



<http://dx.doi.org/10.35596/1729-7648-2020-18-4-96-112>

Оригинальная статья
Original paper

УДК 621.396.218:614.89.086.5

ЭЛЕКТРОМАГНИТНОЕ РАДИОЧАСТОТНОЕ ЗАГРЯЗНЕНИЕ МОЖЕТ ВЛИЯТЬ НА УРОВЕНЬ СМЕРТНОСТИ ОТ COVID-19. 4G/5G/6G МОГУТ БЫТЬ БЕЗОПАСНЫМИ ДЛЯ ЛЮДЕЙ

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Поступила в редакцию 15 июня 2020

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Аннотация. Охватившая весь земной шар пандемия коронавируса COVID-19 явилась причиной смерти сотен тысяч людей и глубоких кризисных явлений в мировой экономике. В работе приводится косвенное подтверждение гипотезы, что, наряду с другими факторами, на уровень смертности населения от коронавирусной инфекции оказывает влияние уровень электромагнитного загрязнения среды обитания. Гипотеза подтверждается наличием корреляции между степенью жесткости гигиенического нормирования уровней радиочастотного электромагнитного фона для населения, главным источником которого являются системы мобильной (сотовой) связи, и уровнем смертности от COVID-19 в различных странах. Эта связь крайне опасна, поскольку реализация существующих планов очень быстрого развития технологий, систем и услуг мобильной связи четвертого (4G) и пятого (5G), а к 2030 году и шестого (6G) поколения, связанного с увеличением на много порядков числа излучающих устройств, скорости передачи данных по радиочастотным каналам и территориальной плотности трафика мобильной связи без принятия специальных мер в самое ближайшее время может вызвать значительный (на 1–2 порядка и более) рост интенсивности электромагнитного фона, создаваемого базовым и абонентским оборудованием мобильной связи. Для количественного анализа этих процессов разработана и верифицирована с использованием результатов многочисленных измерений электромагнитного фона в различных странах практическая методика пессимистической оценки уровня электромагнитного фона, создаваемого этими системами, основные положения которой излагаются в данной работе. Данная методика основана на использовании интегральных системных характеристик беспроводного информационного обслуживания общества и позволяет обосновать необходимые системные, технические и организационные решения, направленные на обеспечение необходимого уровня электромагнитной экологии населенных территорий и электромагнитной безопасности населения в условиях быстрого развития систем 4G/5G/6G без ущерба информационному обслуживанию населения и информационным технологиям в экономике, образовании, здравоохранении и других областях.

Ключевые слова: COVID-19, электромагнитное загрязнение, нормы, корреляция сотовая связь, 4G, 5G, 6G, электромагнитная экология, электромагнитная безопасность.

Конфликт интересов. Автор заявляет об отсутствии конфликта интересов.

Для цитирования. Мордачев В.И. Радиочастотное электромагнитное загрязнение может влиять на уровень смертности от COVID-19. 4G/5G/6G могут быть безопасными для людей. Доклады БГУИР. 2020; 18(4): 96-112.

COVID-19 LETHALITY RATE MAY BE AFFECTED BY ELECTROMAGNETIC RADIO FREQUENCY POLLUTION. 4G/5G/6G CAN BE SAFE FOR PEOPLE

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Submitted 15 June 2020

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Abstract. The COVID-19 pandemic, spanning the globe, caused the death of hundreds of thousands of people and crisis in global economy. I found confirmation of the hypothesis that the level of environmental electromagnetic pollution affects the lethality rate of a population from COVID-19. I found a correlation between the degree of severity of hygienic regulation of levels of radio frequency electromagnetic fields for population, the main sources of which are mobile (cellular) communication systems, and the lethality rate from COVID-19 in various countries. The existence of such a correlation is extremely dangerous, because the implementation of well-known road maps for very fast development of technologies, systems and services of the fourth (4G), fifth (5G) and sixth (6G) generations of mobile communications associated with the increase in the number of radiating devices, data rates in radio frequency channels and area traffic capacity of mobile communications by many orders of magnitude, according to my estimates, can cause a high (1–2 orders or more) increase in the intensity of electromagnetic background created by mobile communications. For a quantitative analysis of these processes, I developed a presented herein a practical technique for worst-case estimation of the level of electromagnetic background created by these systems; it is verified using the published results of measurements of electromagnetic background in various countries. This technique is based on the use of the integrated system characteristics of wireless information services and makes it possible to justify the necessary system, technical and managerial solutions aimed at ensuring the necessary level of electromagnetic ecology of populous areas and electromagnetic safety of people in conditions of rapid advancement of 4G/5G/6G systems without affecting the quality of informational support of the population and information technologies in economy, education, healthcare and other sectors.

