Typical 5G Scenarios in Republic of Croatia – Measured Values of Electric Field

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***Abstract*— This paper deals with a simple statistical analysis of measured values of 5G New Radio electric field carried out in the vicinity of typical base station antenna systems installed in the Republic of Croatia. The measured 5G signals operate in the frequency range of 3.5 GHz to 3.8 GHz and consist of three channels, each 100 MHz wide. The Channel Power measurement method, combined with forced data traffic, are used to determine the electric field levels. A total of 3,000 measurement results have been collected, and a simple statistical analysis has been performed. Furthermore, common issues associated with the Channel Power measurement method are highlighted. Some illustrative results are presented.**

Keywords—5G New Radio, Electric Field Measurements, Channel Power Measurement Method, Typical exposure scenarios, Statistical Analysis.

I. Introduction

Since the 19th century, wireless energy transmission has become an integral part of daily life. In recent decades, modern society has become increasingly reliant on wireless technologies, rendering life without them virtually unimaginable.

In recent years, a new technology known as 5G New Radio (5G NR) has played a significant role in wireless communication. The vision of 5G NR is to hyperconnect society through high-speed data transmission, massive machine-type communications, enhanced reliability, and ultra-low latency. It is worth noting that 5G NR is not merely an upgrade of 4G but it also introduces new possibilities in connectivity and network capacity, particularly through the use of millimeter-wave (mmWave) propagation [1].

However, to mitigate potential adverse effects of non-ionizing radiation and to enable continuous monitoring of electromagnetic field (EMF) levels, measurements conducted in the vicinity of the base station antenna (BSA) are constantly of significant public interest.

The BSA emits high-frequency electromagnetic (EM) energy, which propagates through space in the form of EM waves. Currently, the most commonly used frequency range in 5G NR is between 3.5 GHz and 3.8 GHz. To date, 5G NR technology implemented in Croatia has utilized active channels with a bandwidth of 100 MHz. (Fig. 1).

Additionally, in Croatia, 5G NR operates at frequencies of 700 MHz and 2.1 GHz.

It is well known that within the sub-6 GHz frequency range, the human body absorbs EM energy and the consequence is the local heating of tissues. Therefore, the Specific Absorption Rate (SAR) is considered an appropriate dosimetric quantity. However, since direct measurements on the human body are not feasible, the incident electric field is used as the primary quantity of interest in measurements [2]. The measured values are then easily comparable to given limit values.

The paper is organized as follows: Section II outlines a basic description of 5G signal structure, while in Section III measurement procedure is described. Section IV gives the short description of measurement-based database and the results are presented in Section V. Section VI and VII provide a short discussion of study and conclusion, respectively.

II. 5G NR Signal Basics

5G NR signal is composed of Resource Elements (RE) presented via one subcarrier in the frequency domain and one Orthogonal Frequency Division Multiplexing (OFDM) symbol in time domain. RE's are organized into Resource Blocks (RB). One of the fundamental resource blocks in 5G NR is the Synchronization Signal Block (SSB), sometimes referred to as SS/PBCH. The SSB contains several key signals, including the Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS), Physical Broadcast Channel (PBCH), and PBCH Demodulation Reference Signal (PBCH DM-RS) [3]. The SSB is the only part of the 5G NR signal that is transmitted continuously, while other components are transmitted intermittently (during the data transmission).

5G NR is predominantly implemented in Time Division Duplex (TDD) mode. In other words, the same frequency spectrum is allocated for both uplink and downlink transmissions, but only one direction is active during a given time slot. Therefore, a TDD correction factor is applied during post-processing of measurement results. In most cases, this factor is approximately 0.75 [4].

One of the main differences between 5G NR and previous technologies is the use of active antenna systems providing dynamic changes in the spatial radiation pattern, resulting in higher antenna gain.

Another interesting feature of 5G technology is the use of the Power Reduction Factor (PRF). As stated in [5], PRF allows

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the measured electric field values to be approximated based on the expected (averaged) antenna gain rather than the theoretical maximum gain. Typical PRF values, which depend on the number of transmission elements (TRX) and the antenna manufacturer, are provided in Table 1 [6].

TABLE I. PRF VALUES WITH RESPECT TO MIMO CONFIGURATION (TDD FACTOR NOT INCLUDED)

TRX	**PRF**
≥ 64	≥ 0.13
32 – 63	≥ 0.20
16 – 31	≥ 0.32
8 – 15	≥ 0.40
1 – 7	1

III. MEASUREMENT PROCEDURES IN 5G NR

There are several measurement procedures applicable in 5G NR. A Code-Selective Procedure (CSP), Frequency-Selective Procedure (FSP) as well as Channel Power Procedure (ChP) are explained in [7] in detail.

