Industrial indoor massive MIMO human EM-exposure evaluation

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Summary

We present a numerical method of estimating human exposure to the electromagnetic fields (EMF) of a massive MIMO base station (BS) in an industrial indoor environment e.g., an assembly line or a warehouse. The method relies on a massive MIMO channel model derived from ray-tracing simulations with stochastically generated environments. Incoming rays at the receiver location are used as the input for Finite-Difference Time-Domain plane-wave simulations with a realistic human phantom to obtain EM-exposure estimate.

Introduction

In the next generation wireless access networks, increased requirements on data rates and the number of simultaneously served users need to be met. One of the most promising sub-6 GHz technologies being developed is massive multiple-input multiple-output (MMIMO). The number of antennas in a MMIMO base station (BS) is much larger than the number of serviced users. The high amount of antennas allow spatial focusing of the transmitted signal at the intended user location [6]. In favorable propagation conditions [5], MMIMO provides increased capacity [9] and energy efficiency [3].

There exist methods to assess exposure in far-field conditions. These methods use multiple plane-wave Finite-Difference Time-Domain (FDTD) simulations with known statistics of the propagation environment, such as the number of incident waves, their angular and power distribution [10]. However, no valid stochastic MMIMO channel model currently exist. Moreover, the channel statistics vary significantly between users depending on the BS resource allocation. Therefore, the current methods are not suitable for estimation of exposure to MMIMO. At the same time, certain progress was made in deterministic MMIMO channel modeling using the ray-tracing method [4].

The problem of electromagnetic (EM) exposure estimation of MMIMO has not yet been addressed in the literature, to the author’s knowledge. The development of a numerical technique for EM-exposure estimation and evaluation of human EM-exposure in an indoor industrial scenario are the main goals of this paper.

Methods and materials

We utilize stochastic geometry to generate indoor environments for ray-tracing simulations. The environment consists of a single cuboid room with scatterers inside it, as shown in Figure 1. The dimensions of the room are fixed at 20-by-30-by-6 m^3. The material assigned for walls is a dielectric type with $\varepsilon_r = 7, \rho = 0.015$ (concrete). A scatterer is a cuboid of fixed width and length (2-by-0.2 m^2) and height sampled from uniform random distribution from 2 to 4 m. We applied Poisson Disc sampling algorithm [1] to evenly distribute scatterers in the environment without intersecting each other. In addition, all scatterers are rotated around the z-axis at a uniform random angle in $[0, \pi]$. Scatterers use perfect electric conductor material properties.

The environment contains one massive MIMO BS and a grid of receivers. The BS is a 10-by-10 rectangular array of 3.7 GHz λ-separated isotropic antennas, resulting in the overall size of 0.7-by-0.7 m^2. The BS is positioned at the 3 m height and transmits with 1 W (30 dBm) of power. Each receiver in the grid is positioned at the height of 1.5 m and equipped with a single isotropic antenna. Isotropic antennas are used to simplify further analysis.

The calculated channel is described with complex channel matrix H, which elements has the form

$$H_k^n = \sqrt{P_k^n} e^{i\theta}, \tag{1}$$

where P_k^n is normalized power at the k^{th} receiver when only n^{th} BS element is radiating, and θ is the phase of the voltage across a matched load at that receiver. To calculate the received power, REMCOM Wireless InSite ray-tracing software combines E-fields of all received rays at a given antenna coherently, according to

$$P_k^n = \frac{\lambda^2}{8\pi Z_0} \left| \sum_i E_i \right|^2, \tag{2}$$

where λ is the carrier wavelength, Z_0 is the impedance of free space and E_i is the complex electric field of the i^{th} ray [8].

In this work, we only consider the case of Maximum Ratio Combining (MRC) precoding. MRC precoding matrix is defined as $W = \alpha H^H$, where normalization coefficient α is chosen such that W is unitary [4]. If the BS transmits with the total power of P to the k^{th} receiver, then its received power is

$$P_r = \alpha^2 P (HH^H)_k^k. \tag{3}$$

Using equation (2) we find the total electric field magnitude at the location of k^{th} receiver.

