Conclusions

Overall, this technique is able to resolve the polarizing of living plasma membranes in cell in real time. Using this technique is anticipated to enable a better understand of membrane breakdown phenomena in rapidly applied electric fields and will allow for the direct measurement of dielectric properties governing these interactions in individual cells. Such information will provide higher fidelity to basic circuit models of cells across a wide frequency band and may enable the individualization of models based on specific cell type parameters. Future studies will employ both pump-probe photography and compressed ultrafast photography to image cellular dynamics over the full spatial domain and with time resolution on the order of tens of nanoseconds.

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STUDENT PAPER

Collocated and distributed Massive MIMO from the human EMF exposure perspective: a comparative study

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In this numerical study we compare two deployment strategies of massive MIMO from human exposure perspective. Propagation is modelled using the Ray-Tracing method at 3.5 GHz in a stochastic environment model. An indoor industrial environment is modelled as a square room and scatterers randomly distributed in it. Two base station (BS) configurations are studied: a compact antenna array and an array evenly covering the floorplan ceiling. The exposure is assessed in terms of the psSAR the head normalized to the power density, using the FDTD method. The exposure of the distributed BS is found to be at least two times lower than that of the collocated BS. Implications for the exposure of practical massive MIMO implementations are discussed.

Introduction

Fifth-generation (5G) wireless networks are now on the verge of a widespread adoption. In them the base stations (BS) will be implemented as large antenna arrays of one form or another. The massive MIMO technology has drawn a lot of attention in academia and industry since its inception a decade ago and is expected to deliver record power efficiency and sum data-rates [1]. These are achieved by leveraging the large antenna array aperture to spatially focus the downlink (DL) transmission towards the active user equipment (UE) devices. It was shown that that using computationally-simple reciprocity-based linear transmission precoding schemes, such as Maximum Ratio Transmission (MRT), leads to the formation of small regions of elevated electromagnetic field (EMF) around the target UEs ('hot-spots'). In addition, if propagation conditions are favourable, the inter-UE interference is cancelled automatically.
However, it was recently shown that large in the element number, but compact (collocated) antenna arrays might experience fundamental limitations in real deployment scenarios [2]. As an alternative, a distributed massive MIMO concept was proposed [2], in which the BS array elements are spread throughout the service area. In this implementation, distributed antenna elements provide connection to the UEs towards which the propagation conditions optimal, e.g. lower correlation and less shadowing occurs. The human EMF exposure to massive antenna arrays has been studied extensively. In [3, 4, 5], the time-averaged BS gain is used as a proxi for the far-field exposure to a collocated array capable of the codebook beamforming or reciprocity-based precoding. In [6, 7], the exposure to a collocated BS is assessed in terms of the Specific Absorption Rate (SAR) obtained from a large number of the Finite-Difference Time-Domain (FDTD) simulations. We present, first of its kind to the best of the authors' knowledge, a comparative study of the collocated and distributed massive MIMO implementations in an indoor industrial scenario from the human EMF exposure perspective.

Materials and Methods

Wireless propagation is modelled using the radio-frequency (RF) Ray-Tracing method. The environment model used as an input for the RT simulations is depicted in Figure 1. All geometry is contained within a cuboid floorplan of size 100 m x 100 m x 10 m, to all walls, floor and ceiling of which a concrete material properties are assigned (a warehouse or factory building model). On top of the floor, cuboid perfectly reflecting scatterers are distributed randomly, which model warehouse storage racks or other industrial equipment. The massive MIMO BS is modelled in two configurations. The collocated BS is a 16-by-16 half-wavelength dipole array with a half-wavelength at 3.5 GHz (≈42 mm) inter-element spacing, positioned 0.5 m under the ceiling in the center of the floor area is shown with a blue rectangular patch in Figure 1. In the distributed configuration the same number of the BS elements are equidistantly (≈0.6 m) spaced to cover the entire ceiling surface as shown in Figure 1 with red rectangles. The UEs are arranged in two straight tracks in the upper ('Top') and lower ('Bottom') halves of the area, symmetrically relative to the floorplan center at the height of 1.5 m above the floor. Each track consists of 18 UE locations, spaced 5 m apart, at which the EMF incidence is calculated. The RT output at each UE location is then introduced as a coherent plan-wave set into the FDTD simulation with a realistic human phantom. The UE toward which the DL focusing is targeted is positioned 20 mm to the left of the phantom's head. Oriented this way, the head is shadowing the UE's line-of-sight (LOS) to the collocated BS at all locations on the 'Top' track, and is always in LOS on the 'Bottom' track. The phantom's exposure is evaluated in terms of the peak-spatial Specific Absorption Rate averaged over a 10g cube in the head (psSAR10g), normalized to the time-averaged EMF power density at the location of the UE antenna. 10 independent RT environment realizations were simulated and exposure evaluated in FDTD, resulting in 180 exposure evaluations per UE track.

