s, whatever the throughput is. Once a user has been served, it is forgotten. As a consequence, at each beamforming step i, K_i users are served for $D = 1$s.

2.5.2 Advanced scenario using throughput

In this scenario, each user j has an initial quantity of data to download $Q_{0,j}$. For each beamforming step i, K_i users are served for a duration D_i depending on the throughput $R_{i,j}$ to user j and its remaining quantity of data to download $Q_{i,j}$. We have $D_i = \min\left\{Q_{i,j}/R_{i,j}\right\} = Q_{i,j_x}/R_{i,j_x}$ for a given j_x. Then this user j_x for which the download is finished is forgotten, and the remaining quantity of data to download for other users is updated with $Q_{i+1,j} = Q_{i,j} - R_{i,j} \cdot D_i$, for $j \neq j_x$.

2.6 Full method

UEs are handled as 20 batches of 64 UEs, where each batch keeps the overall ratio between outdoor (20%) and indoor UEs (80%). A global time counter is initialized to zero and for each batch beamforming is performed according to the given scenario. At each beamforming iteration, an exposure map is computed on the ground and on buildings facades and the time counter is updated. These exposure maps are once again computed using ray-tracing techniques. Each exposure map corresponds to the full antenna power, allocated to one or more UEs, with its own duration. When all 64 UEs have been fully served, another batch is processed, until there are no UEs left.

3 Results

3.1 Environments

Two test environments are studied. They were extracted from an exposure simulation study in the city of Paris. The first environment (see figure 3) is a street canyon with a large building in front of the antenna. The antenna is mechanically tilted 10° downward to span generated UEs (see figure 4).

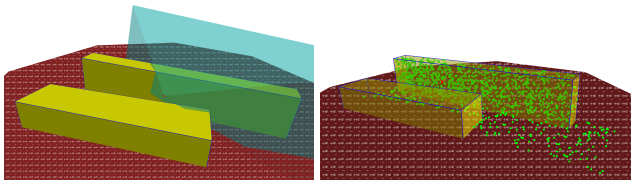

Figure 3. First environment: antenna scan (left) and random UEs distribution (right)

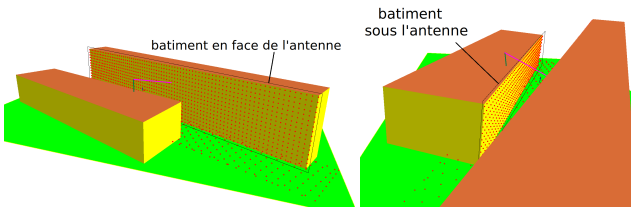

Figure 4. First environment: exposure areas on the ground (left) and on the facades (right)

The second environment (see figure 5) is made of different heterogeneous buildings. The antenna on the very high building is mechanically tilted 30° downward to span generated UEs (see figure 6).

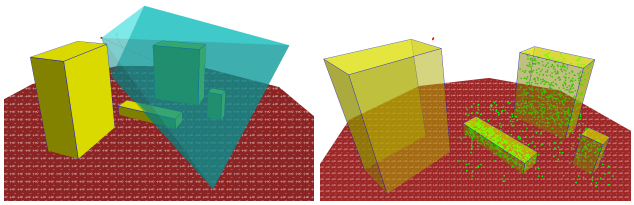

Figure 5. Second environment: antenna scan (left) and random UEs distribution (right)

There are two kinds of results: time-dependant results and time-averaged results. The time-dependant results allow a

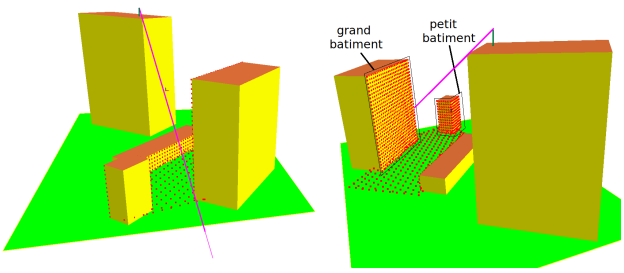

Figure 6. Second environment: exposure areas on the ground (left) and on the facades (right)

visual representation of the beams and the exposure maps and could be used to communicate. They should not be interpreted as realistic instant exposure because of the simplified scenarios, but they can be used to get average exposure over different duration (1 mn, 6 mn, 15 mn, ...).

Furthermore results can be observed both on the exposure maps and on the beamforming antenna patterns.

For exposure maps, we will compare results with French guidelines for 5G exposure [7]. These guidelines assume that users perform a 1 GB download with 500 Mbps throughput over a 6 mn measurement. As a consequence, the antenna has a 4.44% load (-13.5 dB). The antenna pattern used for exposure is then a bounding pattern (120° horizontal and 40° vertical apertures) with a gain of 13.5 dBi (27 dBi - 13.5 dB).

3.2 Overall results

For the constant drop duration scenario, 444 iterations of 1 s (first environment) and 489 iterations of 1 s (second environment) are needed to process all the 1280 UEs. Using a sliding average over 6 mn (hence 360 iterations) we get stable exposure results. This is illustrated on figure 7 by comparing the electric field distributions with different averaging windows (each averaged map is a magenta curve, the distribution of the maximum value at each exposure map is the cyan curve).

