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Assessment of 5G NR base station RF-EMF exposure in a commercial network in Switzerland

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The results of a measurement campaign to assess radiofrequency (RF) electromagnetic field (EMF) exposure in a commercial 5G New Radio (NR) network in Bern, Switzerland, are presented. Four base station sites with massive MIMO antennas were surveyed, which operated at 3.6 GHz and used codebook-based beamforming. The present field levels were very low (< 0.05 V/m) due to low traffic load and low configured antenna powers. However, setting up a maximum downlink traffic stream towards a user device increased the time-averaged exposure level to up to 0.4 V/m. Finally, it was found that the contribution of the NR network to the environmental RF exposure was limited to an average of 2% with maximum downlink traffic.

Introduction

In a number of countries, the roll-out of the fifth generation (5G) of wireless communications technologies is impeded due to uncertainty about the impact that the new radio (NR) radio access technology and the widespread use of massive multiple-input-multiple-output (MaMIMO) and advanced antenna systems (AAS) may have on our everyday exposure to radiofrequency (RF) electromagnetic fields (EMF). To aid the communication of scientific and legislative bodies to the general public, an accurate characterization of this impact is essential. This study provides the first assessment of the time-averaged and the maximum extrapolated RF-EMF exposure levels in a commercial 5G NR network, using the measurement methodology designed in [1]. Furthermore, the used extrapolation method, for which no information is needed from the mobile network operator, was validated with actual antenna radiation patterns.

Materials & Methods

The measurement campaign was conducted in the Swisscom commercial 5G NR network in Bern, Switzerland, in July 2020 [2]. In total, 22 measurement positions (20 in line-of-sight (LOS) of the base station and two in non-LOS (NLOS)) were selected at four sites with Ericsson AIR 6488 NR MaMIMO base stations (BSs), representative of the network. The distances to the base stations varied between 30 m and 410 m. The NR BS radios operated at 3.6 GHz, and the maximum input powers of the BS antennas ranged between 1.6 W and 8.1 W (these powers are well below the product's maximum power of 200 W, because of the EMF limits in Switzerland). Furthermore, the BS were configured with codebook-based beamforming, with eight channel status information reference signal (CSI-RS) ports and only azimuthal beam steering.

In order to assess the maximum exposure of a user in the network, a downlink stream was set up from the BS to an Oppo Reno4 Pro 5G mobile phone (the user equipment, or UE) using the iPerf3 tool (https://iperf.fr/) at 100% (theoretically) capacity of Physical Downlink Shared Channel (PDSCH) resource usage [1]. The measurement probe and the UE were positioned along the same line with respect to the BS, under the assumption that this would direct the PDSCH beam towards the measurement probe just as well when servicing the UE.

The measurement methodology [1] consisted of the following steps:

- Step 1: A quick overview measurement of the telecommunications frequency range was performed to identify all RF signals present at the measurement location, and in particular, the signal from the NR base station under test.
- Step 2: An in-band measurement was performed around the suspected centre frequency of the NR signal to determine the bandwidth and the frequency location of the Synchronization Signal Block (SSB) (its

centre frequency is denoted as SS_{REF}), as well as the channel bandwidth.

- Step 3: The electric-field strength per resource element (E_{RE}) was obtained for both the SSB and the PDSCH resources through a zero-span measurement (i.e., a measurement of the received power as a function of time instead of frequency) with a bandwidth of 1 MHz around SS_{REF}.
- Step 4: The average electric-field strength E_{avg} over the channel bandwidth was measured both without an active UE (i.e., the exposure as is) and with an active UE when maximizing the downlink (in theory up to 100%) to the UE (i.e., the maximum exposure). Since in both cases the signals were relatively stable, an averaging time of 30 s per electric-field component was used.
- Step 5: The maximum theoretical field level E_{max} was calculated both from the SSB's E_{RE} (using the difference in gain between the broadcast and data traffic signals from antenna patterns provided by the BS manufacturer) and directly from the PDSCH's E_{RE}[1,2].

The measurement setup consisted of a Rohde & Schwarz (R&S, München, Germany) FSV30 spectrum & signal analyser (SA) connected to a Satimo INSITE Free tri-axial antenna (Microwave Vision Group, Villejust, Essonne, France). The SA was equipped with the 'spectrogram' option R&S FSV-K14, which allowed us to store up to 20,000 measurement traces with a minimum of lag or 'blind time' in-between. The specific spectrum analyser settings and the discussion thereof can be found in [1].

