The Necessity to Assess the Electromagnetic Environment Near 5-G Radio-Emitting Objects with Instrumental Procedure

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Abstract. The features of the new 5G standard if compared to the currently used 4G lie within a significant frequency range expansion, and the implementation of the Internet of things. They made it impossible to expand the existing safety standard of broadband cellular network construction in large cities to the new standard. Differences between the Western and Russian approaches to the maximum permissible power level assessment and the lack of publications on the subject prompt measurement experiments in order to obtain an approximate electromagnetic environment assess near radio-emitting objects. At the preliminary stage of the measurements, it is necessary to choose the right measuring instruments and procedures, since the choice determines the price-quality relationship of the experiment. In the paper the results of the analysis for the known measuring instruments are given with an account to the special requirements formulated according to 5G standard features. The conclusion on the availability of the measuring instruments with the required characteristics is made. It is shown that the experiment efficiency depends on the measurement area dimensions and the measurement points spacing. In case of reflector antenna of 0.9 m diameter operating at 6 GHz the number of measurement points can be reduced without a loss of accuracy if the measured antenna passport data as well as the recommendations given in the paper are taken into an account.

1. Introduction

Since the 2000s, one of the world trends is the formation of a global information network, Internet, which is based on the capabilities of info-communication technologies and telecommunication transport network [1]. Internet introduction to the manufacturing has already allowed the economy to reach a new development level characterized by its digital form [2, 3]. Its distinctive feature, as shown in [4], is that the value origin is changed from labor to information. At the same time, the efficiency of the main resource of the digital economy is determined by the transmission rate. When transmitting information over telecommunication transport network, the data rate is estimated by the channel capacity \( C \), which due to Shannon-Hartley theorem [5] is described by the following ratio:

\[
C = B \log_2(1 + h^2),
\]

where \( B \) - is the frequency bandwidth [Hz]; \( h^2 = P_s / P_n \) - is SNR value, i.e. the ratio of desired signal power to the channel noise power.

Ratio (1) is the key to understanding the broadband network necessity for digital economy development [6], because if the line properties are constant ( \( h^2 = const \) ), the channel capacity is directly determined by the signal bandwidth \( B \). The interrelation examples are given in table 1 for signal bandwidth and data rate in radio channels for different standards [7].
Table 1. Comparative characteristics of data rate for various communication standards
(http://cnews.ru/articles/2019-10-5_6g_mozet_perebit_appetit_k_5g)

| Communication standard | Year of introduction | Signal bandwidth $B$, MHz | Data transfer rate, $C$ | 2 GB video download time |
|------------------------|----------------------|---------------------------|------------------------|--------------------------|
| 3G                     | 2002                 | 0.2                       | 3.6 Mb/s               | 1.2 h                    |
| 4G                     | 2007                 | 20                        | 100 Mb/s               | 2.7 min                  |
| 5G                     | 2018                 | 100                       | 2 Gb/s                 | 8 sec                    |
| 6G                     | 2030                 | -                         | 1 Tb/s                 | 0.016 sec                |

The table analysis shows that the frequency bands of the 4G standard provide high channel capacity and, consequently, the access to the wide range of Internet applications. Further bandwidth expansion envisaged in 5G standard will allow data rate 20-100 times as much as it is in 4G standard [7-9]. According to IMT-2020 (5G) the theoretical maximum of channel capacity is 20 Gbps downstream and 10 Gbps upstream, and the achievable and sustainable data rate in urban conditions [7] is 100 and 50 Mbps accordingly. According to forecasts [7], the networks of the next 6G generation are to appear by 2025-2030 and their rates will reach 1 Tbps.

Another feature of the modern broadband access networks (WBA) is providing the mobility of users, estimated by the coverage ratio (ratio of population living in the network coverage area). Currently, the global index is 53 %, the leading countries, such as South Korea, have coverage ratio of 100 %. In Moscow the 4G coverage ratio for MTS and Megafon networks is 60 % [7]. The cellular WBA subscriber dynamics is shown on Figure 1 [7]. From the figure analysis one can conclude, that recent number of cellular WBA subscribers (69.3 %) is much higher than the fixed access subscribers (14.1 %). At the same time, the number of subscribers with Internet access is growing.

Figure 1. Internet access technologies dynamics: 1 – total number of cellular network subscribers; 2 – number of internet access subscribers; 3 – number of fixed-line phone subscribers; 4 – number of cellular WBA subscribers; 5 – number of fixed-line WBA subscribers.

Thus, the further development of the world economy, including the Russian economy, is connected to cellular broadband access network usage.