Results

Figure 2 shows the root mean square E-field (E_{RMS}) averaged over all simulated environment realizations and psSAR10g cubes obtained with the collocated (a) and distributed (b) BS configurations. Clearly, the distributed BS configuration creates a much more discrete peak of E_{RMS} at the UE terminal compared to the collocated BS, with which the E-field is distributed noticeably more evenly throughout the FDTD domain. However, the absolute E_{RMS} value is more than twice higher with the collocated BS, which can be attributed to a shorter average BS-UE distance, resulting in lower Path Loss. Figure 2(a) shows that with the collocated BS, the peak exposure cubes are always found in proximity of the UE, following 'hot-spots' of E_{RMS}. This indicates that the UE 'hot-spot' is indeed the area in which the E-field has the highest value, which causes the highest EMF absorption in the surrounding lossy tissues. In contrast to that, in Figure 2(b) the peak cubes are found in all head regions in which high EMF is usually induced (e.g. both ears, nose, eyeballs). This indicates that unwanted or residual peaks occur in some of the exposure samples - another evidence of a poor focusing performance of the collocated BS configuration in this scenario.

To compare exposure in the two studied cases we normalize psSAR10g to the time-averaged power density observed at the UE location. The sample-mean and range from 25^{th} to 75^{th} percentile values are shown in Figure 3 for two tracks and two BS configurations (four exposure scenarios). It can be seen that with the distributed BS, 'Top' and 'Bottom' UE tracks have nearly identical normalized exposure (≈0.03 m^2/kg). This is expected, as for UEs from both tracks a significant portion of the BS antenna elements has the LOS propagation paths to the UE, which make the main contribution to the hot-spot formation. Contrary to that, the collocated BS induced a noticeably higher mean normalized exposure for the UEs on the 'Top' track, when the UE was shadowed by the head (≈0.08 m^2/kg vs ≈0.05 m^2/kg). Average normalized psSAR10g of the collocated BS is around 2 times higher than that of the collocated one (≈0.03 m^2/kg vs ≈0.06 m^2/kg). It should be noted that the reported values are still lower than the value obtained from the International Commission on Non-Ionizing Radiation Protection reference values and basic restrictions (0.2 m^2/kg). This indicates that the hot-spot induced exposure (in all investigated scenarios) is lower than exposure in the far-field region of common BSs.

Conclusions

This contribution investigated and compared the exposure to the massive MIMO BSs in two deployment configurations. It was shown that the collocated configuration leads to approximately two times higher exposure values compared to the collocated configuration, evaluated in terms of the psSAR10g normalized to the UE antenna power density (≈0.03 m^2/kg vs ≈0.06 m^2/kg). If the UE is shadowed from the collocated BS by the head, the mean normalized exposure further increased up to around 0.08 m^2/kg.

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Figures

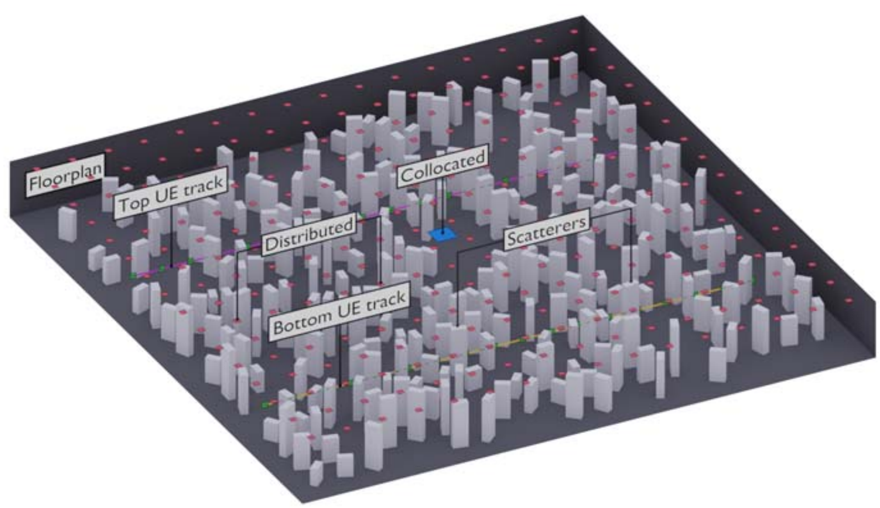

Figure 1. The RT environment model. A square floorplan (concrete material) contains randomly distributed cuboid (metal) scatterers. The collocated BS is shown with a blue patch in the center of the floorplan's ceiling. Elements of the distributed BS are depicted with read patched evenly covering the ceiling surface. The Top and Bottom UE tracks are shown with yellow and pink solid lines, with discrete UE locations along them shown in green.

