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EVALUATION OF THE ELECTROMAGNETIC FIELD AND SAFETY ZONES OF EXISTING BASE STATIONS UPGRADED WITH 5G MASSIVE MIMO ANTENNAS

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Abstract. *The mass penetration of fifth-generation (5G) technology is already a fact. One of the challenges regarding the implementation of 5G networks in Bulgaria is the problem related to the assessment of electromagnetic exposure and determination of safety zones (SZ). Bulgaria has more restrictive national legislation for the protection of public health from exposure to electromagnetic fields (EMF) than the Recommendation 1999/519/EC [1] and ICNIRP guidelines [2]. The first stage of the implementation of 5G undergoes of the upgrading the existing base stations with new installations. This fact raised many questions about the possibility of the maximal permissible values being exceeded. The method in the national legislation for the theoretical calculation of SZ around telecommunication transmitters is based on a conservative approach. It was clear that applying such a method would lead to unrealistically large SZ and will complicate the realization of planned additional 5G emitters on a particular place. The SZ assessment based on the conventional approach was also a complex task for the previous 3G and 4G technologies, but the situation seems more difficult when existing sites must be upgraded with new 5G installations, especially in the urban areas. The presence of different technologies on a certain base station requires the assessment of combined EMF exposure. The specifics of 5G New Radio (NR), characterized by intelligent technologies such as Massive MIMO (Multi-Input Multiple-Output) and beamforming, should also have to be taken into account in this evaluation process. The paper demonstrates the theoretical calculation of the SZ of an existing base station, which is planned to be upgraded with 5G smart antennas. We modified the current method for determination of the SZ boundary around telecommunication sources, which takes into account the specifics of the 5G technology. The application of this method will make the safety evaluation more realistic and the upgrade of existing base stations with the 5G installations to be possible.*

Keywords: *fifth generation, mobile networks, beamforming, Massive MIMO, safety zone*

1. INTRODUCTION

The introduction of a new generation of mobile networks raises many health and safety issues related to EMF exposure from 5G radio equipment. This requires 5G EMF exposure to be investigated and to assess its contribution to the previous generations of mobile technology. Exposure levels must be precisely determined in order to show compliance with safety standards.

The regulation on limiting electromagnetic exposure adopted in Europe is based on the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The new ICNIRP guidelines 2020 [2] are still not implemented broadly in European legislation. Some European countries, such as Bulgaria, Poland, Italy, and others have defined more restrictive national legislation for the general public health protection from EMF exposure.

The Bulgarian document introducing exposure limit values (maximum permissible levels) for general public protection is Ordinance No. 9 of 14 March 1991 – Exposure limit values for Electromagnetic Radiation in Residential Areas and for Determining Safety Zones Around Electromagnetic Sources [3]. It regulates the limit values for a certain frequency range for stationary communication sources emitting in populated areas, and not for a specific broadcasting technology. According to this ordinance, telecommunication sources pass through two stages of health control.

The first stage of the hazard evaluation requires a calculation of the safety zones (SZ) of emitting stationary sources, before putting the site into operation. The assessment is based on a conservative method approved by the Ordinance and it does not take into account the specifics of new telecommunication technologies.

One of the factors that may be important in the mass deployment of 5G networks is the problems associated with the assessment of electromagnetic exposure.

When upgrading an existing base station with 5G New radio (NR), the total exposure of the EMF of all antennas and technologies (2G, 3G, 4G, and 5G) must be taken into account to assess compliance with the national regulations. Conventional approaches based on theoretical assessment at maximum power can lead to very large safety zones, which could complicate the installation and upgrading of base stations in a certain place and it is not realistic, concerning the protection of the population. In addition, the specifics of 5G NR, which is characterized by the dynamic change of antenna radiation patterns means that the base station can use a large number of different beam patterns to be directed to the users located in different places should be taken into account.

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On the other hand, the assessment of exposure based on the traditional conservative approach, in which the theoretical maximum power is transmitted in each possible direction for a long period, seems quite unrealistic [4].

2. OBJECTIVE

The exposure assessment of electromagnetic field was crucial in the implementation of previous 3G and 4G technologies, but the situation seems more complicated when upgrading existing base stations with 5G, especially in densely populated areas.

For the frequency range of 300 MHz to 30 GHz national legislation sets the parameter "power density" (S, $\mu W/cm^2$) and the accepted maximal permissible level is 10 $\mu W/cm^2$ (0.1 W/m^2). For comparison, the reference value in the ICNIRP 2020 guidelines [2] for the frequency range 2000 MHz to 300 GHz is 10 W/m^2.

