EDN: https://elibrary.ru/crhgmk
DOI: https://doi.org/10.31089/1026-9428-2022-62-6-388-396
УДК 614.875

Sergey Yu. Perov, Olga V. Belaya, Nina B. Rubtsova

# The prospects for radiofrequency electromagnetic fields control approaches improvement under 5G wireless communication technologies introduction

Izmerov Research Institute of Occupational Health, 31, Budyonnogo Ave., Moscow, 105275

5G mobile communication system networks improvement leads to scenarios for the use of electromagnetic energy in various sectors of the economy variety increase and radiofrequency electromagnetic fields (EMF) person' exposure with expansion of the exposed by occupational and non-occupational exposure contingent including. Base station EMF distinctive feature is its complex frequency-time and spatial dynamics with constant control signals that should be taken into account in modern EMF control methods.

International practice in case of cellular base stations EMF assessment uses maximal values determination: theoretical and actual levels. EMF theoretical maximal values characterize base station operation mode under highest network load, highest data traffic and time-frequency radio channel resource full usage at the maximum permitted transmission power. Actual maximum EMF levels determination approach is base stations EMF evaluation alternative principle and is based on practically achievable maximum EMF emission, stochastic nature of base station signals with taking into account.

The approaches to statistical assessment of actual maximum exposure levels are becoming a priority for international practice of base station EMF assessment and control due to adaptive antenna technologies in 5G cellular networks development.

This approach to realistic EMF exposure assessment is fundamentally new for Russian practice and will require methodological updating of regulatory framework as well as comprehensive researches with network operators, including approaches to selective measurement results extrapolation for implementation.

**Ethics.** The study did not require the ethics committee conclusion.

**Keywords:** *electromagnetic field; base station; 5G/IMT-2020; selective measurements; hygienic assessment*

**For citation:** Perov S.Yu., Belaya O.V., Rubtsova N.B. The prospects for radiofrequency electromagnetic fields control approaches improvement under 5G wireless communication technologies introduction. *Med. truda i prom. ekol.* 2022; 62(5): 388–396. https://elibrary.ru/crhgmk https://doi.org/10.31089/1026-9428-2022-62-5-388-396

**For correspondence:** *Sergey Yu. Perov,* Head of electromagnetic field laboratory, Izmerov Research Institute of Occupational Health, Dr. of Sci. (Biol.). E-mail: perov@irioh.ru

**Information about the authors:** Perov S.Yu. https://orcid.org/0000-0002-6903-4327
Belaya O.V. https://orcid.org/0000-0003-3937-4950
Rubtsova N.B. https://orcid.org/0000-0001-6306-777X

**Contribution:**
Perov S.Yu. — research concept and design, editing;
Belaya O.V. — research concept and design, data collection and analysis, text writing;
Rubtsova N.B. — research concept and design, editing.

**Funding.** The study had no funding.
**Conflict of interests.** The author declares no conflict of interests.
*Received: 25.04.2022 / Accepted: 21.06.2022 / Published: 15.07.2022*

**Introduction.** 5G wireless communication systems development and implementation indicate the international trends of telecommunications industry intensive development. The various socio-economical fields of modern society are impacted by these trends more and more. New generation wireless networks provide innovation telecommunication services and are considered as for strategic development of industry, healthcare, agriculture, construction, transport and energy infrastructure technological base as well as other priority sectors in framework of "Digital Economy of the Russian Federation" National program. of 5G/IMT-2020 network subscribers distribution by Russian economy sectors in 2026, industry, community housing communal services and healthcare will be the most popular areas with more than 2.1 million users for each segment, according to the forecast [1]. 5G networks implementation leads to increased variety of wireless communications service functionality as well as electromagnetic energy usage scenarios in different economy sectors and of radiofrequency electromagnetic fields (EMF) human exposure change. Contingent exposed by occupational and non-occupational EMF exposure expansion and disappearance of differences between them may be expected due to these changes. All marked aspects define the importance of human electromagnetic safety problems and hygienic assessment and control methods improvement necessity.

5G wireless networks EMF human health effects are the subject of various specialties all over the world including Russia discussion and researches. Despite the available publications on the need to existing regulatory and methodological documents improve [2–6], the application of EMF exposure assessment principles, criteria and methods relevant to various standards mobile systems specific operation are covered in Russian scientific literature fragmentary and insufficiently. For the development of previous concept [7] the worldwide experience of current and perspective mobile standards EMF control is interesting for global trends identifying and recommendation formulation of EMF hygienic assessment system at national level in Russia methodical improvement.