Furthermore, in order to evaluate the impact of the 5G NR network on the environmental RF-EMF exposure caused by mobile telecommunications networks, additional measurements of the exposure levels within specific frequency bands used by 2nd to 5th generation (2G to 5G) networks were performed at 15 positions with a Narda SRM-3006 (Narda Safety Test Solutions, Pfullingen, Germany).

Results

Signal characteristics and measurement of E_{RE}

Based on the spectrum and in-band measurements (not shown here, details can be found in [2]), the network's NR signals all had a channel bandwidth of 100 MHz, and their SSB was situated at an SS_{REF} of 3604.80 MHz and occupied a bandwidth of 7.2 MHz, which meant that the subcarrier spacing (SCS) was 30 kHz.

Using a zero-span measurement with resolution bandwidth 1 MHz, i.e. a width of 33 subcarriers, around SS_{REF} and sampling time equal to one Orthogonal Frequency Division Multiplexing (OFDM) symbol (Figure 1) [1], the E_{RE} of the SSB and PDSCH resources were acquired. For the SSB, this process was trivial, since all resource elements in the captured bandwidth were used during its four-symbol-long duration. For the PDSCH, on the other hand, a distribution was obtained that was made up of a number of Gaussians, each corresponding to a different filling of the bandwidth (i.e. between 0 and 33 REs). Therefore, it was assumed that the Gaussian with the highest mean corresponded with a completely-filled bandwidth, and this mean was retained [2]. (For both SSB and PDSCH, this process was repeated for each electric-field component.)

Furthermore, from this zero-span measurement (Figure 1), it was observed that the NR channel used the Time Division Duplexing (TDD) frame structure DDDSU ('D' is a downlink slot with 14 downlink symbols, 'U' is an uplink slot with 14 uplink symbols, and 'S' is a special slot with 10 downlink and 4 uplink symbols).

The maximum E_{RE} was respectively 0.012 V/m and 0.008 V/m for PDSCH and SSB resources. The difference between the two was assumed to be due to the difference in antenna gain and was found to be about 4 dB in LOS and within the scanning range of the BS, and between 1 dB and 8 dB outside the scanning range. In NLOS, the measured signals were much lower, close to the noise level (~0.001 V/m), which resulted in a higher uncertainty.

Average and maximum exposure levels

In the situation as it was, without generating a downlink data stream towards the measurement location, the time-averaged exposure levels E_{avg} were very low: the highest level recorded was just 0.05 V/m. However, with maximum PDSCH traffic to the UE, in LOS of the BS the field levels increased by 13 to 43 dB (on average 28 dB), and a maximum E_{avg} of 0.5 V/m was observed (on average 0.3 V/m), whereas in NLOS the exposure rose very little.

For the calculation of the maximum theoretical electric-field strength E_{max} (Figure 2), the following factors were taken into account: (a) as the channel's SCS was 30 kHz, the number of resource blocks (RBs) in the channel bandwidth of 100 MHz was 273 (keeping in mind that each RB contains 12 resource elements); (b) since the channel used the DDDSU slot format (which contains 52 downlink and 18 uplink OFDM symbols), an additional TDD factor f_{TDD} of 0.74 was applied; and (c) assuming that the PDSCH signals were characterized by a higher antenna gain than the SSB signals, either the gain difference between SSB and PDSCH signals was obtained from antenna patterns provided by the base station manufacturer (and E_{max} was calculated from the SSB's E_{RE}) or E_{max} was calculated directly from the PDSCH's E_{RE} (Figure 2).

In this study, it was found that the two extrapolation methods were in very good agreement, especially within the BS scanning range, for which the absolute relative error was just 0.9 dB (Figure 2). In LOS of the BS, E_{max} ranged between 0.1 V/m and 0.6 V/m (less than 0.01% of the ICNIRP reference level [3]), whereas in NLOS E_{max} was below 0.1 V/m.

Overall, at maximum downlink transmission towards the UE, E_{avg} and E_{max} were in good agreement; although the extrapolated field levels were generally higher by 1 to 3 dB because the iPerf3 application could not guarantee a steady allocation of 100% to the PDSCH resources (Figure 1). Hence, E_{max} remains the more conservative metric.

Impact on the environmental exposure

Without inducing downlink traffic, the impact of the 5G NR network on the environmental RF-EMF exposure was insignificant (Figure 3), due to NR's sparse broadcast signaling and the negligible amount of users on the network at the time of the measurements. However, even when a maximum downlink stream was generated towards the measurement location – which is the extreme case – the largest contribution of the NR network was about 10% of the total exposure level (with an average contribution of only 2%).

