Phase 1 of the OUTREACH Initiative to Industry*

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BioEM 2024, Crete, Greece, June 16-21, 2024

Summary

A growing population is concerned about health effects of 5G and 6G. While simulation studies with a "worst-case" methodology answer this, an important knowledge gap in literature remains for the layman's simple question: "how much exposure do I *realistically* experience in daily life from 5G?" To enable comprehensive end-to-end simulations, our OUTREACH (OUTdoor Realistic Exposure Assessment for next-generation Cellular networks on Humans) idea aims to collaborate with industrial and governmental partners to share accurate data, including e.g. real smartphone radiation patterns, real base station antenna patterns, and more. The goal and feasibility of the idea are outlined in a short survey. Then, a case is made for industrial and governmental partners to share data securely. A conceptual map analysis helps make this case. In phase 1, support will be garnered in the academic community. Experts at the BioEM 2024 conference expressed strong support for the idea. More support will be garnered before moving on to phase 2 in the summer of 2024. In phase 2, OUTREACH will launch on a specific embargo date with a website, video and dissemination. In phase 3, the initiative will grow using the domino effect.

Introduction

The fifth (5G) and sixth (6G) generations of cellular networks feature order of magnitude increases in antenna density and frequency. A portion of the population is concerned these could result in adverse health effects, sparking deployment stops, protests and general worry. However, no conclusive evidence exists that Electromagnetic Fields (EMFs) from 5G Base Stations (BSs) can exceed the maxima set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Between the transmitting of EMFs from the BS and the absorption in the human body, simulation studies conduct their analysis in a "worst-case" scenario at each step, making assumptions about other parts of the radio channel. There is a gap in the current literature on real daily exposure from EMFs with comprehensive end-to-end simulations. Nevertheless, the findings would interest both concerned citizens and policy-makers due to 5G and 6G's novelty. Also, fully integrated simulations enable EMF-aware network-planning and characterize wavelength-sized "hotspots": regions of increased EMF shaped by the BS technology, the propagation environment and the user [2].

Comprehensive end-to-end simulations can be divided consecutively into the scenario, propagation, hybridization and exposure step [2]. An example is shown in Figure 1. For the scenario step, the following data must be available. First, the 3D location and orientation of every BS in an area emitting 5G and 6G Radio-Frequency (RF) radiation. Second, the antenna pattern of all antenna elements inside the BS and its implementation of massive multiple-input multiple-output (MaMIMO). Third, a 3D mesh of the propagation environment accurate within the scale of the simulation's wavelength. Fourth, realistic electromagnetic material parameters for each polygon in the mesh. In the propagation step, a performant ray-tracer or state-of-the-art map-based deterministic radio channel generator yields the EMFs directed in a beam towards the user. In the hybridization step, the far-fields are evaluated in the near-field of the user, while coupling the channel to the UE. Access to a real antenna pattern and CAD model of a smartphone would significantly improve this channel coupling [2]. In the final exposure

* This document was edited to reflect the latest changes after the BioEM conference and to be published on the initiative's website.