**Mobile base stations operation features.** Environmental EMF levels generated by different standards mobile base stations are characterized by complex spectral structure, stochastic temporal dynamics and electromagnetic energy distribution spatial heterogeneity [8]. Base station signal spectral parameters are defined by operating frequency range, radio channel bandwidth and time-frequency structure in accordance with GSM, UMTS, LTE or 5G/IMT-2020 standard specification. EMF level temporal dynamics is defined by duplex mode with frequency or time division (FDD or TDD), specified by mobile standard and base station configuration, as well as by network data traffic and active subscribers numbers in coverage zone. Spatial EMF distribution is defined by base station antenna radiation pattern, beam steering and beamforming technologies in MIMO and mMIMO systems including. These antenna technologies provide dynamic electromagnetic energy concentration in specified directions within service zone. Base station signal contains constant part (reference signals) with independent from actual network traffic load along with considered alternating components. These constant components synchronize/control signals in accordance with mobile standard specification. Thereby base station EMF levels distinctive features unlike other radio transmitting systems are complex frequency-time and spatial dynamics with constant control signals that should be taken into account in modern EMF human exposure control and assessment methods.

**Base station EMF hygienic assessment principles and criteria.** Maximal EMF levels values evaluation as worst exposure case is the main principle of EMF human exposure hygienic assessment. Theoretical maximal and actual maximal exposure levels are considered for mobile base station EMF according to international practice [9, 10].

Theoretical maximal EMF levels characterize base station operation mode under largest network traffic load and full frequency-time radio channel resource usage for maximum permissible transmission power. Such base station operation mode is critical and highly unlikely case at practice. Therefore, this mode focuses for conventional (conservative) typical EMF assessment. Theoretical maximal EMF levels may be assessed under normal base station operation mode in base of signal from base station to subscriber constant fixed power components selective measurements [8]. Hygienic assessment criteria is theoretical maximal exposure level $PD^{BS}_{max}$ determined by selective measurement results extrapolation described by general equation:

$$PD^{BS}_{max} = PD^{BS}_{ref} \cdot K^{BS}_{extr} \qquad (1)$$

where:
$PD^{BS}_{ref}$ — power density (PD) level for base station reference signal,
$PD^{BS}_{max}$ — theoretical maximal PD level from base station,
$K^{BS}_{extr}$ — extrapolation coefficient for base station configuration.

According to International Electro technical Commission standard IEC 62232-2017 [9] base station EMF assessment and constant component signals are used depending on 2–4G mobile telecommunication standards:

- frequency-selective measurements of broadcast common channel BCCH for GSM (2G) networks,
- code-selective measurements of primary common pilot channel P-CPICH for UMTS (3G) networks, reference signal RS for LTE (4G) networks [8, 11].

For 5G/IMT-2020 base station network constant component is defined by block SSB synchronization signal, specific signals of which are distinguished by code-selective measurements [12].

Extrapolation factor $K^{BS}_{extr}$ used for theoretical maximal EMF levels assessment is defined by configuration parameters of certain base station. This factor includes the set of factors, considering full maximum transmission power and mobile base station reference signal power ratio, applied TDD duplex mode, radiation patterns of reference signals and traffic signals for adaptive antennas difference, in general.

Actual maximal EMF levels determination is base station assessment alternative principle. It is based in determination of practically achievable maximal exposure with regard to stochastic nature of base station signal. Such approach is especially important for hygienic assessment of spatially heterogeneous EMF from adaptive antenna systems with dynamic directional patterns that become widespread due to 5G/IMT-2020 networks deployment [8]. Hygienic assessment criterion is $PD^{BS}_{max\_a}$ actual maximal exposure level defined by correction factor according to general equation:

$$PD^{BS}_{max\_a} = PD^{BS}_{max} \cdot K^{BS}_{stat} \qquad (2)$$

where:
$PD^{BS}_{max\_a}$ — actual maximal base station PD level,
$PD^{BS}_{max}$ — theoretical maximal base station PD level,
$K^{BS}_{stat}$ — correction factor considering base station actual maximal power reduction under base station operation its statistical distribution.

Thereby $K^{BS}_{stat}$ correction factor is applied to theoretical maximal EMF level considered as reference (base) level and determined by statistical research of actual transmission power distribution during base station operation real case[13, 14].

