Abstract

Massive MIMO technology is a key enabler for 5G and future generations of wireless communication standards. Base stations equipped with multiantenna systems, capable of spatial multiplexing and beamforming, significantly enhance capacity and coverage. These systems also facilitate the introduction of higher frequency bands in cellular communications by enabling the construction of large antenna arrays that compensate for increased propagation losses.

However, the use of large multiantenna systems presents challenges in evaluating, controlling, and measuring electromagnetic field exposure. The high gain of these arrays can lead to overly conservative compliance assessments based on maximum radiated power, resulting in significantly overestimated distances. Recognizing this issue, the International Electrotechnical Commission developed the actual maximum approach available in IEC 62232 for compliance assessment of multiantenna systems. This approach considers the dynamic nature of beamforming, leading to significantly lower compliance distances.

Accurate evaluation of Massive MIMO systems in terms of EMF exposure and the application of the actual maximum approach require comprehensive research studies considering various factors that influence compliance assessment accuracy. This dissertation aims to evaluate EMF exposure from multiantenna systems in realistic environments. New models and studies, based on more realistic assumptions, have been developed and validated under practical system operating conditions. These studies incorporate diverse parameter distributions, including terminal distribution, real-world radio frequency propagation scenarios, and different beamforming techniques.

This research makes several novel contributions:

- **Moving Terminal Model:** This dissertation introduces a model for moving terminals, a first in the field, to accurately assess EMF exposure in dynamic environments.
- **Beamforming Algorithm Impact:** The impact of different beamforming algorithms on actual EMF exposure is investigated in detail.
- **Extreme Massive MIMO Evaluation:** Extreme Massive MIMO arrays are evaluated in the context of new frequency bands and the emerging 6G standard.
- **Novel RF Emission Control Methods:** New RF emission control methods, specifically designed for implementation in Massive MIMO base stations, are developed. These methods utilize novel beamforming algorithms, offering an alternative to existing transmit power control methods.

The research findings have been published in peer-reviewed journals and conference proceedings. Moreover, the research outcomes are referenced in the IEC technical report (IEC 62269), providing guidelines for operators of Massive MIMO systems using the actual maximum approach. Feasibility studies will be conducted to evaluate the practical implementation of new beamforming algorithms in base stations.

Marcin Rybakowski