Human RF-EMF Exposure to 3D Beamforming Antennas in Indoor 5G Networks

Mrs. Sk. Shammi[1], P. N. Susmitha[2], P. Prameela[3], V. V. Sai Ramya[4], P. Naga Chandini[5]
[1]*Asst. Prof, Dept of CSE, Tirumala Engineering College, Narasaraopet, Guntur, A.P., India*
[2,3,4,5]*B. Tech Students, Dept of CSE, Tirumala Engineering College, Narasaraopet, Guntur, A.P., India*

ABSTRACT - The deployment of 5G networks in the near future will alter the population's exposure levels to radio-frequency electromagnetic fields. The goal of this study was to investigate the exposure variability in the presence of an access point at 3.4 GHz with a 34 patch element uniform planar array antenna and 3D beamforming capability. The novel aspect of the exposure evaluation methodology was the combination of traditional computational methods with a new approach based on stochastic dosimetry, known as the polynomial chaos kriging method, to estimate exposure levels for 500 different antenna beamforming patterns with minimal computational effort. The simulations were evaluated using a child model and the specific absorption rate in various tissues. The results analysis revealed a high exposure variability scenario based on the array antenna's beamforming patterns, as well as the elevation and azimuth angles of the main antenna beam that may cause the highest levels of exposure.

Keywords: 5G networks, RF-EMF, stochastic dosimetry

I. INTRODUCTION

The Fifth Generation (5G) of wireless cellular networks was created with lofty objectives in mind, such as very low latency, a significant rise in the number of connected devices and data speeds, ultra-reliable connections, and high coverage. With the deployment of 5G, the next future will be defined by the reality of smart houses, towns, and communities, introducing new services and utilities to the entire population in an Internet of Things environment [1]. Innovative technologies, such as the implementation of small-cell networks, the use of large multiple-input–multiple-output (MIMO) base station antennas, device-to-device (D2D) networking, heterogeneous networks, and three-dimensional beamforming (3DBF) techniques, have been proposed and are being implemented in recent years [2–5]. Additional spectrum has been allocated in millimetre wave bands between 3 and 100 GHz to provide very wide channel bandwidths; however, at these high frequencies, there is a need to counterbalance the high path loss that signals encounter. The use of dense micro cell deployments in conjunction with antennas capable of adaptively focusing the beam in the desired direction through sophisticated 3DBF techniques can effectively combat severe path loss and reduce network interference and electromagnetic emission towards undesired directions [6].

Any of the numerous studies dealing with the performance of technical solutions for 5G network implementation often deal with the human exposure levels that such deployments would cause. [8] Formalized paraphrase In the References section, the authors used simpler exposure models to assess the effect of the current mm wave frequency bands. The authors of Reference [10] analysed the exposure levels induced by specific devices in uplink and downlink scenarios, but only on a few configurations, while the authors of Reference [13] faced the heterogeneity of the exposure scenario by using ray tracing and statistical techniques.

The current research sought to address the difficulty of analysing exposure variability in the presence of heterogeneity. The paper's novelty stems from the use of stochastic techniques in conjunction with classical computing techniques for the first time. Stochastic dosimetry has previously been used effectively for both low- and high-frequency exposure scenarios, allowing for massively reduced computational costs by replacing a costly computational model with a practical approximation of the original model that is much easier to test.

Starting with the results of a small number of costly numerical simulations and coupling them with surrogate models, it is possible to estimate exposure in a large number of configurations and perform statistics and sensitivity analyses.

II. RELATED WORK

The beamforming capability of an access point's (AP's) antenna in an indoor setting provided the heterogeneity in this analysis. In particular, the AP antenna was modelled as a uniform planar array (UPA) with 64 patch elements operating at 3.7 GHz, which is within the permitted range of frequencies below 6 GHz that the first 5G network implementations would use (in Italy, the range is 3.6–3.8 GHz [16]). In the simulations, a child model was used to calculate human exposure levels in terms of real absorption rate (SAR), as stated in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [21]. We were able to broaden the exposure assessment from a few basic beamforming patterns of the UPA antenna to the entire space of variability of the antenna pattern by combining deterministic and stochastic methods.

It is undeniable that the advent of new frequencies and radio physical access techniques would have an effect on human radio-frequency electromagnetic field (RF-EMF) exposure, and the design of new exposure tests that account for the heterogeneity of different relation parameters remains a difficult task.

It combines conventional computational methods with stochastic dosimetry, a novel technique that makes use of

Surrogate models are used to achieve the variable of interest at a significantly lower computational cost than conventional computational approaches. This technique has already been used to measure users' EM sensitivity levels in low- and high-frequency ranges.

Surrogate models were developed for SAR values averaged over the entire body, head, and brain, as well as maximum SAR values averaged over 10 g for specific tissues (e.g., skin, brain grey matter, and cerebellum).

