Features of Electromagnetic Situation Estimation Near the 5G Base Station Antennas

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Abstract. The economic attractiveness of 5G networks influences the speed of their worldwide deployment drastically, putting the deployment process ahead of environmental studies. The analysis of 5G network parameters which affect the evaluation of electromagnetic ecology was carried out. It has shown the difference between 5G and 3G/4G networks in the frequency band number, network topology, transmitting power, the radiation parameters of antenna systems, as well as the antenna systems location relative to the service areas and in distance to possible people location. These differences resulted in the following conclusions: it is incorrect to use the decimeter wave propagation models for estimation, and it is incorrect to use maximum permissible power level per unit of human skin surface area as an exposure criterion as well. Hence, the current documents for electromagnetic ecology regulation do not reflect the electromagnetic background of 5G networks. The article presents two possible ways to solve the detected contradiction: medical and biological research for 5G frequencies; scientifically based generalization of international experience in regulation with a transition to the practice of recommendations. It is shown that since the medical and biological research in Russia began only in 2020, it is possible to use the V.I. Mordachev method for the transition period. It is proposed to use the total intensity of electromagnetic background in the territory of broadband networks deployment, which operate in several frequency bands, and to use the old exposure criterion. In the paper the research results were given for a private case of 5G network functioning in three frequency bands (4.4 GHz, 24 GHz and 37 GHz) in Kaliningrad, St. Petersburg and Moscow. The given research results showed the environmental safety of the deployed networks. In addition, it was shown that the technique could be used to assess the electromagnetic ecology in the 5G network territory in the transition phase until new regulations are adopted.

1. Introduction
The year 2020 is of special importance in the development of 5G communication technology, since July 2020 was set as the key date of the beginning of 5G network operation [1]. In fact, the first 5G networks appeared in the United States in 2018, and in South Korea and Japan - in 2019. Currently, in the world there are more than 129 5G networks. Their economic attractiveness is due to the development of online applications with new consumer qualities. For consumers, the top priority is given for such applications [2-4] as unmanned transport, Internet of Things, streaming video, virtual and Tactile Internet. With the convergence of communications and computing, new applications provide such user attractive features, as the cloud office. It allows using the computing capabilities of a cloud server and the licensed software installed there. In this case, the user's own computer is considered ad as a screen with a keyboard only. Also, great opportunities are provided by Tactile Internet. In particular, it will be possible for famous professors to perform surgeries from other cities and countries, to make a virtual fitting-room for online stores, to implement e-learning, etc.

The achievement of high transmission speeds in 5G networks, and, consequently, the reduction of the network delay time from 5 msec to less than 1 msec, is due to the improvement of their technical characteristics compared to 4G networks [2, 3]. Thus, the peak date rate in new networks increases by
10-100 times per subscriber and reaches 10 Gbps or more. The growth of traffic volume density is about 1000 times and reaches more than 10 Tbps/km². The growth of connection density is from 10 to 100 times and amounts to 1 million/km². The growth of technical capabilities of 5G networks will lead to the electromagnetic background changes for the territory [5]. Hence, the question arises: whether this change in the electromagnetic background will have a significant impact on public health. This question is the purpose of this report.

2. Evaluation methods for electromagnetic background in the 5G network areas

2.1. Exposure criteria for electromagnetic ecology estimation for 2G/3G/4G network areas
At present, regulatory documents [6, 7] are used to assess the electromagnetic situation in 2G/3G/4G networks. There, the value of maximum permissible power per unit of human skin surface is used (or can be reduced to [8, 9]) as an exposure criterion for assessment of electromagnetic situation in the Russian Federation and in the Western countries (the USA, the European Union). The differences lie in the numbers of this value: in Russia the maximum permissible level is 10 W/cm² [7], and in the Western countries it is 100 mW/cm² [6]. However, both documents [6, 7] clearly identify antenna/base station antenna complex as source of non-ionizing radiation working at the fixed frequency and human as the biological object.

2.2. Main network parameters of the electromagnetic environment estimation for network technologies
The fullest list of the main network parameters for electromagnetic safety evaluation of network technologies was formulated in [8]:
- Frequency and range properties of equipment (they affect the electromagnetic models used to describe the process of radio wave propagation, as well as the maximum permissible levels);
- Network topology;
- Capacity of network transmitting devices;
- Radiation parameters of antenna systems that determine the directions and the areas of service;
- The antenna system location relative to service areas or the distance to possible people location.