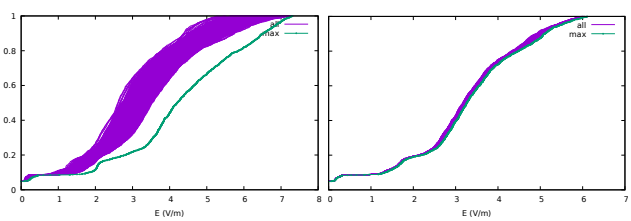

Figure 7. Second environment: electric field distribution in the exposure maps, for 30s (left) and 6 mn (right) averaging window

For the advanced scenario, we use $Q_{0,j}$ = 100 MB as the quantity of data to download for each UE. In the first environment, this is achieved in $\tilde{N}_1 = 1262$ iterations, lasting $\tilde{T}_1 = 1960$ s, with an average throughput $\tilde{R}_1 = 501$ Mbps and an average number of simultaneously served UEs $\tilde{K}_1 = 3.1$. A 9 mn sliding average is used to get stable exposure results. In the second environment, we get $\tilde{N}_2 = 1210$, $\tilde{T}_2 = 2472$ s, $\tilde{R}_2 = 375$ Mbps and $\tilde{K}_2 = 2.7$. A 12 mn sliding average is used to get stable exposure results.

3.3 Exposure maps

The 6 mn averaged exposure maps for the constant drop scenario are compared to the French guidelines pattern. These comparisons highlight the environment dependant spatial distribution of the electric field.

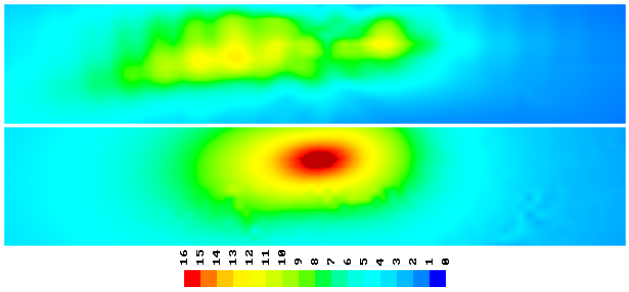

Figure 8. First environment: time-averaged exposure map (V/m) on the wide building in front of the antenna with beamforming (top) and French guidelines pattern (bottom)

For the first environment (see figure 8), the exposure is splattered horizontally on the wide building in front of the antenna, using the full horizontal scan of the antenna. As a consequence, the maximum level with beamforming is lower than with the bounding pattern. This can be explained by the fact that there is no empty (without building, i.e. without UE) area in the antenna span.

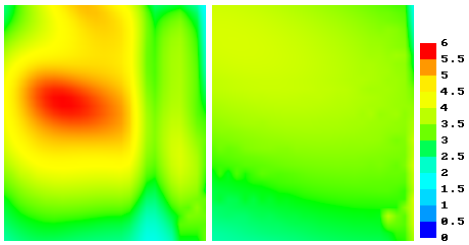

Figure 9. Second environment: time-averaged exposure map (V/m) on the largest building with beamforming (left) and French guidelines pattern (right)

For the second environment (see figure 9), the exposure is concentrated toward the largest building seen by the antenna. As a consequence, the maximum lower with beamforming is higher than with the bounding pattern. This can be explained by the fact there are large empty spaces between buildings (without UE) and that the antenna concentrates its beams (and power) toward the buildings.

3.4 Radiation patterns

It is also interesting to observe the time-averaged radiation pattern of the beamforming antenna. Figure 10 shows the final pattern for the first environment. This pattern emphasizes the main lobe steering toward the opposite building. This main lobe has a 26° horizontal and a 34° vertical aperture and a 14.5 dBi gain.

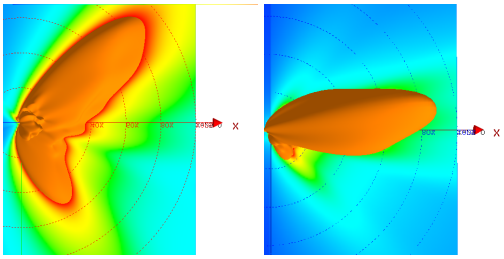

Figure 10. First environment: time-averaged radiation pattern, horizontal view (left) and vertical view (right), linear scale

As hinted we see that the main lobe parameters highly depend on the environment. For the second environment we have a 22° horizontal and a 12° vertical aperture and a 15.1 dBi gain.

4 Conclusion

In this paper we outlined the strong influence of the built environment on both the spatial distribution and the maximum values of the electric field for 5G MU-MIMO beamforming antennas, by using a full numerical approach on simplified usage scenarios. The tests have been carried on two different urban environments but the method can be applied to any other environment for further investigation. This means that exposure simulations should take into account the built environment and its effects on the average pattern to provide reliable results. Furthermore this numerical approach can be used to determine the duration needed to have stable measurements results.

5 Future work

The scenarios used here are very simplified ones and use a "fully loaded" antenna. Using more realistic scenarios with at least an average load would greatly improve the quality of the results without a change in the method. This load could depend on the hour of the day and the location of the antenna (residential area, office towers . . .), to provide more robust results.

A valuable application of this method would be to use it to correlate local environment parameters to the average pattern of the antenna. Such parameters could be the built surface density as seen from the antenna, the width and height distribution of the buildings, . . . By using an important body of built environments (from existing cities) such antenna parameters as horizontal and vertical apertures, gain, side lobe ratio, . . . laws could be deduced from the geometric parameters, and then used as direct inputs of exposure simulation.

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