As could be seen, the recommended exposure values by ICNIRP are many times higher than the maximum permissible values for the general public, regulated in the legislation of our country.

In this report, we present an evaluation of the electromagnetic field and safety zones of existing base stations upgraded with 5G mMIMO antennas.

The aim is to show compliance with the restrictive legislation of Bulgaria, using the requirements regarding 5G in IEC 62232 [5] of the International Electrotechnical Commission (IEC) and IEC Technical Report (TR) 62669 [6].

3. MATERIALS AND METHODS

As it was mentioned above, the current national legislation for general public protection from electromagnetic fields in our country is Ordinance No. 9/1991. SZ are determined according to the approved "Method for calculating the strength and power flux density of electromagnetic fields around emitting sources operating in the range from 30 kHz to 30 GHz". [7]

According to this method, the maximal safety distance of the safety zone for frequency bands in the range up to 1 GHz is determined by the equation (1):

$$R_{\max} = \frac{\sqrt{30.G.P}}{E_{\max}}.F(\varphi).F(\theta).k \qquad (1)$$

where:

E max is the maximal permissible level of electric field, V/m up to 0.3 GHz. For the frequency range from 0.3 to 30 GHz the maximal permissible level is expressed in power density $\mathbf{S_{max}}$, $\mu W/cm^2$.

G is the gain, dBi;

P is the maximum input power to the antenna, W;

k is the coefficient presenting the interaction between the direct and reflected wave. In the calculations for the worst-case scenario of exposure k is considered equal to 1.41.

F(φ) and F(θ) are values calculated or obtained from the horizontal and vertical emission patterns, respectively, for the considered direction, determined by the azimuthal angle φ and the elevation angle θ (the angle between emission direction and the horizontal plane). In the calculations for the worst case scenario of exposure F(φ) and F(θ) are considered equal to 1.

The maximal distance of the safety zone for frequencies above 1 GHz is determined by the following equation:

$$R_{\max} = \sqrt{\frac{25.G.P}{\pi.S_{\max}}.F} \qquad (2)$$

where: **G** is the gain, dBi; **P** is the maximal input power to the antenna, W; **F** is a coefficient taking into account the real conditions of propagation of the electromagnetic wave (reflection and/or absorption) - for the worst-case scenario of exposure F = 1.6; $\mathbf{R_{max}}$ is the maximal distance of the safety zone, m; $\mathbf{S_{max}}$ is the maximal permissible level expressed in power density, $\mu W/cm^2$.

When the source transmits in different frequency ranges, the $\mathbf{R_{sum}}$ is determined by the following equation (3). All calculations take the maximum gain for the respective frequency range.

$$R_{sum} = \sqrt{\sum_{i=1}^{n} R_{i\ \max}^2} \qquad (3)$$

The safety zone determines the space on the border of which the RF EMF is less or equal of the maximal permissible level of 10 $\mu W/cm^2$. The safety zone is not a flat surface but three-dimensional in space. For directional antenna the maximal width of the horizontal and vertical antenna diagrams is considered.

Calculations using the above formulas are suitable to estimate the safety distance and respectively the RF EMF exposure from base station antennas, in particular conventional passive panel antennas. When adding 5G antennas to an existing base station, the total exposure of the EMF from all technologies (2G, 3G, 4G, and 5G) must be taken into account to assess compliance with the national regulations. The current method requires the maximal values of power and gain to be used when calculating EMF exposure.

In Bulgaria, the Communications Regulation Commission has so far permitted 5G distribution licenses in the 3500-3700 MHz frequency band.

For 5G NR with massive MIMOs, it has to be assessed the dynamic change of broadcast and service antenna patterns and the reduction of the total transmission power which contributes to the total exposure in a certain direction.

We adapted the numerical calculation method for safety zones evaluation around telecommunication transmitters, with respect to European practices concerning the new 5G technology [8]. The method considers the specificity of new telecommunication standards. It takes into account the requirements set by IEC 62232 [5] and IEC (TR) 62669 [6] and we considered including some power reduction factors in the existing calculation procedure.