2.3. Differences between 5G technology and the existing cellular networks in terms of electromagnetic environment
In terms of parameters listed in section 2.2, the 5G network infrastructure is fundamentally different from 3G and 4G one [1-4, 8, 10, 11]. Such differences are [3, 4, 11]:
- Simultaneous use of several frequency bands with different bandwidths in the network. For 6 GHz frequencies the radio channel width is up to 100 MHz, for frequencies above 6 GHz and mmWaves the value is 50-400 MHz, which is 5-20 times higher than the same indicator for 4G networks. Potential bandwidth of the channel (the theoretical upper limit of the data transmission rate through an analogue channel subjected to an Additive White Gaussian Noise) and the width of the bandwidth are related by the Shannon-Hartley theorem [12]):
  \[ C = B \log_2 (1 + h^2) \]  
  \( C \) - is SNR value, i.e. the ratio of desired signal power to the channel noise power;
- Difference in the coverage radii of base stations within one network. It equals 2 km for macro cell architectures at frequencies below 6 GHz, and for small cell architectures at frequencies above 6 GHz is less than 200 m in open space and 20 m indoors - femto cell);
- Higher density of base station antennas in urban areas with high building density - up to 30 per 1 km² (11 per 1 km² – for 4G networks);
- Randomness of base stations location within the network, especially in densely populated areas;
- Placing the base station antennas not only at traditional places, like tall buildings and masts (macro cell architectures), but also on lower structures (up to 2-6 m), like power transmission utility posts, light poles near residential buildings, on the walls of various buildings, at public transport stops, on sewer manholes covers (small cell architectures);
Using active antennas with dynamically changing multi-beam directional diagram (macro cell architectures and mmWave) along with passive omnidirectional antennas (small cell architectures) for base stations. Active and passive antenna designs for 5G networks produced by Kathrein are shown in fig.1;

Figure 1 – Antenna design for 5G networks produced by Kathrein [13]:

- Beams are formed by MIMO (Multiple Input Multiple Output) antennas not for a number of User Equipments (UE), as it was done in 4G networks, but for each mobile UE specifically. The UE number for each MIMO antenna can vary from 30 to 100. It is achieved by combining the MIMO antennas into the array, namely, M-MIMO (Massive Multiple Input Multiple Output). The array length can reach up to 256, because the EIRP (Equivalent Isotopically Radiated Power) value should be at least 65 dBm for macro cell architectures;

- The use of transmitters of different power depending on the frequency range, service area and base station membership as the network element. Thus, a single transmitter in a local zone should have a power above 0.25 W; the power of same transmitter in a medium-sized zone should be above 6.1 W; the number of transmitters is not limited for large service areas, and their power can reach tens of watts.
The analysis of the above mentioned features of 5G networks allows drawing a conclusion on the impossibility to clearly divide separately located objects into emitting one and objects of influence. We can only talk about the general electromagnetic background created by small cell architectures and amplified by radiation from macro cell architectures. In this regard, it is fundamentally impossible to use the value of the maximum permissible radiation power per unit of human skin surface as an exposure criterion.

Moreover, the simultaneous operation of radiation objects at different frequencies, including mmWave, within one network makes the electrodynamic models [6, 7] usage incorrect to describe the process of wave propagation in the decimeter or centimeter range near the media interface. Besides, the methodology of electromagnetic monitoring used in the techniques [6, 7] is concentrates on the sectoral antennas only. At the same time, the use of antennas with dynamically variable pattern changes the approach to the predicted electromagnetic environment management fundamentally [8]. Thus, the existing regulatory documents [6, 7] for electromagnetic environment estimation become inapplicable in 5G networks.

2.4. Possible ways to solve the detected contradiction in the electromagnetic environment estimation method for 5G networks

As the issue of the contradiction arises, one can propose either to carry out medical and biological research for 5G frequencies, or to generalize the international experience in regulation on scientific basis [8].

According to C-News, medical and biological research in Russia has already begun in 2020. Thus, C-News reports that in 2020 Moscow requested a study on the impact of 5G networks on human health at the Research Institute of Occupational Medicine named after N.F. Izmerov. The research will be carried out with a specialized stand equipped with a complete set of equipment for all currently operating cellular networks, starting from 2G. As shown in [9], the required devices are available. However, it takes time to conduct medical research and summarize the results.