Conclusions

The first assessment of the range of actual and maximum exposure levels in a commercial 5G New Radio (NR) network was presented. It was found that the investigated network in Bern, Switzerland, had only a minor impact on the total environmental RF-EMF exposure. The highest maximum theoretical exposure level was 0.6 V/m, less than 0.01% of the ICNIRP reference level. In fact, the increase in the environmental exposure was limited to a few percent, even in the case of maximum downlink traffic. Moreover, an extrapolation method was demonstrated for which no prior information from the network provider or radio equipment manufacturer is necessary, and validated using the actual antenna radiation patterns. In the future, aspects of the described method will be adapted to frequencies above 24 GHz ('mmWaves') and further refined as 5G technologies evolve (e.g., when introducing reciprocity-based beamforming and other more advanced MaMIMO techniques).

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Figures

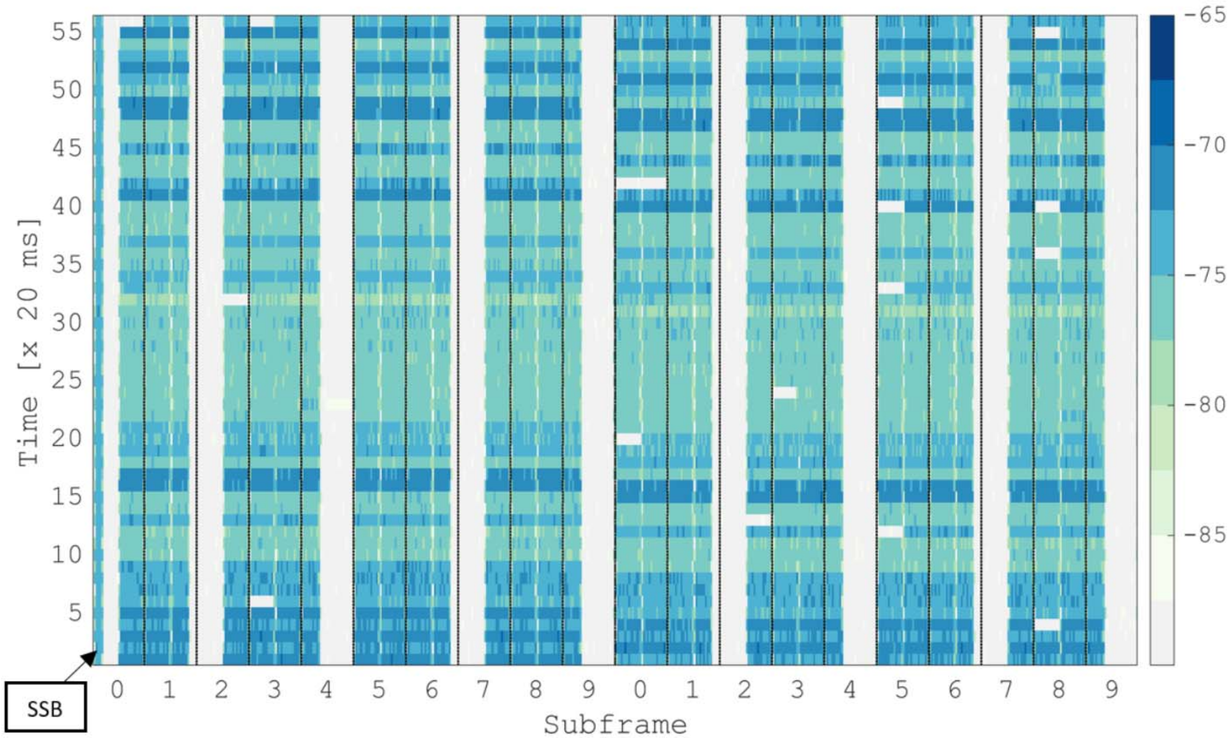

Figure 1. ‘Waterfall diagram’ plot [1] of a zero-span measurement trace of 1.1 s (55 x 20 ms) of the NR channel measured with the FSV setup in a 1 MHz-bandwidth around the channel’s SSB center frequency during a “maximum” downlink data stream. Successive pairs of NR frames (i.e., 2 x 10 ms, with each frame containing 20 slots (two slots per subframe) of 14 Orthogonal Frequency Duplexing Multiplexing (OFDM) symbols) are stacked on top of each-other. The four-symbol-long SSB is visible on the left. The other coloured bands – with different colours indicating different received powers within the 1MHz-bandwidth – show a clear DDDSU pattern, with three downlink (D) slots, one special (S) slot (which contains 10 downlink symbols), and one (empty) uplink (U) slot.