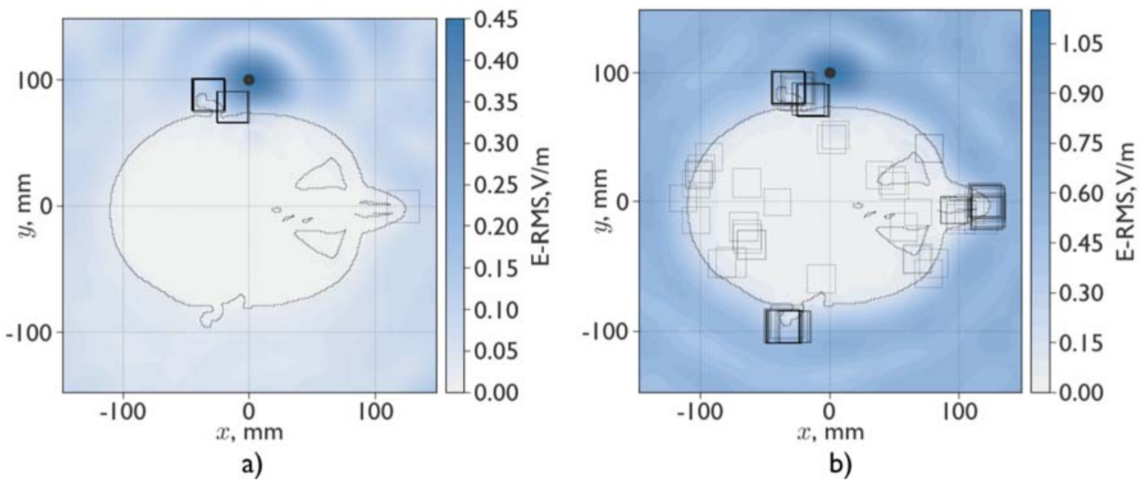

Figure 2. The horizontal plane slice of the E_{RMS} averaged over all 18 Top track UE locations. The slice location along the vertical axis coincides with the location of the UE antenna, shown with a black solid dot. The phantom's head outlne is shown with a dashed line. Black squares depict $psSAR_{10g}$ cubes observed in 10 environment samples (180 exposure evaluations). a) Distributed BS. b) Collocated BS.

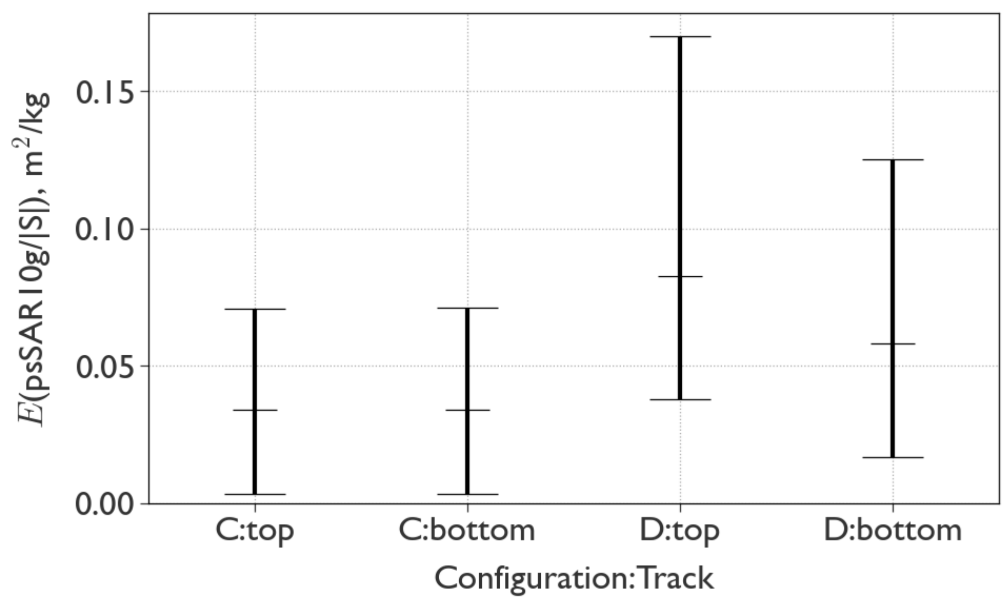

Figure 3. The sample-mean and 25th - 75th percentile range of the $psSAR_{10g}$, normalized to the time-average power density at the location of the UE antenna. The horizontal axis lists the BS configuration and UE track pairs, where 'C' stands for 'Collocated' and 'D' - for 'Distributed'.

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