One of the reduction factors is the F_{TDC} scaling factor (deterministic factor). In the TDD configuration, there is one-time period (UL - transmission of data from the user to the antenna) for three periods (DL - transmission of data and service information from the antenna to the user), which leads to a duty cycle factor of 75%. Typical F_{TDC} values are between 0.75 and 0.8 [5, 6]. When the exact value is not specified, an approximate value of 0.75 (i.e. 3 / (3 + 1)) considering TDD protocol transmission. So, configured power must be multiplied by 0.75. To reduce the maximum power, the following formula is used, when taking into account TDD:

$$P_{reduced} = P_{max}.\ F_{TDC} \qquad (4)$$

where: $\mathbf{P_{max}}$ is the maximal input power to the antenna, W; $\mathbf{F_{TDC}}$ is a coefficient that reflects the specifics of using the TDD protocol for data transmission.

The base station can dynamically adjust the phase and amplitude of groups of antenna elements in that way it can control the path and form of the transmitted signals. In the case of generating a traffic, the characteristics of the antenna pattern are different and the beam width is very narrow due to the service of a single client, but the gain is higher, in order to qualitatively transmit the required data to the user.

A base station can concentrate its transmitted power into a form of narrow beams.

The number of these predefined traffic beams depends of the type of the antenna (passive or active) and the settings of the operator.

It should be noted that depending on the transmission mode of the antenna (broadcast, service) there are different pattern beams.

By taking into account the additional factor concerning the total power distribution it could lead to a more realistic estimation of the emitted power. So, formula (4) will be transformed as follows:

$$P_{\text{reduced}} = \frac{P_{\max}}{F_{NB}}.F_{TDC} \qquad (5)$$

The $\mathbf{F_{NB}}$ is the number of discrete predefined traffic beams that are emitted simultaneously in the same timeslot of the antenna. The maximum transmitted power is divided to $\mathbf{F_{NB}}$. It is considered that each beam operates with equal portion of the total power of the antenna.

The evaluation of SZ presumes the requirement of “worst case” scenario over the wider broadcast diagram with the maximal gain of the antenna.

The broadcast beams define a geographical location of the sector in vertical and horizontal plane. Their pattern is wider than traffic beams to cover the maximum area of potential users, but the gain is less.

The equation (2) along with reduced power derived from formula (5) for NR Massive MIMO antenna in a TDD configuration will be transformed as follows:

$$R_{\text{max5G}} = \sqrt{\frac{25.G_{SB}.P_{\text{reduced}}}{\pi.S_{\max}}.F} \qquad (6)$$

where: $\mathbf{G_{SB}}$ is the maximum gain of the antenna.

For the definition of R_{max5G} in three-dimensional safety zone, the envelope of all broadcast beams diagram is taken.

For each building or place of interest located in the direction of radiation of an antenna, it is checked whether it is below the horizontal plane passing through the phase center of the antenna by the following equation (7).

$$H_1 - H_2 \le r.tg\alpha \qquad (7)$$

where:

α is the angle subtended between the considered radiation direction and the horizon, i.e. the angle between the line connecting the phase center of the antenna with the point where the intensity of the electromagnetic field is determined; $\mathbf{H_1}$ is the absolute elevation of the phase center of the antenna, in m; $\mathbf{H_2}$ is the absolute elevation of the point of interest; **r** is the distance in a horizontal plane from the vertical axis passing through the antenna phase center to the vertical axis passing through the point of interest, in m.

In the next section, we present a practical example of the evaluations of the electromagnetic field and safety zone of base station upgraded with 5G.

4. RESULTS

We evaluate the safety zone of one of the three-sectoral base station situated on the rooftop of a residential building. The configuration of the base station sector consists of one conventional antenna (2G, 3G, and 4G technologies) and one additional 5G mMIMO antenna.

The main frequencies of conventional antenna are in the ranges of 900 MHz (GSM/LTE/UMTS), 1800 MHz (LTE), 2100 MHz (UMTS/LTE) and 2600 MHz (LTE). The maximum antenna gains are taken from the manufacturer data sheet. For the above frequencies ranges they are respectively 16.90 dBi; 17.70 dBi; 18.00 dBi and 18.30 dBi.

The maximal input power given by the operator is as follows: 90.35 W for the range of 900 MHz; 34.36 W for the range of 1800 MHz; 59.86 W for the range of 2100 MHz and 34.03 W for the range of 2600 MHz.

The 5 G antenna emits in the licensed frequency range of 3600~3700 MHz (NR-TDD). The maximal antenna gain for service beam is 24.00 dBi. The maximal output power is 200 W.

The azimuth of the evaluated sector is 260°.

The base station’s signal goes to a specific user through a narrower beam generated by multiple antenna elements. In our case, the antenna contains 6 predefined beams that are emitted simultaneously in the same timeslot. On that base using formula (5), the reduced power is calculated.