One of the possible options for the second way of solving the contradiction issue is to move away from strict regulations and restrictions to recommendations, as is done in the majority of developed countries. One can consider the regulatory document of 2016 [14], adopted not in all CIS countries, as an example. According to [8], instrumental control in this case should be used only for special, critical and controversial cases of network fragment topology.

V.I. Mordachev’s works [15, 16] can be considered another example of taking the second way of solving the contradiction issue. There, the concepts of electromagnetic load on the territory and the electromagnetic load on the population are proposed to use as an integral system characteristic of electromagnetic safety of the radio electronic environment and electromagnetic ecology of the territory of urban development with broadband networks. The coefficient of electromagnetic load on the territory is defined as the total of equivalent isotropically radiated power (EIRP) of UE or cellular base stations, corresponding to the unit of territory [16]:

\[ L_E = P_e \rho, \]  

(2)

Where \( P_e \) is an average EIRP, \( \rho \) is an average territorial density of the radiating object placement in the area. For mobile subscribers

\[ \rho_{MS} = \rho_S E, \]  

(3)

Where \( \rho_S \) is the population density of mobile subscribers in the area; \( E = 0.025...0.08 \) - specific traffic intensity.

In this case, the electromagnetic radiation of the base station and UE are considered to be independent. As a result, the model Poisson’s distribution is used to describe the arbitrary location of radiating objects as point sources of electromagnetic field on a flat surface.

A composite model is used to describe the conditions for radio waves propagation from an electromagnetic field source to an observation point with arbitrary coordinates located at an altitude \( H_{op} \) above the surface. In accordance with it, the energy flux density depends on the distance \( R \) between the observation point and the source and is determined by the ratio [16]:

\[ E = \frac{1}{2 \eta} \frac{P_e}{R^2}, \]  

(4)

where \( \eta \) is the energy efficiency coefficient.
\[ \Pi = \begin{cases} \frac{P_e}{(4\pi R^2)}, & R \leq R_{BP}, \\ \frac{R_{BP}^2 P_e}{(4\pi R^4)}, & R \geq R_{BP}, \end{cases} \]  \tag{4} \\
R_{BP} = 4H_{OP}H / \lambda, \tag{5} \\
\]

Where \( H \) is an antenna suspension height; \( \lambda \) is radiation wavelength; \( R_{BP} \) is the boundary between the radio wave propagation zones taking multi-beam into account (\( R \geq R_{BP} \)) and without it (\( R \leq R_{BP} \)).

In [16] the analytical dependencies of electromagnetic load on the territory are also given according to parameters of cellular communication radio equipment. Thus, the base station EIRP is determined by the expression [16]:

\[ P_e^{RS} = P_e^{MS} + \Delta_e^{RM}, \]  \tag{6} \\
\[ \Delta_e^{RM} = G_A^{RS} - G_A^{MS} + D_{UD}, \]  \tag{7} \\

Where \( G_A^{RS} \), \( G_A^{MS} \) are the antenna gain for base station and UE accordingly; \( D_{UD} \) is the difference in the radio lines energy in Uplink and Downlink channels.

The electromagnetic load on the population is determined by the total intensity of the electromagnetic field from the base stations or UE near the earth’s surface. In [16] a connection between the electromagnetic load on the territory with the probability of exceeding the maximum allowable level of the total intensity of all electromagnetic fields in the observation point near the Earth’s surface was revealed. Thus, for the \( p \)-value \( p \leq 0.1 \) the value of the total intensity of the electromagnetic background excited by base stations antennas and UEs in the observation point at height \( H_{OP} \) is determined by expression [16]:

\[ \Pi_\Sigma \approx 0.5L_{TMS} \left( \Delta_e^{RM} \ln \left( \frac{6.6H_{OP}}{\lambda} \right) + \frac{1}{2} \left( Z + 1 + \frac{1}{p} \right) \right), \]  \tag{8} \\
\[ Z = \sum_{h=0}^{N} \frac{1}{H - 1}, \]  \tag{9} \\
\[ N = \left[ \pi \rho_{MS} \frac{16H_{OP}^4}{\lambda^2} \right], \]  \tag{10} \\

Where \( L_{TMS} \) is the average electromagnetic load on a territory created by UE; \( [\cdot] \) is an integral part of a number.