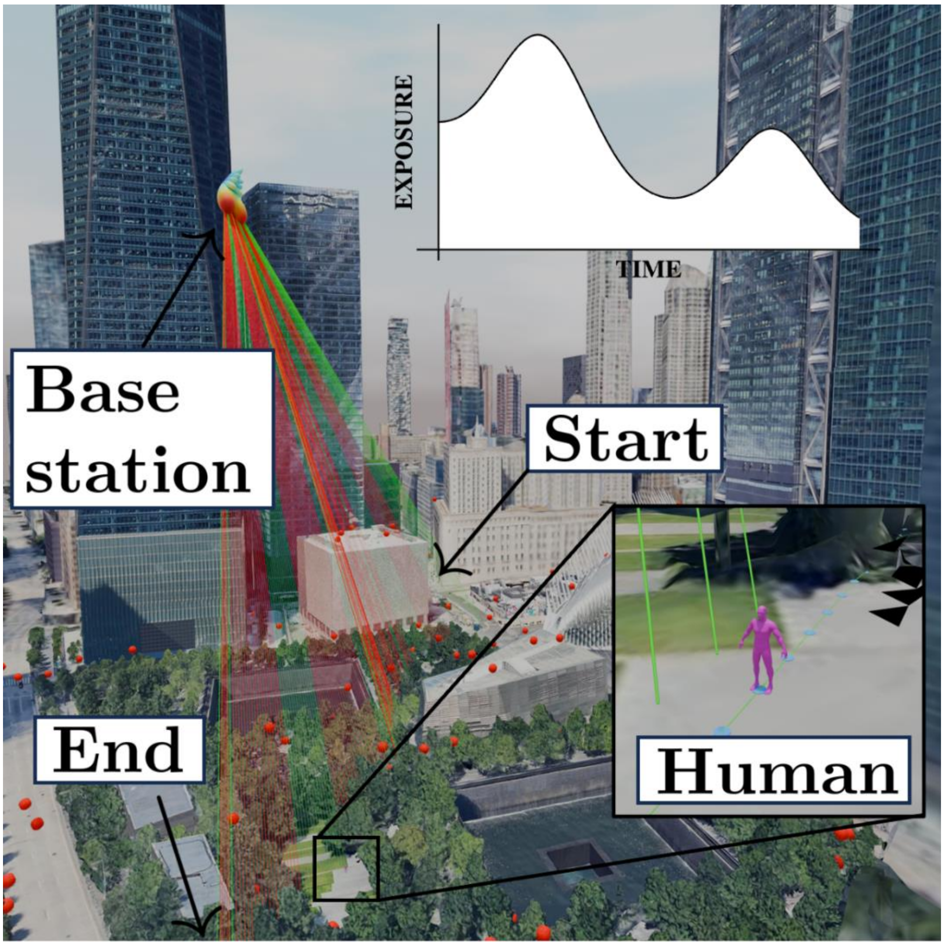


Figure 1: A 5G MIMO BS on One World Trade Center exposes a human to RF-EMF along a 6-minute walk in New York City. The red dots represent (insufficiently accurate) locations from OpenCellID's database of BS. Both the BS and UE have arbitrary radiation patterns. The QuaDRiGa channel model generates data based on, e.g., LOS/NLOS data as indicated by the green and red lines.

step, an anatomically correct 3D human model suitable for mmWave frequencies must be accessible. The exposure levels are then evaluated after performing a finite-difference time-domain (FDTD) simulation. Ultimately, end-to-end simulations with minimal assumptions are mainly hampered by a lack of available data and high computational costs.

Through industry outreach, the OUTREACH idea aims to close these data gaps for the outdoor downlink case with 5G and 6G networks. The acronym OUTREACH stands for "OUTdoor Realistic Exposure Assessment for next-generation Cellular networks on Humans". The feasibility of OUTREACH is first established based on a short survey of recent advancements in academic research and industry. Then, a case is made for industrial and governmental partners to securely share the required data. Finally, preliminary results of the first phase are discussed, including polling at the Third International Conference on Bioelectromagnetics (BioEM 2024) conference, indicating a strong support within the academic community. The second phase consists of launching the OUTREACH initiative at a specified date and contacting partners.