The maximal safety distance of 5G antenna in horizontal plane of the safety zone was calculated, using the formula (6).

R_{max5G}=89.44 m

The summary of all maximal distances of the safety zone is calculated on the base of formula (3).

R_{sum} = 159.12 m

In Figure 1, R_{max5G} is illustrated in blue color and R_{sum} in red color.

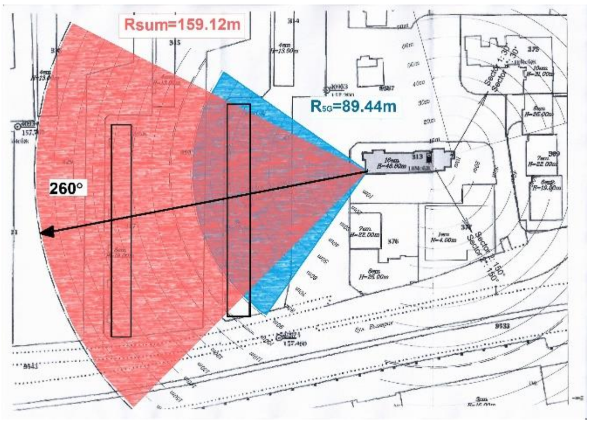

Figure 1. Illustration of calculated maximal distances of the safety zone of R_{max5G} in blue color and R_{sum} in red color

The building where the base station is positioned is 47 m high. As it could be seen in Figure 1, there are two residential buildings (19 m height each) positioned on a distance less than R_{sum} in horizontal plane respectively on distances of minimum 60 m and 120 m from the antennas. Using the technical parameters of vertical diagrams of the antennas, tilt of the antennas ($\alpha \approx 10.75°$) and equation (7) it is checked if they are within the summary safety zone of the third sector of the BS. For both of the buildings it is fulfill the condition H_1-H_2 < r.tgα. Hence the expected EMF values in the buildings are less then maximal permissible level of national legislation – S, power density (0.1 W/m^2).

In order to get a more complete idea of the distribution of EMF in space, a simulation of the antenna patterns for third sector of the base section was made. The simulations represented two cases – a 5G antenna pattern and the combined EMF distribution of all emitters using the previously mentioned data and technical parameters.

NARDA EFC-400 EP software for computing and simulating electromagnetic fields' propagation is used for the purpose. The software calculates field strengths and power density according to DIN VDE 0848 [9], while the radiation pattern is taken into account by the angle quota of normalized spherical harmonics. The calculation takes into account the complete information through which the far-field region of a transmitter is defined. Methods for the numeric solution of the wave equation are over-meant for far-field region calculations. The form of the spherical functions gets determined numerically by the technical data such as the aperture angles.

The valuation criterion is set to cover the maximal permissible level of national legislation – S, power density (0.1 W/m^2) [3]. In all simulations in black color are the values above 0.1 W/m^2.

The software is set to calculate the simulations with a ground reflection of 50 % and shielding factor for all buildings of 6 dB.

The first case is shown in Figure 2. In the 5G simulation case, we used an envelope antenna pattern to be able to distribute the total power equally among the beams in that way we eliminate the influence of the potential user traffic. So, the maximal resource of the base station is forcedly distributed over the antenna area of radiation.

The vertical slice shown in Figure 2 is chosen to show the cross section along the maximum of one of the beams.

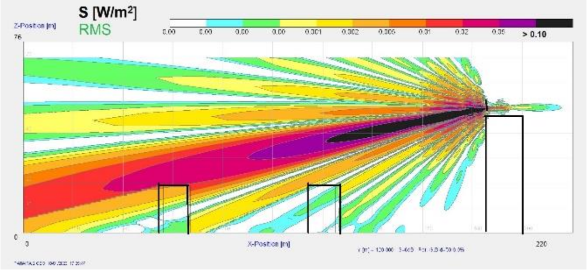

Figure 2. Simulation of vertical distribution of 5G antenna pattern along the maximum of one of the beams with a 6-degree vertical tilt

The second case shows the worst-case scenario which presents the superposition of the conventional and the 5G antennas' patterns. The cross-section illustrated in Figure 3 is set to pass through the direction of maximal radiation of the conventional antenna coinciding along with one of the 5G antenna beams.

