Numerical Assessment of Human Electromagnetic Exposure in ATTO-cell Wireless Networks

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Abstract. We present a numerical method for assessment of human exposure to EMF in the ATTO-cell floor, a future ultra-dense wireless networking technology of the future. In the ATTO-floor humans are exposed to the radiation of multiple uncorrelated transmitters. We propose a statistical approach, based on a set of FDTD simulations, which, for the first time, allows to estimate human EM-exposure in the ATTO-cell network. We applied the presented approach to assess the localized absorption in terms of peak-spatial SAR_{10g} values. We obtained an average exposure level of around 4.9 mW/kg, reaching 7.6 mW/kg in 5% of cases. These exposure levels are well below the basic restriction for general public of 4 W/kg specified by ICNIRP.

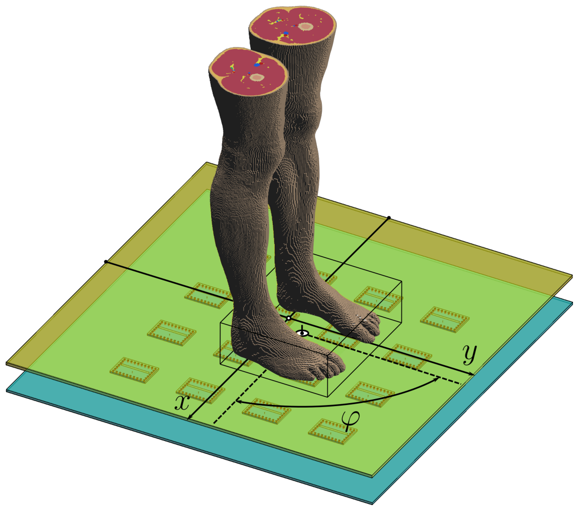

Fig. 1. The simulated configuration consisting of a 4-by-4 ATTO-cell floor and the legs of a human phantom 10 mm above the floor. φ denotes rotation angle of the phantom with respect to x-axis.

I. Introduction

The ATTO-floor is an emerging ultra-high capacity wireless network technology. It is designed to provide wireless connection to robots moving around the floor surface. The entire floor area is tiled with ATTO-cells which are hidden under its surface (Fig. 1). An ATTO-cell has dimensions of 15-by-15 cm^2 and an antenna is supplied with a maximum power of 1 mW at a 3.5 GHz carrier frequency [1]. Provisioned applications of the ATTO-cell technology are industrial warehouses and factories of the future, where robots and human workers operate side by side. In such conditions humans will be mostly exposed to the scattered fields of antennas serving surrounding robots and direct exposure is unlikely to occur. However, compliance testing requires the worst-case exposure scenario to be assessed, i.e. a human on top of active ATTO-cells.

Exposure from a *single* ATTO-cell was studied in [2]. Peak spatial specific absorption rate averaged over a 10g cube ($psSAR_{10g}$) was found to be around 2.8 mW/kg. This is far below International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines for the general public (4 W/kg) [3].

Using the presented numerical method we estimated the exposure when multiple antennas radiate simultaneously. In addition we evaluated statistical properties of exposure, in assumption that signals from different antennas are uncorrelated.

II. Methods

II.1. Simulations

We used the Finite-Difference Time-Domain (FDTD) method implemented in Sim4Life v3.2 (ZMT, Zürich, Switzerland). The simulation domain is shown in Fig. 1. We used the Virtual Population v.3.1 heterogeneous Duke phantom [4] in standing posture. The shortest distance between the feet and the surface of the floor is 10 mm. A 4-by-4 ATTO-cell array is placed 58 mm under the floor surface. The phantom's footprint is fully covered by such array, which ensures that the contribution to the exposure of unaccounted cells is low.

To decrease computational resources required, only the part of the legs up to the knees of the phantom was included into the simulation domain. This does not effect the results, as EM-fields vanish almost entirely at that height [2]. With perfectly matched layer (PML) boundary conditions and 1.2 mm resolution in lossy regions, it resulted in around 150M voxels in total.

The feet of the phantom are located inside the near-field region of some of the antennas and thus become mutually coupled with them. To account for this we conducted 147 multi-port simulations with different positions of the

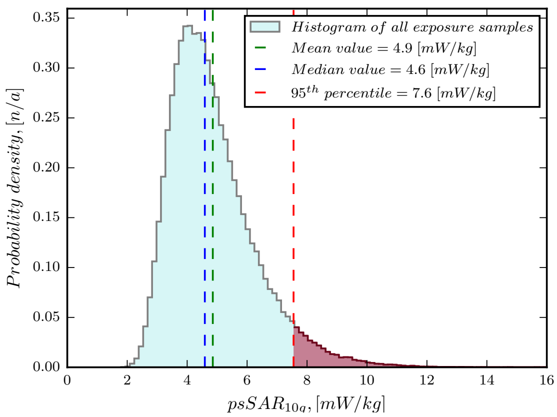

Fig. 2. Histogram of all 147000 exposure samples. Mean, median and 95th values are shown with colored dashed lines.

phantom inside a 150-by-150 mm^2 center rectangle. In total 49 locations and 3 angles of phantom's rotation were considered.

For every configuration we performed a multi-port FDTD simulation. A multi-port simulation consisted of 16 single-port simulations. In each of them only a single antenna is excited with a 3.5 GHz sinusoidal signal of normalized input power. E-fields in lossy regions were extracted and saved for processing.

II.2. Statistical approach

We assume that signals from antennas are not correlated. Thus we generate random numbers in $[0, 2\pi)$ and assign them as the phases of the antennas in the array. After that we calculate vector sum of the electric field distributions found in each of 16 single-port simulations and normalize total input power to 16 mW (1 mW per antenna). The resulting electric field is used for $psSAR_{10g}$ evaluation, using Sim4Life built-in numerical routines.

We repeated the described procedure 1000 times for each multi-port simulation which altogether yielded in $147{\cdot}10^3$ exposure evaluations.

III. Results

2 shows a histogram of all obtained exposure values. The PDF is bell-shaped skewed to the left. Its nonparametric skew, defined as $S = (\mu - \nu)/\sigma$, where μ - its arithmetic mean, ν - median and σ - standard deviation, equals 0.19. Its arithmetic mean is interpreted as an average exposure of ATTO-floor and equals 4.9 mW/kg. This is nearly twice the upper limit found in [2] for a *single* ATTO-cell but still three orders of magnitude lower than ICNIIRP general public guidelines (4 W/kg). 95^{th} percentile indicates the level of exposure that has a small (5%) chance to occur and was found to be around 7.6 mW/kg.

IV. Conclusion

We estimated the exposure of ATTO-floor in terms of peak-spatial SAR_{10g}. We utilized a novel statistical approach to obtain the average exposure of 4.9 mW/kg and a 95^{th} percentile value of 7.6 mW/kg on the ATTO-floor. Observed exposure levels are well below the corresponding ICNIRP guidelines for the general public. The method we presented can be exploited to assess exposure in other systems with multiple antennas.

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