2. The problem of harmful effect estimation for 5G network emitters on human health

The expansion of 3G and 4G cellular networks has negative consequences. As it is shown in [10, 11], network expansion is accompanied by an increase of electromagnetic background level at the locations, and, consequently, by the deterioration of electromagnetic situation near BTS antenna locations. The introduction of 5G networks has just begun, but it has brought up the following question: whether 5G emitting elements would be as dangerous for human health as the elements of the previous generations were. Preliminary studies conducted by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [7] show, that non-ionizing radiation of 5G cellular network does not have harmful effect
on human health. However, Western researchers do not consider long-term exposure to the electromagnetic field of low intensity to be a harmful factor and observe the human skin heating by these fields only, as it was shown in [10, 11, 13, 14]. Moreover, in Western standards [12] the maximum permissible level of such radiation is set at 100 mW/cm², which is four orders of magnitude higher than the level assigned in Russia (10 µW/cm²). Thus, one can only rely on the analysis of scientific research results to unambiguously solve the problem of human health influence by electromagnetic fields excited by 5G devices. Since there are currently no publications on this topic, it is necessary to conduct a measurement experiment to determine the energy flux density near the emitting object, as it is recommended in [14]. As it is shown in [15], the instrumental procedure does not always provide accurate results, since the energy flux density level at the measurement point can be influenced not only by the measured object, but also by a number of factors, such as stationary and mobile sources of electromagnetic energy, physical processes (including atmospheric disturbances, switching equipment), low, medium, and high voltage equipment etc. However, the procedure can be used at the initial research stage to obtain information on the electromagnetic environment.

When conducting research with the instrumental procedure, it is necessary to have measuring equipment capable of operating in complex electromagnetic environment, as well as the measuring procedure, which defines the period of operation frequency change, frequency of measurements, antenna orientation etc.

Let us focus on two issues in more detail: the availability analysis of sustainable measuring equipment and measurements recommendations driven by the differences between 5G and 4G standards.

3. Features of 5G standard in terms of electromagnetic ecology

Let us analyze the differences between 5G and 4G standards, which should be taken into account when assessing the electromagnetic situation near BTS antenna. Such differences include [7, 9]:

- Using wide range of frequencies;
- Using Massive MIMO technologies;
- Network slicing;
- D2D (proximity-based direct communications between devices) or IoT (Internet of Things).

World radio congress has allocated frequency bands of 3.4-3.8 GHz, 4.8-4.99 GHz, 24.25-27.5 GHz, 37-43.5 GHz, and 66-71 GHz for 5G networks. However, in Russia it is supposed to use slightly different bands:

- Low (<1 GHz) for mass coverage of territories and zones with low traffic density;
- Medium (1-6 GHz) for traditional cellular usage scenarios in cities and towns;
- High (>24 GHz) for hot-spots, which are zones with extremely high consumption of data services and innovative info-communication services.

Low frequencies are expected to be used for routes with low bandwidth requirements, including communication lines in buildings. The main cellular consumption will be provided on medium and low radio frequencies. At the same time, the 3.4-3.8 GHz band is supposed to be main, and 4.8-4.99 GHz and 25.25-27.5 GHz bands are considered additional. Ultra-high bandwidth will be provided in certain areas and inside buildings by creating small cells with high and medium frequencies. At the same time, as it is shown in [7], Ministry for Digital Development, Communications and Mass Media of Russian Federation proposes shutting the WiMAX fixed wireless access systems and withdraw satellite ground stations from large cities. Telecommunication networks are not currently used to organize D2D exchange.

The introduction of Massive MIMO technologies, refarming, and expanding the use of the radio frequency spectrum will significantly (up to 50-60 times, depending on the number of active antennas) increase the bandwidth of existing cells of 4G cellular operators, operating at 1.8/2.6 GHz. This is determined by the fact that Massive MIMO technology provides a significantly larger signal transmission radius. So, in [7, 9] it was shown that the coverage radius of a 5G cell at 3.5 GHz is comparable to the coverage of a 4G cell at 2.6 GHz.

Network slicing technology allows deploying logically isolated networks, each one dedicated to specific needs, for example, for IoT, WBA, video broadcasting, etc. In this case, the operation will be carried out in its frequency range.

The allocation of separate networks for D2D data transmission is determined by their high traffic. So, according to [7], as of June 2019, there are 1bn IoT connections, and by the end of 2024 their number
may increase up to 4.1bn. This is due to the fact that when creating scenarios of mass machine-type communications (mMTC) of the so-called “smart” cities, as well as “smart” networks (Smart Grid), it is planned to place up to 100K devices per 1 square kilometer. If one uses telecommunication networks for communication, each base station will have up to 1M subscribers.

4. Results and Discussion

4.1. Requirements for instruments measuring energy flux density in 5G cellular communication systems

To assess the electromagnetic environment near BTS antenna of cellular communications, the following requirements must be taken into account when choosing instruments for measuring electromagnetic fields and radiation, according to [7, 16]:

- The measured parameter is the energy flux density [13];
- Frequency range of measurements is 0.8-71 GHz;
- Energy flux density level – from 1 µW/cm² to 5 mW/cm²;
- The nature of the electromagnetic field and radiation - harmonic fields;
- Specific requirements: the ability to provide reception of circular polarization signals (measurements have no dependence on the sensor orientation).

Due to the 5G standard features, there is a special requirement for measuring instruments, which is expanding the frequency range from 0.8 to 71 GHz.

