Publishable Summary for 18SIP02 5GRFEX
Metrology for RF exposure from Massive MIMO 5G base station: Impact on 5G network deployment

Overview

Current radiofrequency electromagnetic field (RF-EMF) exposure limits have become a critical concern for fifth generation (5G) mobile network deployment across Europe. Regulation is not harmonised and in certain countries and regions goes beyond the guidelines set out by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This project produced specific RF-EMF exposure measurement guidance for 5G massive multiple-input-multiple-output (mMIMO) base stations which were disseminated to technical, business and regulatory communities to support the development of effective regulation and enable 5G implementation that balances performance with public safety.

Need

Currently, associated wireless industries employ 1.3 million people in the EU, representing a contribution of €160bn to the economy. 5G is set to become a basic requirement in the fields of eHealth, smart grids, smart cars, connected homes, entertainment, and smart asset tracking systems. Reliable mobile and fixed connectivity will make new digital applications a reality, e.g. virtual and augmented reality, autonomous driving, artificial intelligence, smart manufacturing, and precision farming. The European telecommunications industry plays a crucial role in the development of emerging wireless technologies for 5G mobile networks. The move to wider bandwidths at different RF bands and the industrial adoption of complex new radio signals in 5G mMIMO base station systems, places greater demands on the measurement equipment used in production and testing, and in research and development. While the 5G standardisation processes are ongoing, the key challenges are a lack of practical metrology to support new radio RF exposure assessment. This project directly addressed these challenges faced by the 5G technical, business and regulatory communities as well as supported the development of the relevant 5G infrastructure and standards.

The rollout of 5G networks is leading to fundamental changes to our society, impacting not only consumer service but also industries embarking on digital transformations. In Europe, exposure to RF-EMF is regulated based on the 1998 or 2020 guidelines of the ICNIRP. Within the European Union (EU) legal framework these guidelines are enshrined in Council Recommendation 1999/519/EC for general public. However, certain EU member states have imposed stricter EMF exposure limits which are significantly lower than the ICNIRP guidelines. For example, in Switzerland and Italy, a different regulation has been put in place where the current RF-EMF exposure limits are 4 V/m and 6 V/m, respectively, which is much stricter than the ICNIRP guidelines at 61 V/m. This more stringent exposure limit has had an impact on 5G network rollout and deployment.

Proximus Belgium (Belgium's leading mobile network operator and primary supporter of this SIP) has identified the need for robust methods to measure the realistic RF-EMF exposure from 5G base stations. Current measurements of RF-EMF exposure from third generation (3G) and fourth generation (4G) base stations include an exclusion zone (a compliance boundary around the BS with no access to general public), based on the assumption that the theoretical maximum power is transmitted in every possible direction for a defined time-period. However, the beamforming mMIMO base stations employed in 5G new radio allow energy to be focussed in sharp high-gain beams in the direction of a specific mobile user. This means that it is difficult for operators to deploy 5G mMIMO on sites with pre-existing 3G and 4G base stations. Regulators, operators and 5G equipment suppliers therefore require up-to-date, reliable and agreed assessments of RF-EMF exposure levels to support consistent and effective 5G regulation and network design.

Previously, EMPIR project 14IND10 MET5G developed 5G testbed capability that sought to establish metrological traceability for mMIMO base stations and measurement capability in generating traceable known EMF measurements. This project developed and validated these measurement techniques for RF-EMF exposure, made recommendations on how to properly measure RF-EMF exposure from 5G mMIMO base stations to the relevant technical, business and regulatory communities (e.g., CENELEC, IEC, IEEE, ITU, Proximus, Ofcom, ANFR, Swiss OFCOM, Swiss Federal Office of Environment).