Keywords: COVID-19, electromagnetic pollution, regulations, correlation, mobile communications, 4G, 5G, 6G, electromagnetic ecology, electromagnetic safety.

Conflict of interests. The author declares no conflict of interests.

For citation. Mordachev V.I. COVID-19 lethality rate may be affected by electromagnetic radio frequency pollution. 4G/5G/6G can be safe for people. Doklady BGUIR. 2020; 18(4): 96-112.

Relevance of the Problem

Due to the extremely intensive development of wireless technologies and systems of public information services and their deep penetration into all areas of human activity, the electromagnetic (EM) pollution associated with these processes is becoming an increasingly threatening anthropogenic factor. Its danger, as a rule, is underestimated, and in the coming years may turn out to be commensurate with the danger of the known processes of global warming and environmental degradation.

Numerous measurements of the levels of electromagnetic background (EMB) generated by cellular communications (CC) in places with different population density in 2005-2019 [1–11, etc.] indicate that CC radio networks of the second (GSM, IS-95) and the third (UMTS, CDMA2000) generations, which provided the bulk of mobile telephony services and a relatively small volume of mobile Internet services during measurement periods, as a whole, posed no danger for the population. In the places where these measurements were carried out, the area density of sources of radio frequency EM radiation did not exceed 10^3 – 10^4 devices/km², the area traffic capacity (ATC) did not exceed 0.1–1.0 kbit/s/m² at data rates on the radio channels of user's interface no higher than 0.032–2.0 Mbit/s. As a result, the intensity of EM background created by these sources was

no more than a few $\mu\text{W}/\text{cm}^2$ in the overwhelming majority of cases, not exceeding the level of $9.5\text{--}10 \mu\text{W}/\text{cm}^2$, defined in many countries (Azerbaijan, Belarus, Bulgaria (short-term), Canada (Toronto), Chile (sensitive), France (Paris), Hungary, Italy (general), Kazakhstan, Lithuania, Poland, Russia, Switzerland, Ukraine, etc.) [12] as the maximum permissible level (MPL) of EM background intensity for population.

In the early periods of CC development (first and second generations of CC), when the main type of service was mobile telephony, uplink and downlink traffic rates (the amount of information transmitted from mobile (MS) to the base (BS) station and vice-versa) were symmetrical, it was supposed that the main hazard to health is brought about by EM radiation of CC MS, since the mobile phone is located near the human body, and voluntary environmental risks during the CC operation are predominant.

However, as a result of the subsequent evolution of CC in the direction of intensive development of data transmission technologies and services (mobile Internet, interactive broadcasting, etc.), the situation has changed quite significantly, giving the room for the following to take place:

- a constant decrease in the average range of cellular radio-telephone communications with a corresponding decrease in the average power of MS EM radiation in this mode and an attendant decrease in voluntary environmental risks due to the fast development of the CC radio network infrastructure and the increasing use of indoor hotspots, urban micro-cells, etc. [13];
- a constantly increasing asymmetry of downlink and uplink traffic rates, the ratio of capacities of information transmitted from BS to MS and in the opposite direction reaches $10\text{--}100$ [14] with a corresponding change in the ratio of EM energy radiated by sets of BS and MS;
- as a result, the environmental risks caused by the increased intensity of EM background created by CC, come to the fore and become predominant.

The observed dynamic evolution of CC generations from 2G (GSM, IS-95) and 3G (UMTS, CDMA2000) to the 4G (LTE) [13–15], and then to the upcoming 5G [16–18] and 6G [19, 20] is an inevitable process, due to the highest efficiency of digital mobile communication systems in almost all areas of human activity and the extreme attractiveness of a wide range of wireless information services.