The analysis of the given ratios of the technique described in [16] shows that the introduced indicators of electromagnetic load on the territory and on the population allow taking into account the intensity of electromagnetic background created by all components of the cellular network. The main disadvantage of this method is the use of the maximum permissible power level regulated by the existing document as an exposure criterion [7]. However, it should be noted that at the transition stage, while new regulatory documents are not adopted and 5G networks are already being deployed, the method [16] can be used to estimate the electromagnetic ecology in the territory where these networks are deployed.

3. Results and Discussion

Using the method from [16] described in section 2.4 of the current work, the influence of population density on the total intensity of electromagnetic background was studied for various \( p \)-values. The \( p \)-value was taken as in [16], i.e. its variation range was \([10^{-4}, 10^{-1}]\). The studies were carried out to analyze the situation in three cities of the Russian Federation: Kaliningrad, with a population density of 2177 people/km\(^2\), St. Petersburg, 3847 people/km\(^2\), and Moscow, with a population density of 15000 people/km\(^2\). Specific traffic intensity was accepted as in [16], equal to \( E = 0.05 \) Erlang. Fig.2
shows the dependencies of changes in the total intensity of the electromagnetic background when a 5G network operates at the frequencies $f = 4.4$ GHz ($\lambda = 6.8$ cm), $f = 24$ GHz ($\lambda = 1.3$ cm) and $f = 37$ GHz ($\lambda = 0.8$ cm). The antenna suspension height at the observation point was supposed to be 2 m.

![Figure 2](image_url)  

**Figure 2** – Dependence of the total intensity of the electromagnetic background on the population density of the territory  
1 – Kaliningrad (population density 2177 people/km²);  
2 – St. Petersburg (population density 3847 people/km²);  
3 – Moscow (population density 15000 people/km²);  
4 – maximum permissible power level [7]

The analysis of the obtained dependencies shows that for $p$-values $p \geq 10^{-2}$ even for the cities with extremely high population density, like Moscow, the total intensity of electromagnetic background does not exceed the maximum permissible power level. Thus, we can say that the deployment of 5G networks is safe by the criterion of the maximum permissible power level. At the same time, as noted earlier, the application of this criterion is inappropriate.

### 4. Conclusion

Rapid deployment of 5G broadband networks in the world, and in Russia in particular, is ahead of the process of estimating the electromagnetic environment near them. The analysis of differences between 5G and 3G/4G networks carried out for the parameters, which are taken into account in the existing methods of electromagnetic environment estimation, has shown that:

- The network operates in several frequency bands, ranging from decimeter to millimeter. Due to this fact, it becomes incorrect to apply the radio wave propagation model from the method [7], which is fair for the decimeter wavelength range only;

- The placement of macro and small cell emitting antennas at different heights and in a chaotic manner, as well as the use of antennas with dynamically variable directivity instead of sectoral antennas makes it impossible to use an approach from [7], where the position of the emitting element and the person are considered fixed;

- The change in the electromagnetic wave direction of arrival to a comprehensive one makes it incorrect to use the value of maximum permissible power level per unit of human skin surface area as an exposure criterion.

Thus, either a review of the documents regulating electromagnetic safety estimation or the approach to its estimation is required. The way may include medical and biological studies for 5G frequencies ordered by the Moscow City Government in 2020. If considering the second way, it was proposed to move away from strict regulation and restrictions to the recommendations, as it is done in the majority of developed countries. For the transition period, until the legal issues are resolved to assess the electromagnetic environment, it was proposed to use the V.I. Mordachev method, which
introduces the concept of electromagnetic load on the territory and the electromagnetic load on the population. Mordachev’s method still uses the maximum permissible level of power per unit area of the human skin surface as an exposure criterion. The research was carried out to study the influence of population density on the total intensity of electromagnetic background on the territory with 5G networks operating in three frequency ranges (4.4 GHz, 24 GHz and 37 GHz). It showed that the currently used criteria of 5G network estimation are environmentally safe. In addition, it can be noted that at the transition stage, until new regulations are adopted, the method can be used to assess the electromagnetic ecology in the territory of 5G networks.

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