Goal and feasibility

The goal of our idea OUTREACH is to provide a clear and accurate answer to the layman's question "how much exposure do I experience in daily life from 5G in my city?". The answer can be expressed statistically as a percentage of the ICNIRP reference levels and basic restrictions and as function of location, e.g., as a heatmap. The idea is illustrated in Figure 2. Accuracy and coverage should be

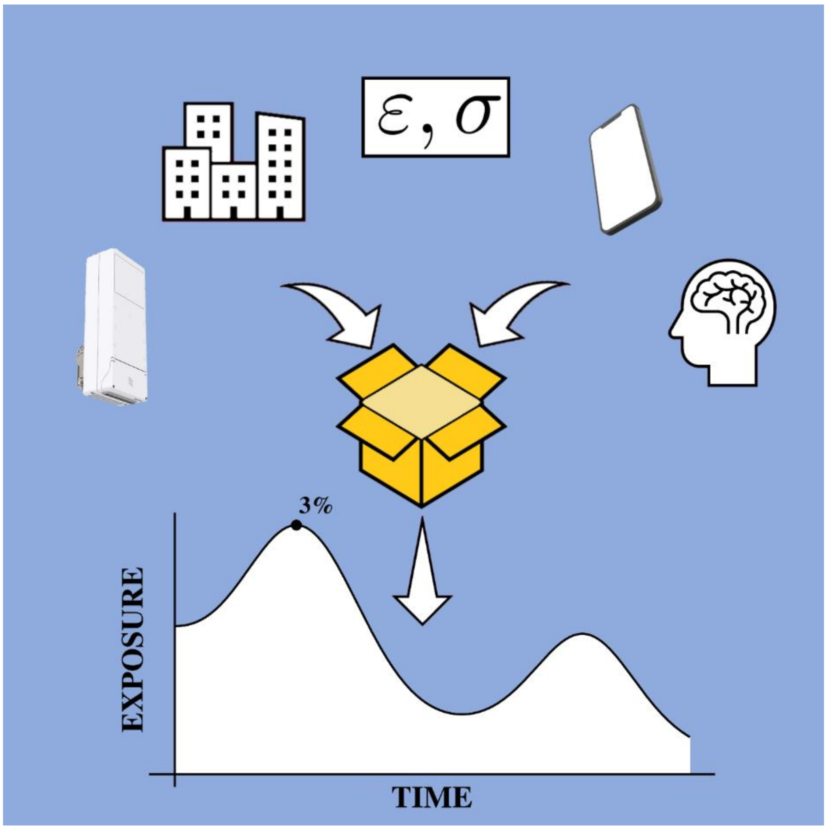


Figure 2: A simple illustration of the OUTREACH idea. Some of the required data from industry is shown in the top half of the image. These should be securely assembled and utilized in an end-to-end simulator to produce the daily realistic exposure experienced as a function of time. The result is the exposure metric as a percentage of ICNIRP's EMF safety guidelines as a function of time along a realistic walk.

maximized to obtain convincing results to individuals and policy-makers. The scope can be extended to sub-THz 6G applications such as distributed MaMIMO systems.

In the following section, a short survey details areas where realistic data is most needed, with examples of partners that could provide them. Recent advancements in industry and government are highlighted**,** which enable realistic end-to-end simulations. A working pipeline is published alongside this paper that combines all data currently freely available [1]. This demonstrates feasibility of the OUTREACH idea as every critical step has fallback options.

Survey of available data

The exact locations and orientations of 5G BSs is often not easily available to the public on city or country scales. First, crowd-sourcing based services such as OpenCellID, CellMapper, Combain use signal strength triangulation to offer an estimate of their locations. However, the accuracy is insufficient, in particular for regions with sparse data. Second, some governmental institutions keep a record in the cadastre of an antenna's location (and other details) when it is registered by an operator. One example is the United States' FCC Antenna Structure Registration. However, the registration is incomplete because it is not always mandatory. Data is more thorough in European countries such as France, Belgium, and the Netherlands. To achieve high coverage on a continental scale, collaboration is necessary as not all API's are always accessible to the public. Finally, large mobile operators (e.g. Verizon, AT&T, Deutsche Telekom, Vodafone, …) presumably keep track of every BS's detail in their whole network. This data could be shared for the OUTREACH idea.