To estimate the exposure of an adult man at the location of k^{th} receiver we modeled and simulated the exposure as multiple plane-waves incident on Duke phantom (a 34 years old adult male from the Virtual Population v.3.1) [2] using an FDTD solver. Frontal exposure was assumed ($\varphi \in [0, 180°], \theta = 90°$) with 18 plane-waves having equal angular spacing. Equal power densities were assigned to all 18 plane-waves, such that their algebraic sum equals to the power density at the receiver's location found with the ray-tracing method. Phases of the waves are adjusted for constructive interference at the center of the domain. The center of the phantom's head is aligned with the center of the domain.

The described approach is simplified. It approximates the angular distribution of the incident rays, which a real massive MIMO system would have, by a combination of several plane waves with fixed wave-vectors and the spatial focusing is created artificially. However, massive MIMO spatial multiplexing gain is accounted for.

Results

The presented method was applied to calculate the exposure of a user 15 m away from the BS, and only experiencing non line-of-sight signals (see Fig. 1). The received power was found to be around 5.4 mW. From (2), sum E-field magnitude is around 88 V/m, or 4.9 V/m per plane-wave.

In the free-space FDTD simulation, the RMS E-field magnitude in the hot-spot (Figure 2, left) was approximately 63 V/m. Simulation with the phantom yielded peak-spatial Specific Absorption Rate in 10g ($psSAR_{10g}$) of around 76 mW/kg. The resulting exposure is just below ICNIRP basic restrictions for head and trunk [7] (80 mW/kg). Its relatively high value, given that the BS radiates 30 dBm, can be by part explained by focusing of electromagnetic energy in a narrow spatial region by MMIMO system.

Conclusion and future work

In this paper we introduced a numerical approach for human EM-exposure estimation to MMIMO system, that combines ray-tracing and FDTD numerical methods. It was applied to assess the exposure of an adult male in an industrial indoor environment with a single MMIMO BS.

The ongoing research is aimed at including direction of arrival, amplitude and phase properties of the incoming rays in FDTD simulations. Large number of environments having similar propagation characteristics will be simulated in order to evaluate statistical properties of a human EM-exposure.

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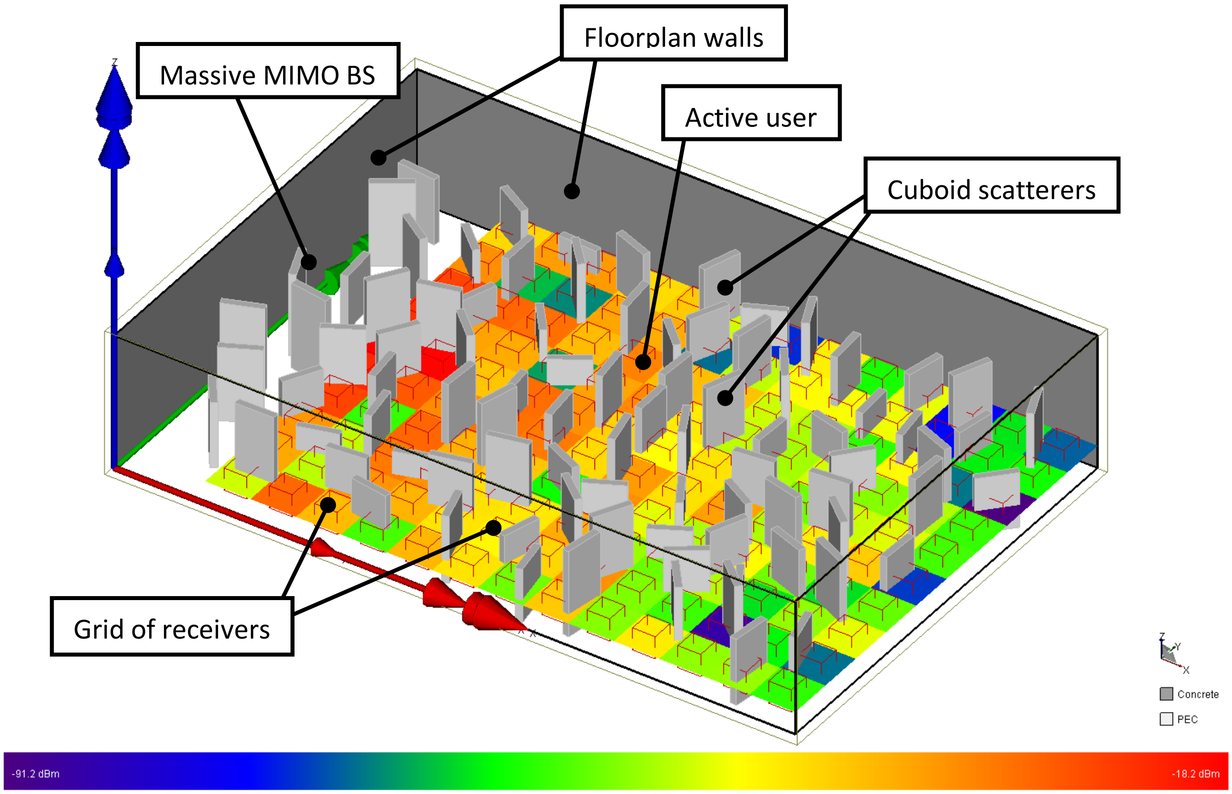