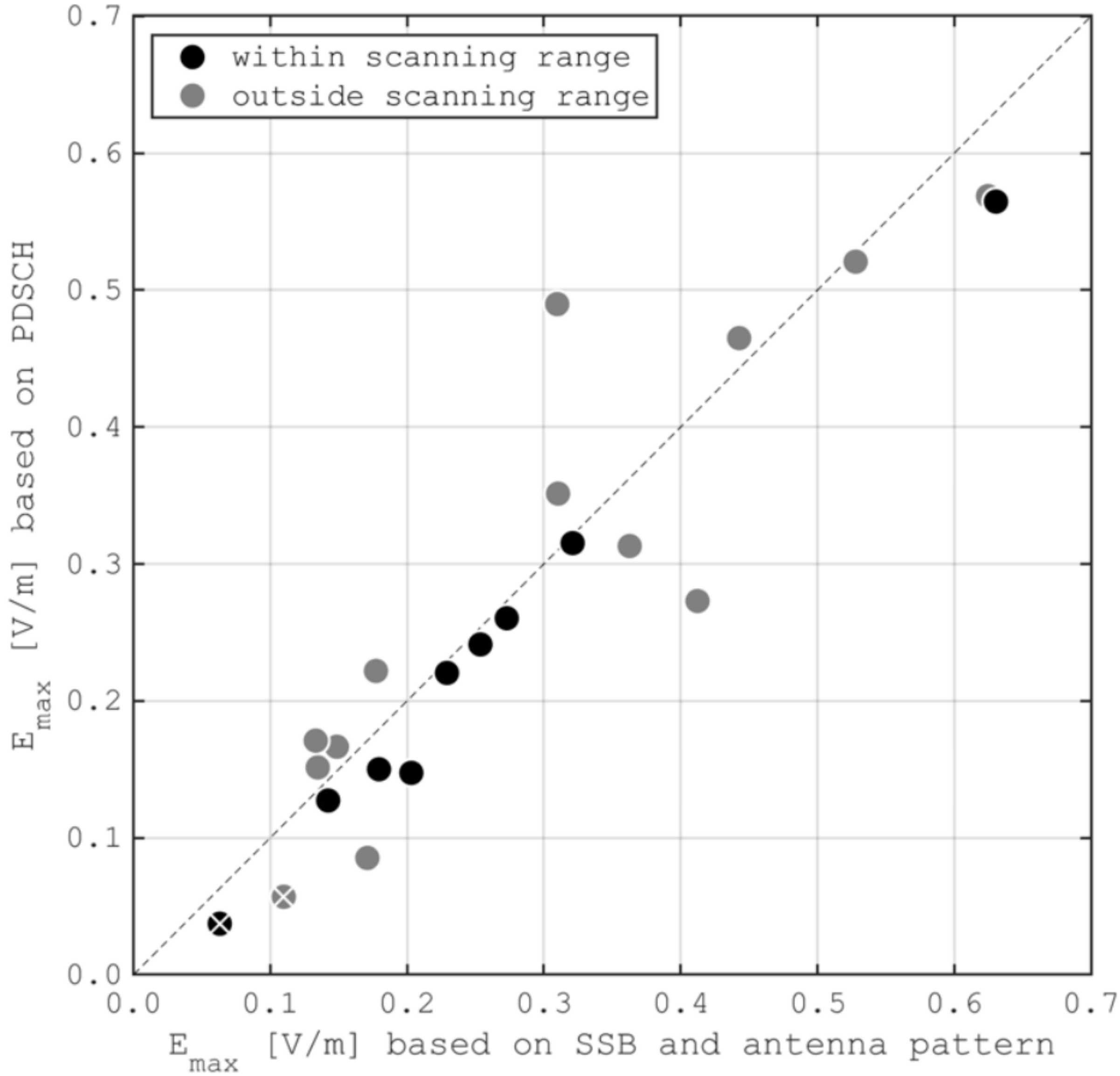

Figure 2. Scatterplot of the maximum theoretical electric-field strength E_{max} based on the direct measurement of the resource elements (REs) of the Physical Downlink Shared Channel PDSCH, versus E_{max} based on measurement of the RE's of the channel's Synchronization Signal Block (SSB) and the difference in antenna gain derived from the antenna patterns provided by the base station manufacturer. The locations were grouped by their relative position to the NR base station: within (black dots) or outside (grey dots) its scanning range. Markers with a white X depict positions in non-line-of-sight.