Let us consider the summary data of Table 1, characterizing the planned growth of six main system parameters of wireless information services in near future. An increase in the values of parameters No. 1, 2, 3, 4 is associated with a proportional increase in the power of EM radiations of BS and MS of CC, and an increase in the values of parameters No. 5, 6 provides a proportional decrease in this power. Moreover, the aforementioned parameters experience an increase for the following reasons:

- the expected cumulative increase in parameters No. 1, 2, 3, 4 is at least $\approx 10^4$ times for $4\text{G} \rightarrow 5\text{G}$ evolution, and the same $\approx 10^4$ times for $5\text{G} \rightarrow 6\text{G}$ evolution (in total about 8 orders of magnitude for $4\text{G} \rightarrow 6\text{G}$ evolution), and
- the expected total increase in parameters No. 5, 6 is only $\approx 30\text{--}300$ times for $4\text{G} \rightarrow 5\text{G}$ evolution, and $50\text{--}1000$ times for $5\text{G} \rightarrow 6\text{G}$ evolution (in total no more than 3–4 orders of magnitude for $4\text{G} \rightarrow 6\text{G}$ evolution taking into account the uncertainty of estimates [16–20]), the declared development of mobile communications from 4G to 5G and further to 6G using traditional approaches can cause a sharp (by several orders of magnitude!) increase in the intensity of EM background created by CC in places with a high population density, and a corresponding sharp degradation of the environmental EM ecology, and, in general, an unacceptable reduction of public EM safety.

On the one hand, such prospects are a cause of growing concern about the health and well-being of population, which may result in local government-level decisions that restrict the use of wireless services in critical places, such as decisions [21–23] adopted in Switzerland and France in order to limit the use of wireless solutions and services in buildings and in public transport.

Table 1. Summary data characterizing the planned evolution of the system parameters of mobile communication networks, according to [15–20]

Таблица 1. Сводные данные, характеризующие планируемую эволюцию системных параметров сетей мобильной связи, по данным [15–20]

System parameters Системные параметры	Generation of mobile (cellular) communications Поколение мобильной (сотовой) связи			Total increase in evolution 4G→6G Суммарный рост при эволюции 4G→6G
	4G	5G	6G	
1. Peak data rate	100 Mb/s	10–20 Gb/s	≥1 Tb/s	≈10 ⁴ times
2. Experienced data rate	10 Mb/s	0.1 Gb/s	1–10 Gb/s	≈10 ² times
3. Area traffic capacity	0.1 Mb/s/m ²	10 Mb/s/m ²	1 Gb/s/m ²	≈10 ⁴ times
4. Connectivity density (density of radiating MS)	0.1 Devices/m ²	1.0 Devices/m ²	10 Devices/m ²	≈10 ² times
5. Spectrum efficiency	1 ^x	3 ^x that of 4G	(5–10) ^x that of 5G	≈15–30 times
6. Network energy efficiency	1 (relative base level)	10–100 times increase compared to 4G	10–100 times increase compared to 5G	≈10 ² –10 ⁴ times

On the other hand, there is a noticeable worry that such local government decisions, as well as growing radio phobia of population, can impede the CC development on a scale and pace [16–20]. Apparently, this was the reason for the emergence of the latest corporate recommendations ICNIRP [24], declaring the safety of 5G systems and services at levels of radio frequency EM background that 100 times or more higher than the MPL of EM background accepted in many countries.

It should be noted that these recommendations, taking into account only the thermal effect of radio frequency EM fields on human body, determining upper boundary of the range of their supposedly safe intensity at a level of 10 W/m² (1000 μW/cm²) and above, and allowing them to heat the human upperparts to 2 degrees and some parts of the body up to 5 degrees in 6 minutes, are extremely optimistic from the point of view of EM safety of the population. They have a pronounced corporate character, do not take into account various non-thermal effects of exposure to radio-frequency EM fields [25–36, etc.] and, apparently, can only illustrate the boundaries between the non-fatal and fatal effects of radio-frequency EM fields on human body.