4.2. Analysis of known energy flux density measuring instruments for the 5G standard

According to the formulated requirements and the sales sites [7] data, an analysis of the currently known Russian instruments for the electromagnetic background measuring was carried out. The results are shown in table 2.

Table 2 analysis shows, that only one of Russian-built devices, PZ-42, satisfies all the above mentioned requirements for assessing the electromagnetic background generated by 5G radio-emitting objects. The other two devices can be used to carry out measurements in a limited frequency range. All devices listed in table 2 have isotropic antenna-converters, are certified in the state register and can be used to issue a sanitary passport for a radio-emitting object.

For all of the abovementioned devices, the design is approximately the same and includes one or several isotropic antenna-converter, as well as the measuring device itself. The device weight does not exceed 0.3 kg. It is possible to connect it to a computer. The measurement range of the energy flux density, as well as its measurement accuracy satisfies the stated requirements.

Table 2. Comparative characteristics of known devices for electromagnetic background assessing

| Device brand | Frequency range | Π measuring range | Π measurement accuracy | Cost, KP |
|--------------|-----------------|-------------------|------------------------|---------|
| Narda NBM-550, by «EKOTEST» | 100 KHz – 60 GHz | 0.027 nW/cm² – 2.653 KW/cm² | 0.0001% - 99.99 % | 2.000 |
| PZ-41, by «EkoSfera» | 0.3 GHz – 40 GHz | 0.26 W/cm² – 1 W/cm² | 0.0001% | 664.5 – |
| PZ-42, by «EkoSfera» | 0.3 GHz – 95 GHz | 0.26 W/cm² – 1 W/cm² | 0.0001% | 765.0 – |

Thus, currently there are measuring devices that satisfy the formulated requirements for the electromagnetic background assessing near 5G radio-emitting objects.
4.3. Recommendations for conducting the measurement experiment

The electromagnetic environment assess methods are well-known and are given, for example, in [13, 17, 18]. When visualizing the electromagnetic environment near a radio-emitting object, one should determine, among other issues, the spacing of measurement points. The spacing directly affects the accuracy of the obtained results on the one hand, and the elapsed time and the experiment cost on the other. So, in [19] it was shown that the incorrect choice of measurement points when neglecting the preliminary studies data obtained by the calculation method leads to a significant (about 3 times) increase in the amount of measuring. When laying out the optimal measurement plan, the following requirements are essential [19]:

- Measurements should be carried out in two main planes, horizontal or vertical, instead of the entire volume. The vertical plane should pass through the antenna phase centre and the maximum radiation direction of the antenna. The horizontal plane should be located 2 m above the ground (when determining the sanitary protection zone) or above the roof surface;
- One should take passport data of the measured antenna into account, if they are known;
- The dimensions of calculated planes are selected according to the following rules: in the maximum radiation direction, the distance between antenna phase center and the plane edge should be about $800\lambda$, and $400\lambda$ in the opposite direction. In the transverse direction, the size of the calculated plane should be not less than $400\lambda$;
- The distance between the measuring points should be uneven. In the front half-space, the step should be larger (about $50\lambda$), and in the back half-space it should be less by half ($25\lambda$);
- Using additional information about the generated electromagnetic field structure (to define the characteristic areas described in [10, 11, 15, 17]) is necessary when visualizing the measurement results.

To demonstrate the effect of the formulated recommendations application when measuring the electromagnetic environment let us consider the following example, shown in table 3: a reflector antenna with 0.9 m reflector operates at 6 GHz, and a transmitter power is 100 W. Figure 2 shows the contour graphs of the energy flux density distribution at maximum radiation direction in two cases: when the recommendations are neglected and when they are considered.

| Measurement points spacing (wavelength) | Total number of measurement points |
|----------------------------------------|-----------------------------------|
| Front half-space | Back half-space | |
| 100 | 100 | 2.760 |
| 50 | 50 | 11.200 |
| 25 | 25 | 44.800 |
| 100 | 25 | 6.400 |

An analysis of the results shows that the number of measurement points can be reduced by a factor of eight without a loss of accuracy.

Thus, the optimal measurement plan allows reaching the high accuracy and minimal cost of results visualization at the measurement stage, i.e. reaching the optimum price-quality relationship.
5. Conclusion

The implementation of 5G broadband networks as part of the digital economy development requires an electromagnetic environment assessment near radio-emitting objects to justify the absence of harmful effects on human health. It is impossible to apply the 4G estimates directly, since there are a number of differences between the 4G and 5G standards. These, in particular, include the wider frequency range, the IoT implementation, and the use of Massive MIMO technologies.

The lack of information about the electromagnetic environment generated by 5G standard radio-emitting objects, as well as the approach difference in assessing the harmful health effect of non-ionizing fields of low intensity between Russian and foreign standards require measurement experiments based on the instrumental method. At the preliminary stage, it is necessary to prepare a justification for the measurement device choice, as well as the measurement procedure itself. The paper provides an analysis of well-known Russian measuring instruments that can be used in research, and justifies the absence of foreign analogues. It is shown that the use of the measurement procedure with the consideration of the formed recommendations provides the optimum price-quality relationship.

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