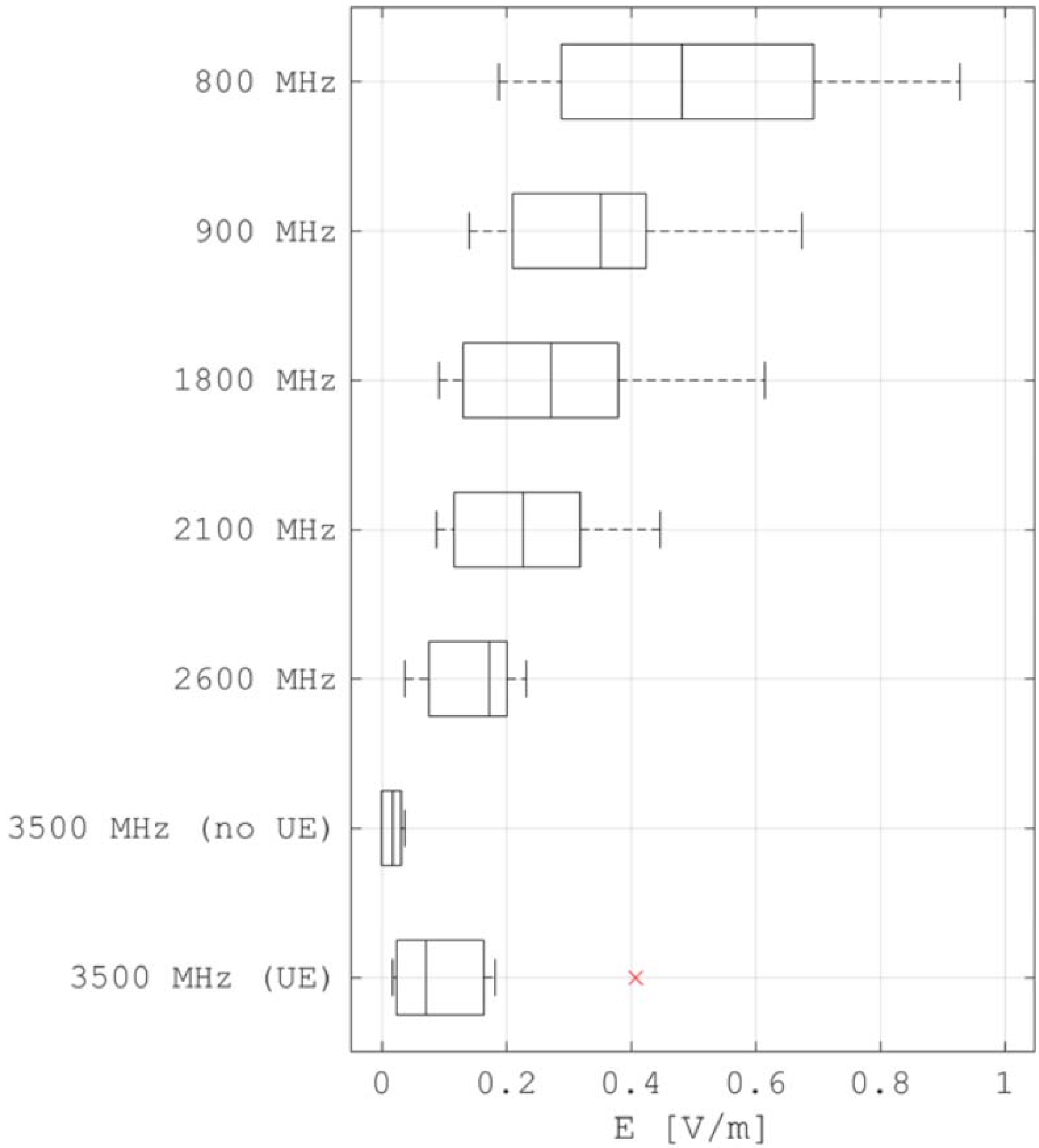

Figure 3. Boxplots of the electric-field levels captured in different frequency bands used by mobile telecommunications networks. The considered 5G NR signals were located in the 3500 MHz band, and there was a distinction between measurements with an active (i.e. with a maximum downlink data stream set up) user device ('UE') and without one ('no UE').

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