While CSP and FSP procedures require extrapolation techniques, the ChP procedure is relatively straightforward to perform. However, to measure the maximum field strength using the ChP method, the field technician must ensure that the base station operates at its maximum transmission power thus-requiring a specific download duration and data volume.

Generally, the ChP measurement procedure relies on a conservative measurement method, also used in previous technologies such as 2G, 3G, and 4G. It is based on measuring the power (typically the electric field) of the transmitted channel in the frequency domain. To perform ChP measurements, an active data flow is required. One of the simplest ways to activate data flow is by using a 5G mobile phone and performing a *Speedtest* (Fig. 1) [8].

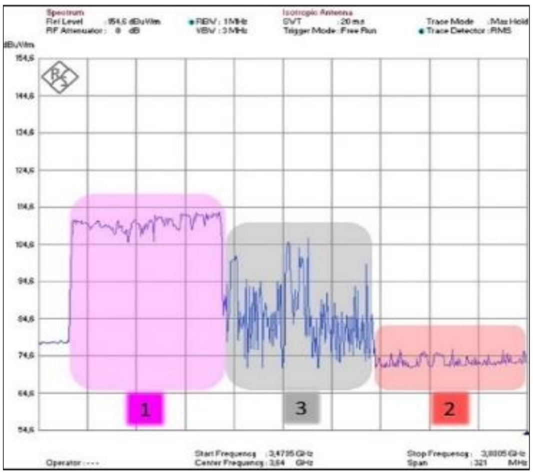

Fig. 1. 5G NR frequency spectrum between 3.48 GHz and 3.80 GHz containing to 3 active channels, 100 MHz wide each

IV. MEASUREMENT-BASED DATABASE

For the purpose of this study, a measurement-based database has been developed. The database comprises 3,000 measurement records collected between 2023 and 2025 in the vicinity of 547 BSA distributed across the territory of Croatia.

In addition to the measured electric field values, the database includes the distance between each measurement location and the corresponding BSA, exposure area type, MIMO configuration, antenna type, total antenna tilt, effective isotropic radiated power (EIRP), main lobe horizontal offset, and an indoor/outdoor measurement indicator.

It is important to emphasize that all measurement results have been obtained using the ChP measurement procedure, taking into account the TDD correction factor and a predefined measurement uncertainty. However, no PRF factor was included in the post-processing procedure.

Additionally, all measurements were conducted using an FSH12 Rohde & Schwarz spectrum analyzer and a B2 isotropic antenna [9], [10]. All measurement points were positioned within the line of sight (LOS) of the BSA.

V. RESULTS

A. Technical Data Analysis

As mentioned, the measurement-based database consists of 3,000 measurements conducted within the 5G NR frequency spectrum (3.5 GHz – 3.8 GHz). These measurements have been taken at various locations across 547 BSA. Each BSA corresponds to one of the three largest mobile operators in Croatia. Once more, it is important to emphasize that the TDD factor is included in the presented results, while the PRF factor is not.

Thanks to the provided technical antenna data, it has been determined that only four 5G antenna manufacturers are represented. The distribution of shares within the collected data is depicted in Fig. 2.

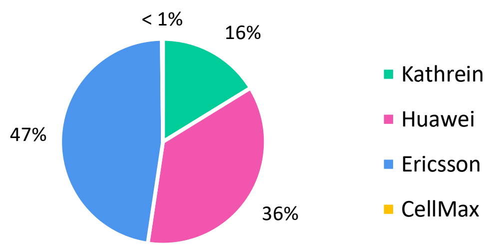

Fig. 2. The shares of 5G antenna manufacturers

Since 5G technology employs multiple transmitters and receivers, it is interesting to examine the MIMO systems present in the considered BSA, shown in Fig. 3.

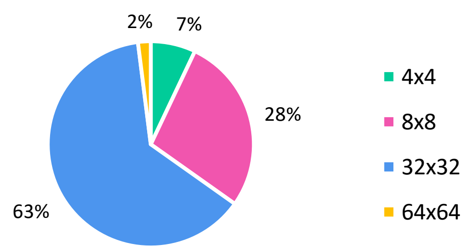

Fig. 3. MIMO configuration shares

The measurements have been conducted at distances ranging from 3 m to 382 m from the BSA. As shown in Fig. 4, nearly 85% of the measurements have been taken within 200 m of the BSA.