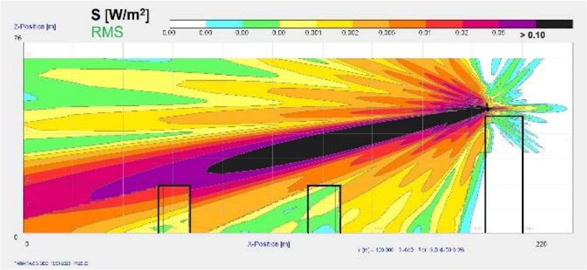

Figure 3. Simulation of vertical distribution of conventional and 5G antenna pattern along the maximum of one of the 5G beams with a 7-degree vertical tilt of the both antennas

The theoretical calculations of the safety distance and the evaluation of the summary safety zone with the technical parameters provided by the operator show compliance with the requirements of national legislation [3]. That is confirmed by the software model of the EMF emission of the conventional sectoral and 5G antennas.

5. DISCUSSION AND CONCLUSION

Base stations with 5G NR equipment must comply with the same safety restrictions as other radio equipment. They must be strict enough to ensure conditions for the safe introduction of 5G NR, but at the same time to provide an adequate assessment of the exposure, taking into account all the specifics of this new technology.

Considering the compliance with the national RF EMF legislation introduction of massive MIMO 5G base stations can be a challenge due to dynamic beamforming. As it was demonstrated, the application of the power reduction factors to the total transmitted power leads to provision of more realistic evaluations of the electromagnetic field and safety zone of 5G antenna.

Nevertheless, some existing base stations which have to be upgraded with a 5G antenna might be compromised regarding the compliance with the national EMF legislation.

This improved method for the calculation of safety distances from telecommunication sources of new generations should be a base for the implementation of new requirements in the national legislation.

REFERENCES

1. The Council of the European Union. (Jul. 12, 1999). *1999/519/EC: Council Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).*
   Retrieved from:
   http://data.europa.eu/eli/reco/1999/519/oj
   Retrieved on: Mar. 17, 2021
2. ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health Physics*, vol. 118, no. 5, pp. 483–524, May 2020.
   https://doi.org/10.1097/HP.0000000000001210
3. Министерство на здравеопазването/Министерство на околната среда. (Май 3, 1991). *Наредба № 9 от 14 март 1991 г. за пределно допустими нива на електромагнитни полета в населени територии и определяне на хигиенно-защитни зони около излъчващи обекти.*
   (Ministry of Health/Ministry of Environment and Water. (May 3, 1991). *Ordinance No. 9 of 14 March 1991. on the limit values of electromagnetic fields in populated areas and the identification of hygienic-protective zones around radiating objects.*)
   Retrieved from:
   https://lex.bg/laws/ldoc/-551794688
   Retrieved on: October 26, 2022
4. B. Thors, A. Furuskär, D. Colombi, C. Törnevik, "Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO," *IEEE Access*, vol. 5, pp. 19711–19719, 2017.
   https://doi.org/10.1109/ACCESS.2017.2753459
5. *Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*, IEC 62232:2017, Aug. 23, 2017.
   Retrieved from:
   https://webstore.iec.ch/publication/28673
   Retrieved on: Jan. 19, 2021
6. *Case studies supporting IEC 62232 – Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*, Technical Report IEC TR 62669:2019, IEC, Geneva, Switzerland, 2019.
   Retrieved from:
   https://webstore.iec.ch/publication/62014#additionalinfo
   Retrieved on: Dec. 10, 2020
7. "Методика за изчисляване напрегнатостта и плътността на енергийния поток на електромагнитните полета около излъчващи обекти, работещи в обхвата от 30 kHz до 30 GHz," *Служебен бюлетин на МА и НИХПЗ*, София, България, 1991.
   ("Method for calculating the strength and power flux density of electromagnetic fields around emitting sources operating in the range from 30 kHz to 30 GHz", *Official Bulletin of Medical Academy and National Institute for Hygiene and Occupational Diseases*, Sofia, Bulgaria, 1991.)
8. T. Shalamanova, M. Israel, H. Petkova, V. Zaryabova, M. Ivanova, "Determination of RF field strength and safety zone, regarding the specificity of the 5G technology," *Bulgarian Journal of Public Health*, vol. 13, no. 4, Supplement, pp. 67–78, 2021.
   Retrieved from:
   https://ncpha.government.bg/uploads/pages/3029/4S-2021_BG_Journal.pdf
   Retrieved on: Mar. 17, 2022
9. *Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz - 40 GHz)*, DIN EN 50383 VDE 0848-383:2011-06; Jun. 2011.
   Retrieved from:
   https://www.vde-verlag.de/standards/0848042/din-en-50383-vde-0848-383-2011-06.html
   Retrieved on: Mar. 17, 2022