As Björnson *et al* wrote in 2019: "The development of MaMIMO communication technology is now in the hands of the product departments of companies such as Ericsson, Huawei, Nokia, etc." [3] Commercial BSs are now available for in the highest Frequency Range 2 (FR2) with a large number of elements in MaMIMO arrangements. In academia, this is typically modeled with an arbitrary arrangement of dipole or patch antennas. 3GPP [4] provides a more detailed description of these antenna patterns but they are ultimately not real patterns. It also does not account for inter-element interaction. The exact MIMO configuration, power control, duty cycles, and precoding schemes are unknown while being crucial to the amount of RF-EMF exposure. Therefore, any antenna pattern from a BS supplier would significantly improve the realism of the simulations.

The same is true for the UE, where a smartphone will be used. A generic smartphone model, simple antenna pattern and arbitrary orientation is often used in academic research. The antenna pattern of the receiving 5G module, which is now ubiquitous in smartphones, has an influence on the radio channel at the UE side. The model of the smartphone itself also has an influence on the scattering of the near-field onto the human. Thus, obtaining any of the above data from a smartphone (e.g. Apple, Samsung, Xiaomi, …) or component (e.g. Qualcomm) manufacturer would improve the realism significantly.

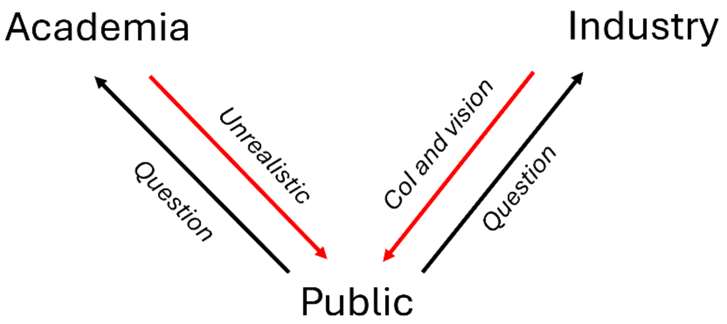
Databases with 3D meshes of outdoor environments exist with varying degrees of Level of Detail (LoD) and coverage. First, Open Street Maps (OSM) provides a freely licensed map consisting of buildings, streets and many other features. The coverage is expansive, in particular for Europe and the United States. The LoD of buildings varies from footprints with height information (2.5D) to custom-modeled buildings (3D). However, wavelength-sized details are not always resolved and 3D foliage is absent. Therefore, the radio channel can exhibit a lack of multi-path diversity. The strength of OSM is in its semantic nature, such that material parameters can be assigned by feature type without the use of machine learning. Second, photogrammetry data with wavelength-sized precision is available using for example LiDAR scanning technology. The coverage however does not extend past the city scale. Finally, several companies also offer wide-coverage and high-LoD maps with 3D buildings. The 3D layer is typically generated from aerial survey imagery and therefore not completely semantically labeled. In some cases, the mesh has accuracies down to several centimeters. The maps also usually include real foliage. Google Maps, Bing Maps and ArcGIS are examples of key industrial players in this space. In recent years, most of these (notably Google in 2023) provide an API with low-cost access. While the data can be streamed in, legal restrictions apply to offline use. Cooperation to share the data is essential to accurately compute the channel in end-to-end simulations.

Radio channel models can be classified as either stochastic or deterministic. Based on a comparative survey of stochastic models [5], a hybrid of the map-based QUAsi Deterministic RadIo channel GenerAtor (QuaDRiGa) v2.8 [6] with the mmMAGIC model integrates the most amount of software features. A characterization of the propagation environment type with Line-of-Sight/Non-Line-of-Sight detection is sufficient to model the channel. The model calibration is ultimately based on measurements, improving the level of realism. Deterministic models have the potential to be even more accurate. Full ray-tracing however requires accurate, heterogeneous knowledge of the constitutive material parameters, which remains scarce [7]. A differential ray-tracer can be used to optimize the material parameters to a reference signal by means of gradient descent. NVIDIA released *Sionna* in 2023, the first radio propagation differentiable ray-tracer, which also takes full advantage of their GPU's [8]. We intend to use this open-source software with stochastic modeling as fallback.