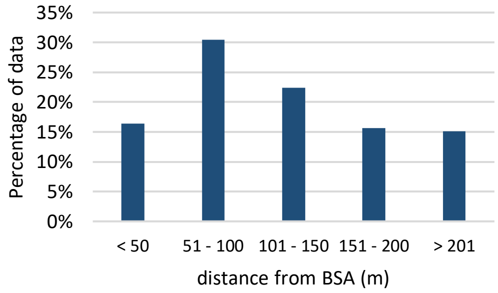

Fig. 4. Distribution of distances between measurement locations and BSA

Analyzing the EIRP data, it is evident that the 5G antenna operates within a range of 52.5 dBm to 71.5 dBm. However, the average radiated power is 64.6 dBm, and within two standard deviations, the radiated power is most likely to fall within the range shown in Fig. 5.

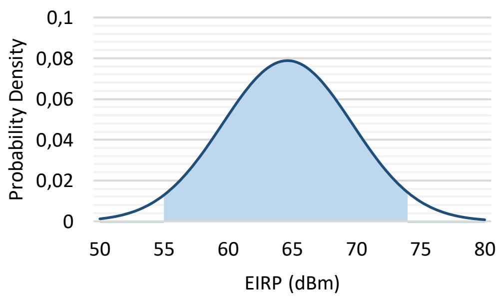

Fig. 5. Probability density function (PDF) of EIRP

To identify the micro-locations with the highest likely exposure levels, measurement technicians aim to minimize the horizontal and vertical main lobe offsets. While vertical offset is often unavoidable, the horizontal offset can be set to a minimum or even zero degrees.

It is worth noting that, in most cases, horizontal offset in active antenna systems significantly affects the electric field only at angles of 60° or greater, where radiated power losses — due to the horizontal antenna radiation pattern — exceed 3 dB.

Based on data processing, the average horizontal main lobe offset is found to be 10.7°. It is worth emphasizing that nearly 65% of the measurements have been taken within a 10° offset, and nearly 94% within a 30° offset, as depicted in Fig. 6.

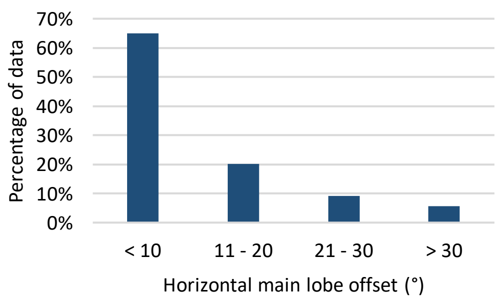

Fig. 6. Percentage of data within specific horizontal main lobe offset

B. Measurement Data Analysis

At the measurement locations examined in this study, the minimum detected electric field strength is 0.1 V/m, while the highest value reaches 34.9 V/m. The average measured value is 4.5 V/m. Although the average value is well below the limit of 24.4 V/m for private areas (e.g., homes, buildings, and schools) and below the 58.0 V/m limit for public exposure (e.g., open fields, roads, parks, and forest areas) [11], it is important to highlight the significant variability in the results. With a standard deviation of 3.6 V/m and a double standard deviation of 7.2 V/m, respectively, a wide dispersion of data can be expected, as presented in Fig. 7.

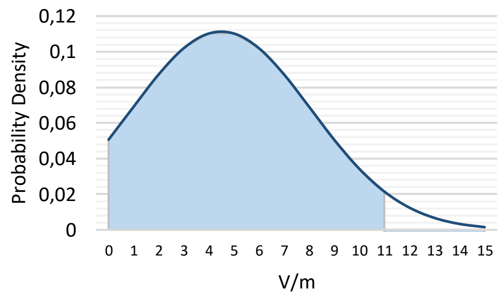

Fig. 7. Probability density function (PDF) of measured electric field with 95% confidence interval

However, it is interesting to take a look at the measured values with respect to distance from BSA, shown in Fig. 8.