Approaches of 5G/IMT-2020 systems EMF hygienic assessment development trends. Technological features of 5G/IMT-2020 networks deployed parallel to current 2–4G mobile networks operation require the enhancement of new EMF sources hygienic assessment methodology. In particular, actual maximal exposure by statistical assessment becomes priority principle for complex electromagnetic environment created by adaptive antennas with beamforming and beam steering technologies. This approach is included in IEC international regulatory document [9, 10].

5G/IMT-2020 base station EMF instrumental assessment methods are regulated from 2020-2021 at nation levels in Switzerland [12], China[15] and Malaysia [16].These national instructions reveal two different approaches to theoretical maximal exposure evaluation. Whereas Switzerland [12] and Malaysia [16] methods are based in code-selective measurement of secondary synchronization SSS signals synchronization signal SSB block extrapolation, China method [15] is based in frequency-selective measurements of traffic signal from base station to subscriber. Both method types model the worst from hygienic viewpoint base station operation mode case, but this approach may lead to actual EMF exposure unreliable assessment (overestimation). So, this approaches are considered by international specialists as outdated especially for mMIMO antenna systems [17 –19]. Similar antenna type output transmission power is distributed among many antenna array elements that use for multiple synchronization and traffic beams forming in various directions. Therefore, full array radiation power concentration at one direction assumption is considered as nonrealistic from practical point of view [20, 23]. This problem solution is the subject for statistical research of correction factors determination to consider antenna radiation temporal and spatial variability, beamforming technology, scenarios of different standards base station operation in real environment and corresponding EMF exposure [8, 10].

Statistical assessment methods for base station EMF exposure in real operation scenarios consider varying active subscribers' number, their spatial distribution, connection moments and durations, etc. These methods represent actual maximal exposure approach and include theoretical [19, 21, 22] as well as instrumental [17, 23–25] survey. Maximum radiation power realistic thresholds are determined depending on base station operation conditions as result.

For example, statistical model suggested for realistic conservative assessment of mMIMO base station antennas EMF showed that actual maximum EMF level according to 95$^{th}$ percentile criterion was 7–22% of theoretical maximum level considering possible operation scenarios [19]. The results of spatial transmission channel with respect of realistic traffic configurations and subscribers' distribution within the cell three-dimensional modeling showed that mMIMO base station actual transmission power cumulative distribution function 95$^{th}$ and 99$^{th}$ percentiles were 22–26% and 27–32% of theoretical maximum respectively [22].

mMIMO antenna systems operation beamforming stochastic nature technologies study [17] was carried out in basis of EMF laboratory measurements, EMF spatial variations around laboratory mMIMO antenna setup especially were estimated at different data transfer rates and beam pattern configurations depending on subscribers' number and location.

mMIMO base stations' of 5G commercial networks (Australia) emission power levels were monitored for realistic assessment of EMF exposure [23]. 24 hours dynamic distribution of base stations' transmission power were monitored for each beam served connected users. The data were collected by means network management system based on network counters and base station operations events. The results showed that base station actual maximal emission power was lower than theoretical maximal level by 8.8 dB according to 95$^{th}$ percentile criterion. By study [24] data actual 4G networks base station (Italy) emission power levels were 20-23% of maximum. The results of similar monitoring studies for 3G networks (Sweden) showed that base stations actual radiation power levels according to average, median values and 90$^{th}$ percentile criteria were 23%, 17% and 35% of maximum power respectively [25]. At the same time, there were a strong correlation between base stations power network measurements and in-situ EMF selective measurements with 2.7% average relative error [25].

Considered methods for actual maximal EMF levels determination in relation to mobile base station hygienic assessment are developed actively abroad and seem promising as standard approach in the new edition of IEC 62232 International standard [23]. However, currently the results of statistical studies have already used in regulatory documents at national level in Switzerland, where the correction factors were introduced to consider the operation of adaptive transmitting antennas with dynamic radiation pattern for base station compliance assessment to EMF hygiene regulations. Correction factors applied to maximal transmitted antenna power based on scientific statistical studies results are regulated in range from 0.1 to 1.0 depending on antenna array size (subarrays number — antenna units). For example, for antenna arrays with number of sub-arrays of 64 or more, a correction factor defined to allow the greatest increase in transmission power-up to 10 times relative to the worst exposure conditions. The correction factors application implies the possibility of adaptive antennas in real operating conditions maximum transmission power short-term increase to fixed level. In turn the base station operator should ensure this possibility by equipping the antennas by automatic power limiter — a software that continuously monitors the total transmit antenna power within cell [26].