Objectives

The overall objective is to create impact from the use of the hardware and metrological capabilities of JRP-14IND10 MET5G by establishing real-world 5G scenarios in a laboratory environment, developing metrology for RF exposure from 5G Massive MIMO base stations, and validating the methods with real-world measurements. The specific objectives of the project are:

1. To establish a realistic, rigorous measurement capability for traceable RF-EMF measurement of 5G new radio new radio mMIMO base stations. This will include RF-EMF assessment of real-world 5G new radio mMIMO base stations based on RF-EMF measurement and data processing methods/protocols of 5G mMIMO base stations.
2. To make recommendations to the technical, business and regulatory communities (e.g. EU regulatory bodies and ICNIRP, ITU, 3GPP, CTIA, IEEE, ETSI, GSMA) on how to robustly measure RF-EMF from 5G new radio mMIMO base stations in order to establish appropriate base stations exclusion zones for 5G.

Results

To establish a realistic, rigorous measurement capability for traceable RF-EMF measurement of 5G new radio mMIMO base stations (Objective 1)

NPL, Keysight and SURREY have jointly established a new traceable RF-EMF measurement capability for 5G new radio mMIMO transmitter, which consists of a fully user-controllable mMIMO beamforming testbed system and two different types of RF-EMF measurement systems. The work has been focused on establishing traceability and developing suitable RF-EMF measurement methods in the context of 5G mMIMO base stations serving different number of mobile users within realistic real-world environments and scenarios. To achieve traceability, all these measurement systems have been traceably calibrated to the UK national standard. In preparation for the measurement campaigns, modifications to the established user-controllable mMIMO beamforming testbed system were made so it could be used with static zero-forcing precoding and beamforming operations; for single- to multiple-user MIMO fixed static beamforming scenarios; with different combinations of data traffic flow patterns. Consequently, several indoor and outdoor RF-EMF measurement campaigns have been successfully completed (3 indoor and 2 outdoor) including the assessment of a commercial 5G beamforming mMIMO base station in an outdoor environment.

During the measurement campaigns varying factors such as number of users, position of users and data duty cycles were considered. Also, where possible, several other varying factors that influence the RF-EMF of mMIMO system have also been investigated: 1) spatial RF-EMF variation at different locations; 2) temporal RF-EMF variation at a fixed location; 3) mMIMO operating with different number of active transmitting antennas; 4) different line-of-sight and non-line-of-sight scenarios. By considering these varying factorsit is possible to gain an insight towards understanding the statistical nature of mMIMO RF-EMF exposure distribution, if feasible, over the whole area or some selected locations, and to assess into how their relevant changing exposure over time are affected by: the fluctuation of the environment, number and position of different users, changes of data usage activities (i.e. data traffic pattern) of the active users. Note that the user-controllable mMIMO beamforming testbed is envisaged to produce static beam(s) for different varying factors whereas the live commercial 5G base station system is envisaged to produce adaptive beam(s) without any specific knowledge on the beam patterns and its relationship with the varying factors present at the time.

Given the nature of the mMIMO adaptive beamforming transmission, where the spatial pattern of transmission (i.e. number of beam used, direction of the beams) can change every few milliseconds, it makes sense that the new metrology for 5G base stations was based on statistical RF-exposure models, either system level simulations or real-world measurement data acquired from deployed 5G base station. Some evidence already indicates that such modelling provides realistic and implementable exclusion zones for 5G base stations. Therefore, based on the obtained experimental-based evidence on the stochastic nature of mMIMO operation, the measurement data was evaluated to identify the suitable measurement methodologies/protocols and approaches on the application of statistics over data processing for rigorous RF-EMF assessments of 5G new radio mMIMO base station systems. The results were presented to the Primary Supporter. Overall, the work undertaken to achieve this objective, has produced one key output: a validation report describing rigorous measurement capability for traceable RF-EMF measurement of 5G new radio mMIMO base stations / systems based on RF-EMF measurement and data processing methods/protocols. This report and the relevant measurement data can be accessed and downloaded via the following open access link – http://empir.npl.co.uk/5grfex/publications/.