Figure 1: An example of a ray-tracing simulation environment. The MMIMO BS is supplied with 1 W of power. The power at each node of the receiver grid is shown and intended receiver is indicated.

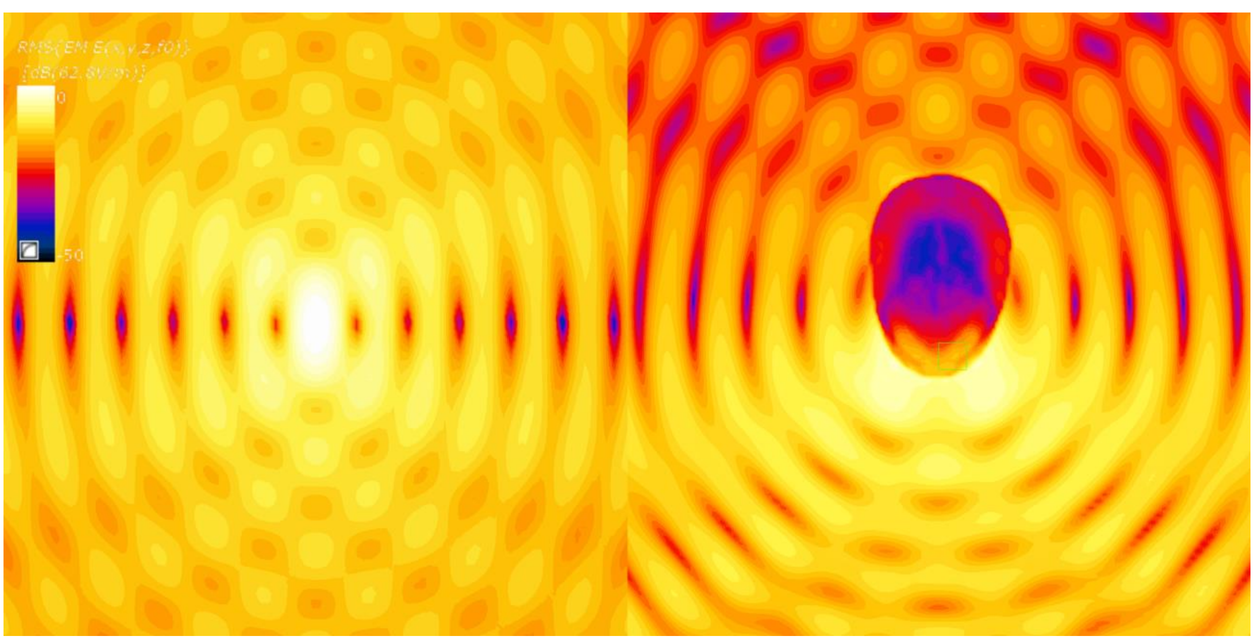

Figure 2: E-filed RMS magnitude in free space (left) and in presence of the phantom's head (right). The location $psSAR_{10g}$ peak-cube shown in green coincides with the free-space E-field area of focus.