**Conclusion.** *The active study and implementation of actual maximal exposure concept by means of computational and instrumental methods can be noted as international trend of base station EMF hygienic assessment and control practice with 5G mobile networks of adaptive antenna technologies development. Such approach aimed to realistic exposure assessment is fundamentally new for Russian practice and its implementation will require not only methodological updating of regulatory framework, but comprehensive studies together with mobile network operators carrying out also, the tests of selective measurement results extrapolation approaches including. Accordingly, of Russian system of mobile base station EMF hygienic assessment methodical improvement requires:*

- *current and future generations mobile standard base stations EMF assessment selective measurement methods implementation;*
- *implementation of selective measurement result extrapolation approach to theoretical maximal EMF exposure assessment;*
- *development of actual base station power emission monitoring methods by means of network controllers, network operation support systems, etc.;*
- *development of actual maximal exposure assessment approach based on transmitted power distribution under base station operation in real conditions statistical studies;*
- *development of regulatory documents to interaction between sanitary and epidemiological service and base stations owners/operators ensure in EMF control framework.*

## References


1. Order of the Russian Federation Ministry of Communications No. 923 dated December 27, 2019 "On approval of the Concept of creation and development of 5G/IMT2020 networks in the Russian Federation". Available at: https://legalacts.ru/doc/prikaz-minkomsvjazi-rossii-ot-27122019-n-923-ob-utverzhdenii/ (in Russian).
2. Zaitseva N.V., Ulanova T.S., Ponomarev A.L., Molok O.A., Odegov A.A. Evaluation and substantiation of the necessity to revise guidelines for measuring electromagnetic radiation of cellular base stations. *Public Health and Life Environment — PH&LE.* 2020; 5: 29–35. https://doi.org/10.35627/2219-5238/2020-326-5-29-35 (in Russian).
3. Egorova A.M., Lutsenko L.A., Sukhova A.V., Kolyuka V.V., Turdyev R.V. Hygienic assessment of the impact of 5G/IMT-2020 communication networks on public health (literature review). *Gigiyena i sanitariya.* 2021; 100(9): 929–32. https://doi.org/10.47470/0016-9900-2021-100-9-929-932 (in Russian).
4. Nikitina V.N., Kalinina N.I., Lyashko G.G., Dubrovskaya E.N., Plekhanov V.P. Special features of the architecture of 5G networks. Probabilistic forecasting of the impact of electromagnetic fields of radio frequencies on the population (literature review). *Gigiyena i sanitariya.* 2021; 100(8): 792–6. https://doi.org/10.47470/0016-9900-2021-100-8-792-796 (in Russian).
5. Sizov D.V., Pankratov D.Y. Assessment of electromagnetic fields impact of 5G networks on humans. Telekommunikatsii i informatsionnye tekhnologii. 2021; 8(1): 13–2 (in Russian)
6. Maslov M.Yu., Spodobaev Yu.M. Convergence in norming and control of modern wireless technologies electromagnetic

