On the special challenges in characterizing the 5G base station RF environment

Sam Aerts, Robert G. Olsen, and Wout Joseph

The global rollout of the fifth generation of cellular networks (5G) brings new challenges to the characterization and measurement of their emissions of radiofrequency (RF) electromagnetic fields (EMFs). The new generation of telecommunications is focused more than ever on efficiency, flexibility and adaptability and features (among other things) a wide range of carrier frequencies (from 410 MHz up to 52.6 GHz), lean 'always-on' (though periodically transmitted) broadcast signaling, and base stations containing advanced antenna systems (AAS) with phased antenna arrays that consist of tens to hundreds of antenna elements.

The scarcity of broadcast signals means that without users, the contribution of a 5G network to the environmental EMF exposure – defined in terms of the electric-field strength (in volts per meter) or the power density (in watts per square meter), which, in the antenna's far field, are related – is low (e.g., in a commercial 5G NR network (operating in the 3.5 GHz band) in Bern, Switzerland, maximum power density levels of 0.0007 μW/cm^2 without user and 0.1 μW/cm^2 with user – i.e. about 140 times higher – were measured [Aerts, 2021]). Moreover, the use of AAS enables beamforming, i.e., directing the power only to the intended receivers, so that the additional exposure from the 5G network remains concentrated where the users are. Therefore, the impact on the exposure of non-users is alleviated compared to legacy networks (older generations). To account for this usage-dependency, user devices are now required to correctly assess the potential exposures from the base stations [Aerts, 2020], while for legacy technologies the assessment was done without user device, and a new protocol for the characterization of the total exposure (i.e. the sum of the exposures from the network and the user device) has been proposed [Velghe, 2021].

The high antenna array gains achieved by beamforming can cause higher exposure levels compared to base station antennas in legacy networks. However, current exposure safety guidelines issued by international standardization bodies, such as the IEEE International Committee on Electromagnetic Safety (ICES) Technical Committee (TC) 95 and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), prescribe for RF EMF averaging periods of the exposure levels of 6 to 30 min [Bailey, 2019; ICNIRP, 2020]. With AAS, the antenna patterns are software-configurable and multiple algorithms or beamforming schemes (e.g. codebook and reciprocity-based beamforming) exist to ensure an optimal spatiotemporal distribution of the power. In case of multiple simultaneous users, the antennas' Multiple-Output-Multiple-Input (MIMO) capabilities also shape and reshape their antenna pattern to accommodate the ever-changing distribution of users. Considering the stochastic natures of the spatiotemporal distribution of users and their data needs, the 6 or 30-min average gains in any given direction about the antenna array will – under real circumstances – be typically 6 dB (factor 4) lower than the maximum [Thors, 2017; Shikhantsov, 2021]. To adequately account for this new dimension, distributed networks of EMF sensor nodes will be required that can monitor the rapidly changing EMF environment over longer periods of time [Aerts et al., 2018]. However, with the societal integration of the Internet-of-Things (IoT) there is a growing number of 'smart city' platforms for which the monitoring of environmental variables is a main objective that may be well suited for their deployment [Diez, 2017].

In order to achieve the increase in capacity expected from the new generation, frequency spectrum above 24 GHz was allocated (the so called 'FR2' frequency band). Given the physical properties of the EMF at these frequencies – e.g., higher propagation loss, weak diffraction and easy blockage, and higher atmospheric attenuation compared to microwave frequencies (i.e. sub 6 GHz) – networks working at these frequencies require a high density of base stations in the near vicinity of the users (e.g., indoors in every room and outdoors on each street corner) to ensure line-of-sight (LOS) communication. However, at these 'millimeter-wave' (or mmWave) frequencies, antenna elements are so small that large antenna arrays with hundreds of elements can be created with dimensions of 100 cm^2 or less, so that 'small cells' (i.e. smaller, lower-power base stations) become an optimal solution. The impact of their proximity and high-gain narrow beams ('pencil beams') on the EMF exposure of users and non-users compared to e.g., Wireless Fidelity (Wi-Fi) networks remains unknown. At the moment, mmWave exposure research is lacking – current measurement methods for sub-6-GHz signals may be extrapolated [Aerts, 2020], but more specialized measurement equipment is required.

Finally, given the exponential increase of sources of RF-EMF in our everyday environment owing to 5G (e.g., increased machine-to-machine (M2M) communications) and IoT infrastructures, there is a need for the assessment of the resulting simultaneous exposures [Hirata, 2021]. A total exposure evaluation framework has been proposed [Varsier, 2015] and efforts are currently underway to include the aforementioned additional dimensions using stochastic dosimetry [Tognola, 2021].

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