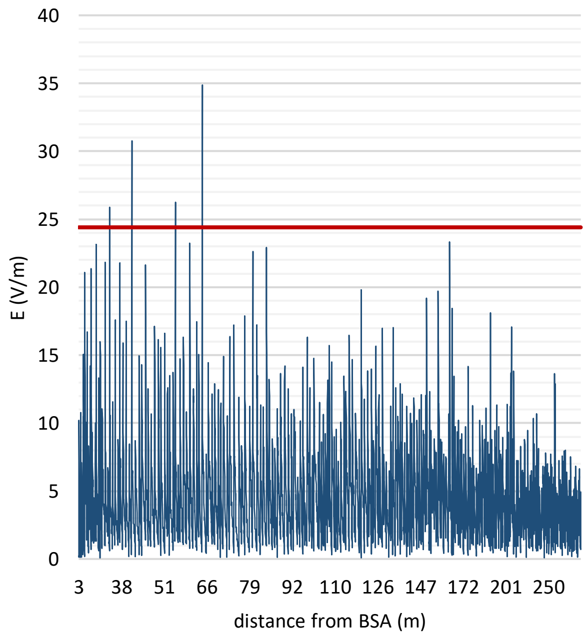

Fig. 8. Electric field strength with respect to distance from BSA; red horizontal line stands for private area safety limit of 24.4 V/m

As shown in Fig. 8, the highest electric field values were measured within 200 m of the BSA. However, the electric field curve does not follow the expected decreasing trend with increasing distance up to 200 m. Notably, higher field values are not observed at the shortest distances; instead, measurements within 10 m of the BSA show lower field strengths compared to those at greater distances (Fig. 9).

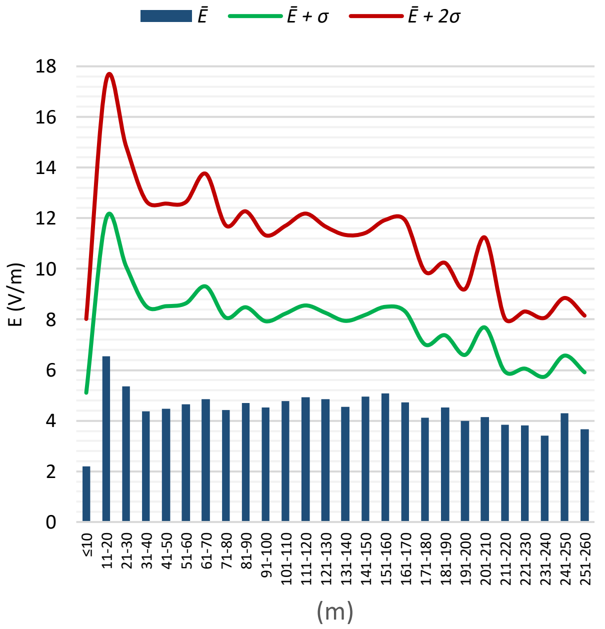

Fig. 9. Electric field mean values with standard deviation (σ) and double standard deviation (2σ)

The absence of a clear decreasing trend, as well as the unexpected behavior of the electric field distribution, can be attributed to several influencing factors beyond distance. These include horizontal and vertical offsets of the antenna's main lobe, the presence of reflective objects, and other environmental conditions.

Specifically, the lower electric field values observed within 10 m of the BSA are primarily due to a significant vertical main lobe offset, as the BSA is mounted on a relatively tall mast.

VI. Discussion

Although the measurement-based database provides several useful insights into the electric fields in the vicinity of 5G antennas, some crucial information is still missing, such as the vertical main lobe offset, antenna height, measurement point height, altitudes, and related parameters.

In this paper, only a simple statistical analysis is presented; a more comprehensive analysis remains to be carried out in future work.

As part of future work, not only will a comprehensive analysis be performed, but a calculation-based database with corresponding statistical analysis will also be generated.

VII. Conclusion

In this paper, 3,000 electric field measurements in the vicinity of 5G antennas are presented. A simple statistical analysis of both the technical antenna data and the measured values is provided.

Based on the delivered data, it can be concluded that three 5G antenna manufacturers are predominantly represented in Croatia. The most common MIMO configuration is 32T32R, although other configurations, particularly 8T8R, are also present. The average EIRP value is also reported.

The measurement results revealed the minimum, maximum, and average electric field strengths at specific distances from the BSA. In addition, based on mean values and double standard deviations, the expected range of values is presented. It is important to emphasize that all measured values are below the private area safety limit of 24.4 V/m and the public exposure safety limit of 58.0 V/m, respectively, except of four specific cases.

However, had the PRF factor been included in the post-processing, the EMF values would have decreased in proportion to $\sqrt{PRF}$, leading to more representative average exposure levels and a lower exposure ratio. The relevant PRF values are listed in Table 1.

Acknowledgment

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