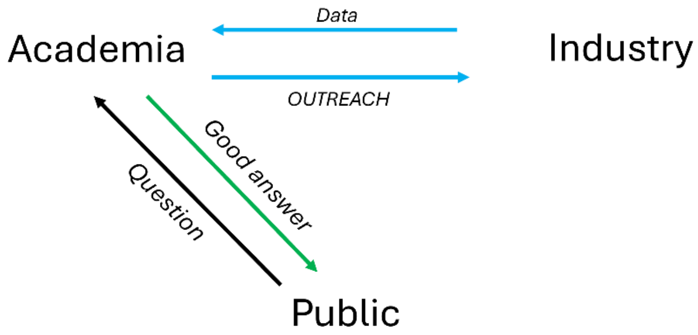
The case for data sharing from industry and approach

The required data contains proprietary intellectual property from the company or its stakeholders, causing reluctance. However, sharing data exceptionally for the OUTREACH idea affords companies the opportunity to appease individuals and policy-makers of 5G deployment. Moreover, they contribute academically to cutting edge research, as the results are unparalleled within the EMF exposure literature. Progress in end-to-end simulation tools is difficult without access to data, while they enable the investigation of EMF-aware network planning and the influence of RF-EMF hotspots in realistic scenarios. Finally, all data will be kept inaccessible to other partners and contractually safeguarded.

Two conceptual maps are shown in Figure 3 with the three main actors in RF-EMF research: the public, academia, and industry. The current segregated approach is shown in Figure 3(a). The public and policy-makers ask the question to academia what the realistic exposure metrics are from 5G and 6G technologies. Academia can not conduct studies using actual devices as they are not easily available. Therefore, worst-case assumptions are taken, such that the exposure is often overestimated and unreliable. When the public asks the same question to industry as a whole, the answer will depend on the specific institution. Generally it will take the form of compliance test reports of their commercial device, which fails to present realistic exposure results in end-to-end simulations. Moreover, the public perceives a conflict of interest (CoI) and the exposure assessment is focused on current technologies rather than visionary technologies. Instead, the OUTREACH initiative would result in a collaborative model, as shown in Figure 3(b). Here, the question is asked to academia, which accesses realistic data from industry. Using the data under strict data safety conditions, the answer related to realistic end-to-end exposure assessment can be given to the public. To the best understanding of the authors, no disadvantages exist for all three actors with the collaborative approach when data safety is performed rigorously, while circumventing all the issues present in the current segregated model.



(a) Current segregated model



(b) Envisioned collaborative model

Figure 3: Conceptual map of the segregated and collaborative models, respectively before and after the OUTREACH initiative. The black arrow denotes the public asking important questions on how large the realistic exposure levels are from 5G and 6G technologies.

Phased approach and embargo

OUTREACH will proceed in two phases. In the first phase, the initiative is introspective within the academic community. The initiative was presented at the BioEM 2024 conference, after which RF-EMF exposure experts were polled whether they support the initiative. The results from this phase were positive because the submitted paper won an award and 51 forms were signed, including from prominent experts, the BioEM board and presidents of large research organisation in RF-EMF. The first phase will continue by garnering support in the wider RF-EMF community. In the second phase, the initiative is outward-looking. Using a dedicated website, video and dissemination on social media, the idea is presented to industry and governments worldwide. Specific industry leaders will be contacted for collaboration on the OUTREACH initiative. The second phase will have a specific embargo date in the summer of 2024, enabling the message from academia to be correctly represented and the message to be convincing. In the third phase, the number of partners should grow. Here, a *domino* effect will hopefully influence partners not yet convinced to participate in the OUTREACH initiative because of the backing of prominent industry leaders.

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