To make recommendations to the technical, business and regulatory communities on how to robustly measure RF-EMF from 5G new radio mMIMO base stations (Objective 2)

By applying the traditional approach of considering the theoretical maximum transmitted power in all directions for defining the exclusion zone of 5G new radio mMIMO base stations would result in unrealistic large exclusion zone areas, which would prevent operators from deploying 5G base stations at sites with pre-existing third-generation (3G) and fourth-generation (4G) base stations. A key difference with traditional base stations is that rapid beamforming update, varying user equipment data traffic profile and multiple user scheduling such that computing the RF-exposure of a transmission based on an average over several minutes does not make that much sense anymore. Despite on-going work on defining measurement methods and exclusion zone for 5G base stations, the definition of a robust and effective model and/or experimental-based methods remains an open problem under evaluation by international organisations.

This project achieves this objective by producing a Good Practice Guide (GPG) for traceable RF-EMF measurement and data processing methods/protocols for 5G beamforming mMIMO base stations. Measured scientific evidence on the impact of current RF-EMF regulatory limits on 5G network deployment was disseminated via presentations at workshops, conferences, and webinar meetings to the 5G technical, business and regulatory communities, in particular, to the end users (the mobile network operators) and relevant EU regulatory bodies. The guidance supports the development of effective regulation and 5G implementation – that balances 5G performance and public safety. Such analysis is particularly relevant in certain EU Member States where the RF-EMF regulation is not harmonised and goes beyond international regulatory requirements in some areas (e.g., at the country level, Switzerland and Italy have different RF-exposure limits at 4 and 6 V/m, respectively, while similarly at the city level, Paris and Brussels have different RF-exposure indoor limits, i.e. 5 and 6 V/m, respectively. All these limits go well beyond the guidelines of 61 V/m set by ICNIRP for the general public). Another key outputs from this project has been an evaluation report describing how the stringent RF-EMF limits affect 5G wireless communication performance. This form the baseline recommendations on how to robustly measure RF-EMF from 5G new radio mMIMO base stations. These reports and the relevant measurement data can be accessed and downloaded via the following open access link – http://empir.npl.co.uk/5grfex/publications/.

Impact

The project website (http://empir.npl.co.uk/5grfex/) has been set-up, and contains information on the project and accessibility to the Good Practice Guide for traceable RF-EMF measurement and data processing methods/protocols of 5G mMIMO base station systems and the evaluation report describing how the stringent RF-EMF limits affect the 5G wireless communication performance.

During this project, the project members presented preliminary outcomes to key influential EU regulatory bodies, such as OFCOM (UK), ANFR (France), Swiss OFCOM, Swiss Federal Office of Environment, etc that encouraged these organisations to become Stakeholder Advisory Board members. The project team gave presentations on "Metrology for 5G MIMO EMF Limits", "An Assessment of the Radio Frequency Electromagnetic Field Exposure from A Massive MIMO 5G Testbed", "A Study of Experiment-based Radio Frequency Electromagnetic Field Exposure Evidence on Stochastic Nature of A Massive MIMO System" were given at three international conferences in November 2019, June 2020, and March 2021, respectively. The audience included key European 5G communication industry representatives, academic and regulatory bodies with responsibility for developing the necessary infrastructure and regulations for 5G base stations. Furthermore, the project outcomes were disseminated to other influential EU and international technical, business and standardisation communities, such as CENELEC, IEC, ITU, and IEEE and, by NPL's wider network via METAS (Swiss' national measurement institute), and IMTelecom (chairs the CENELEC CLC/TC 106X, active members of IEC TC 106 MT3, and IEEE ICES TC95). Two of the presentations resulted in two open access papers being published in IEEE conference proceedings.