III. EMF LIMITS

EMF limits are maximum EMF exposure levels imposed by national legislation to ensure that devices emitting electromagnetic fields do not endanger public health. In the case of 5G systems, radio access networks would operate across a broad spectrum of frequencies, ranging from hundreds of MHz to tens of GHz, in order to support the wide range of requirements entailed by the many emerging mobile applications [29]. At 5G frequencies, EMFs are known to primarily cause thermal effects on the human body (i.e., induced current, or skin and body heating); therefore, the issues raised above easily extend to next-generation cellular deployments.

Many countries around the world, as well as the European Council, have adopted the ICNIRPss' EMF limits. Despite the fact that ICNIRP limits are already fairly tight, Italy imposes different EMF limits on its national territory that are even more restrictive. The Italian law introduces two distinct types of limits: I general limits that are typically 30% lower than the ICNIRP limits, and (ii) stringent limits that are 10 times lower than the ICNIRP limits. In fact, the restrictive limits extend to a large portion of the national territory, including houses (including terraces and balconies), schools, and buildings for human long-stay purposes in general.

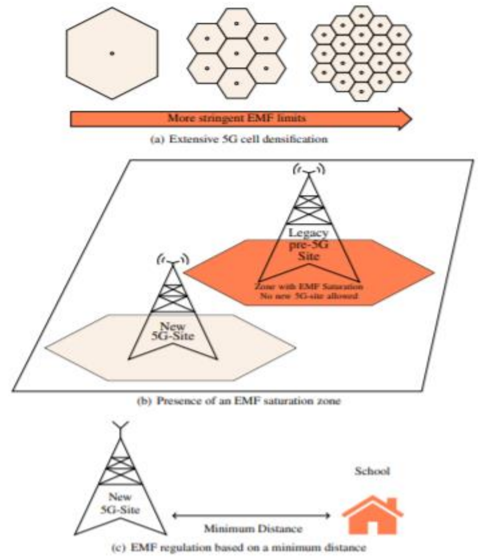

Figure 1. EMF Exposure on Humans

The current directives above, taken together, point to a scenario in which EMF risk limitations have a substantial effect on the implementation of 5G radio access infrastructures. Indeed, EMF restrictions limit operators' ability to build new base station sites in a variety of ways. Figure 1 depicts three representative instances. The cell densification phenomenon is depicted in Fig. 1(a): strict EMF limits enforce low radiation power at each antenna, which forces a dense distribution of low-power sites, resulting in a significant increase in CAPEX for the operator. Figure 1(b) depicts a scenario in which the 3G/4G sites servicing the target area have already reached their EMF limits, forcing the operator to mount 5G antennas in a new location, resulting in increased CAPEX and less options for network planning optimization. The preceding are only a few simple examples of the types of barriers that EMF limits may impose on the planning and implementation of next-generation cellular network radio access infrastructures. Furthermore, the existence of several competing operators will intensify the issue, exposing 5G networks, as well as the numerous and diverse disruptive applications they are supposed to create, to serious risks of underperformance.

IV. OBSERVATION

To begin, the validation LOO-CV errors (Equation (7)) for the obtained surrogate models were computed based on the results of N = 60 simulations, i.e., 60 different combinations of beamforming scan angles. They ranged from 0.27 percent for the average SAR in the entire head to 5.70 percent for the SAR10g in the cerebellum, demonstrating sufficiently low error values to validate the model. After validating the surrogate models, they were used to approximate exposure levels in terms of both average SAR and maximum SAR12g for 500 different combinations of azimuth and elevation angles of the main radiation beam.

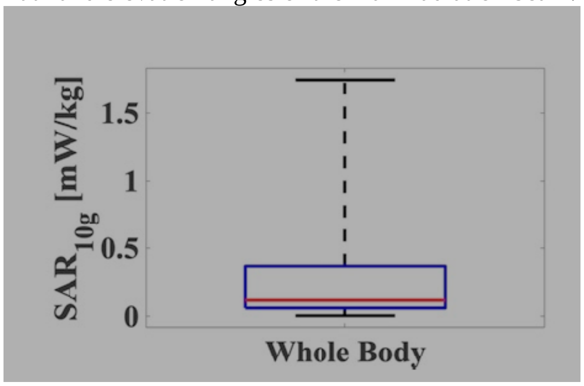

Figure 2. Boxplot representation of Results

V. CONCLUSION

Finally, stochastic dosimetry has been demonstrated to be appropriate for dealing with the variability of EMF body exposure levels in next generation networks, which will be characterised by inherent increasing ambiguity, heterogeneity, and complexity. In this regard, there is a need to validate numerical estimation approaches using low-cost computational efforts, progressing from practical to surrogate models. The PCK process, in particular, proved to be an effective surrogate modelling technique for dealing with the exposure levels introduced by 5G APs' 3D beamforming of array antennas.

VI. REFERENCES

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