fields. *Med. truda i prom. ekol.* 2020; 60(9): 610–3. https://doi.org/10.31089/1026-9428-2020-60-9-610-613 (in Russian).
7. Perov S.Yu., Belaya O.V., Balzano Q., Rubtsova N.B. The problems of mobile communication electromagnetic field exposure assessment today and tomorrow. *Med. truda i prom. ekol.* 2020; 60(9): 597–9. https://doi.org/10.31089/1026-9428-2020-60-9-597-599 (in Russian).
8. Adda S., Aureli T., D'elia S., Franci D., Grillo E., Migliore M.D. et al. A Theoretical and Experimental Investigation on the Measurement of the Electromagnetic Field Level Radiated by 5G Base Stations. *IEEE Access.* 2020; 8: 101448–63. https://doi.org/10.1109/ACCESS.2020.2998448
9. IEC 62232-2017. *Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure.* Geneva: IEC; 2017.
10. TR 62669-2019. *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.* Geneva: IEC; 2019.
11. Salahov A.Z. Assessment of human exposure to fifth-generation 5G mobile communications through experimental measurement and extrapolation of the maximum electromagnetic field strength. *Vestnik Rossijskogo novogo universiteta. Seriya slozhnye sistemy: modeli, analiz i upravlenie.* 2020; 5: 29–39. https://doi.org/10.25586/RNU.V9187.20.05.P.029 (in Russian)
12. METAS-report 154.1-2020-5218-1016. Technical Report: Measurement Method for 5G NR Base Stations up to 6 GHz. Federal Institute of Metrology METAS. Bern-Wabern. 2020: 25. Available at: https://www.metas.ch/metas/en/home/dok/publikationen/meldungen/2020-02-18.html
13. Adda S., Aureli T., Coltellacci S., D'elia S., Franci D., Grillo E. et al. A Methodology to Characterize Power Control Systems for Limiting Exposure to Electromagnetic Fields Generated by Massive MIMO Antennas. *IEEE Access.* 2020; 8: 171956–171967. https://doi.org/10.1109/ACCESS.2020.3024764
14. Franci D., Coltellacci S., Grillo E., Pavoncello S., Aureli T., Cintoli R. et al. Experimental Procedure for Fifth Generation (5G) Electromagnetic Field (EMF) Measurement and Maximum Power Extrapolation for Human Exposure Assessment. *Environments*. 2020; 7(3): 22. https://doi.org/10.3390/environments7030022
15. HJ 1151-2020. Monitoring method for electromagnetic radiation environment of 5G mobile communication base station (on trail). 2020: 16. http://www.guiyang.gov.cn/zwgk/zdlyxxgkx/sthj/hyfsaqjg/202103/P020210303363740255142.pdf
16. MCMC MTSFB TC G032:2021 Technical code. Prediction and measurement of RF RMF exposure from base station. 2021: 78. Available at: https://www.mcmc.gov.my/skmmgovmy/media/General/registers/MCMC-MTSFB-TC-G032_2021-Prediction-and-Measurement-of-RF-EMF-Exposure-from-Base-Station.pdf
17. Loh T.H., Cheadle D., Heliot F., Sunday A., Dieudonne M. A Study of Experiment-based Radio Frequency Electromagnetic Field Exposure Evidence on Stochastic Nature of A Massive MIMO System. 2021 15th European Conference on Antennas and Propagation (EuCAP). 2021: 1–5. https://doi.org/10.23919/EuCAP51087.2021.9411325
18. Stepanets I., Fokin G. Features of Massive MIMO in 5G networks. *Pervaya milya.* 2018; 1: 44–50 https://doi.org/10.22184/2070-8963.2018.70.1.46.52 (in Russian).
19. Thors B., Furuskär A., Colombi D., Törnevik C. Time-averaged realistic maximum power levels for the assessment of radio frequency exposure for 5G radio base stations using massive MIMO. *IEEE Access.* 2017; 5: 19711–19. https://doi.org/10.1109/ACCESS.2017.2753459
20. Chiaraviglio L., Lodovisi C., Franci D., Grillo E., Pavoncello S., Aureli T. et al. What is the Impact of 5G Towers on the Exposure over Children, Teenagers and Sensitive Buildings? *arXiv preprint.* 2022: arXiv:2201.06944. https://doi.org/https://doi.org/10.48550/arXiv.2201.06944
21. Xu B., Anguiano Sanjurjo D., Colombi D. Törnevik C. A Monte Carlo Analysis of Actual Maximum Exposure From a 5G Millimeter-Wave Base Station Antenna for EMF Compliance Assessments. *Frontiers in Public Health.* 2022; 9: 777759. https://doi.org/10.3389/fpubh.2021.777759
22. Baracca P., Weber A., Wild T., Grangeat C. A Statistical Approach for RF Exposure Compliance Boundary Assessment in Massive MIMO Systems. In: *WSA 2018; 22nd International ITG Workshop on Smart Antennas.* 2018: 1–6.
23. Colombi D., Joshi P., Xu B., Ghasemifard F., Narasaraju V., Törnevik C. Analysis of the Actual Power and EMF Exposure from Base Stations in a Commercial 5G Network. *Applied Sciences.* 2020; 10(15): 5280. https://doi.org/10.3390/app10155280
24. Persia S., Carciofi C., D'Elia S., Suman R. EMF evaluations for future networks based on Massive MIMO. In: *2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC).* 2018: 1197–202. https://doi.org/10.1109/PIMRC.2018.8580893
25. Colombi D., Thors B., Persson T., Wirén N., Larsson L.E., Jonsson M. et al. Downlink power distributions for 2G and 3G mobile communication networks. Radiat Prot Dosimetry. 2013; 157(4): 477–87. https://doi.org/10.1093/rpd/nct169
26. Erläuterungen zur Änderung der Verordnung über den Schutz vor nichtionisierender Strahlung (NISV) 17. Dezember 2021: 10. https://www.newsd.admin.ch/newsd/message/attachments/69619.pdf