This project has focused on the development of rigorous RF-EMF measurement techniques using the measurement capabilities that generate a known traceable EMF field and the 5G MIMO testbeds (developed under EMPIR 14IND10 MET5G) to establish a fully user-controllable mMIMO testbed. Based on the study of the experimental-based evidence on the stochastic nature of mMIMO operation, a Good Practice Guide now exists on how to measure EMF exposure from 5G mMIMO base stations in real-world conditions and provides evidence to inform discussions concerning 5G regulation with regulatory bodies. This in turn will support the safe, effective implementation of 5G. The timing of this project was ideal for 5G infrastructure development, which was planned for deployment from 2020. The project's primary supporter, Proximus Belgium, is Belgium's leading national operator. In Belgium, there are three separate RF-EMF regulation limits across the three regions of Brussels, Flanders and Wallonia, all of which are more stringent than the Council Recommendation 1999/519/EC based on ICNIRP guidelines. These more onerous local RF-EMF limit restrictions have resulted in Proximus's business being impacted. The outputs from this project now enable mobile network operators to inform the European Commission on the need for harmonisation RF-EMF exposure limit policies based on international guidelines and the rigorous RF-EMF exposure measurement methods that will help industry assess 5G mMIMO base station performance more reliably in order to prove their safety to regulators. This will facilitate the adoption of evidence-based policies that will enable more effective deployment of mobile broadband and other wireless technologies.

The requirement to design mobile networks in compliance with more restrictive RF-EMF exposure limits results in less flexibility in network deployment. Network operators, in order to respect stricter limits, have to reduce the output power of their antennas. Such reduction affects coverage and creates gaps in the network, which then affects the quality of the service provided to consumers. This project has developed rigorous RF-EMF exposure measurement methods that will help industry assess 5G mMIMO base stations performance more reliably in order to prove their safety to regulators. Furthermore, this project focused on areas where 5G is subject to complex scenarios and/or technologies, or, where it is in an early stage of development, such as mMIMO. The outputs from this SIP support industry end users (mobile network operators) by providing scientific evidence to enable them to better influence policy discussions and future regulatory decisions concerning 5G regulation with EU, international and local regulatory bodies to support effective 5G implementation – that balances 5G performance and public safety.

The advantages of 5G and emerging wireless technologies will extend well beyond telecommunications and is increasingly underpinning all aspects of social and business activities. The growing demand for high-speed communication for a wide range of new applications such as autonomous driving, artificial intelligence, remote surgery and 3D holographic display, has driven the European Digital Agenda to speed up on the need to better exploit Information and Communication Technologies (ICTs) in order to foster innovation in emerging wireless technologies and economic growth. Information handling services (IHS) economics have estimated that the 5G networks and beyond will enable USD12.3 trillion of global economic output in 2035. The European Commission estimates that almost 100 million students, more than 70 million workers, almost 2 million doctors and more than 2.5 million patients in hospitals across EU will benefit directly from the emerging wireless technologies with much faster data transfer speeds by 2025.

For the European citizen, 5G and emerging wireless technologies are envisaged to provide a universal communication environment that enables us to address the wider societal challenges, such as transport, automotive, safety, employment, health, environment, energy, manufacturing and food production. By underpinning the 5G deployment with sound metrology, this project will help satisfy the EU citizen's demand for more and better data, providing huge societal benefit. Furthermore, fast reliable high bandwidth communications will change the way in which we interact with the medical and social services e.g. 24/7 monitoring of Dementia patients in their own homes. This project has disseminated the project outcomes to influential technical, business, regulatory and standardisation communities via project partners' wider network.

List of publications

1. T. H. Loh, F. Heliot, D. Cheadle and T. Fielder, "An Assessment of the Radio Frequency Electromagnetic Field Exposure from A Massive MIMO 5G Testbed," the 14th European Conference on Antennas and Propagation (EuCAP 2020), Copenhagen, Denmark, 15 – 20 Mar. 2020, pp. 1-5.http://dx.doi.org/10.23919/EuCAP48036.2020.9135291;https://arxiv.org/pdf/2112.09637
2. T. H. Loh, D. Cheadle, F. Heliot, A. Sunday, and M. Dieudonne, "A Study of Experiment-based Radio Frequency Electromagnetic Field Exposure Evidence on Stochastic Nature of A Massive MIMO System", the 15th European Conference on Antennas and Propagation (EuCAP 2021), Düsseldorf, Germany, 22 – 26 Mar. 2021, pp. 1-5. https://doi.org/10.23919/EuCAP51087.2021.9411325; https://arxiv.org/abs/2008.04345

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		01 June 2019, 30 months
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