Such levels of EM exposure actually correspond to the modes of gentle defrosting of food products in a microwave oven and, in the author’s deep assurance, cannot be considered as acceptable for the whole population.

The author is sure that MPL values of EM fields of the order of 2.5–10 μW/cm² (0.025–0.1 W/m²), accepted in many countries as a result of in-depth scientific research and many years of analysis of the health of separate population groups subjected to forced or voluntary exposure to radio-frequency EM fields, and reflecting the real danger of non-thermal effects of exposure to these fields on the human body, are more adequate to the required degree of protection of the population from EM background created by modern and future CC systems.

These effects, in particular, are associated with impairing of nervous and mental activity [26–30], decreasing of reproductive function in both men and women [31, 32], and an appreciable increase in DNA damage [32], impairing of heart rhythm and peripheral arterial pressure [33, 34], suppression of the immune system [35, 36], when exposed to radio frequency EM fields with levels significantly lower than those recommended in [24]; finally, by a WHO decision [37], radio-frequency EM fields are classified as a potentially carcinogenic hazard.

Correlation between EM environmental pollution and harm to population by COVID-19

Quite numerous publications, such as [25–37], make us take a fresh look at the causes of a rather uneven harm to population by the COVID-19 in different countries. In conditions of complete “multilayer” area coverage (i. e. coverage by several radio networks of various operators) with mobile communications, the effect of the adopted restrictions on MPL of radio frequency EM fields on the population’s exposure to infections like COVID-19 is apparently inevitable.

Although a large number of other factors (the degree of general environmental pollution, food quality, climate features, epidemic phase, timeliness and effectiveness of restrictive measures taken, etc.) affects public health and susceptibility of the population to infections, and also data of different countries on morbidity and lethality have a different degree of reliability and reflect the different effectiveness of national health systems in struggle with COVID-19, today one cannot fail to see the area correlation between the use of recommendations [24] and the distribution of lethality from COVID-19.

In particular, an analysis of WHO reports [38–40] indicates that in a group of countries where, according to data [12], hygienic restrictions on radio frequency EM fields of 1–10 $\mu\text{W}/\text{cm}^2$ are accepted, the relative level of lethality from COVID-19 is (1–5) % of the number of the infected, and in a group of countries where the hygienic regulation of EMB is carried out in accordance with corporate recommendations [24], this level is (5–20) %.

Tables 2 and 3 shows the results of a correlation analysis of the relationship between the degree of severity of hygienic regulation of levels of radio frequency EM background for the population in different countries according to data [12] and the lethality rate from COVID-19 in relation to the number of people infected according to [38–40].

The data in Table 2 were obtained for the first version of definition of the relative lethality rate from COVID-19 as the ratio of the total number of deaths to the total number of the infected, and the data in Table 3 correspond to the second version of its definition as the ratio of the number of deaths to the country's population in millions of people.

In this analysis, the representativeness of the samples is ensured by quota sampling – ensuring approximately equal representation of data from countries of both groups; the limited sample size is caused by the lack of more complete data on hygienic regulation of EMF in the countries listed in [38–40].

When determining the relative lethality rate as the ratio of the number of deaths to the total number of the infected, the Pearson's correlation coefficient for the three different correlated samples turned out to be 0.551–0.552. When determining the relative lethality rate as the ratio of the number of deaths to the total country population, the Pearson's correlation coefficient for these samples was even higher, i.e 0.577–0.6. This convincingly confirms the existence of a correlation between the factors under consideration.

The detected correlation is quite stable - its multivariate analysis when varying MPL values for countries where MPL value pairs are used (for Bulgaria (“long-term”/“short-term”) and Chile (“sensitive”/“others”), which differ by 10 times), as well as when trying correction of lethality for some countries suspected of distorting medical statistics, indicates that in all cases the resulting Pearson's correlation coefficient turned out to be no lower than 0.45–0.55.

Of course, the hygienic regulation of MPL radio frequency EMB in accordance with [24], or the absence of such regulation in a number of countries does not mean the mandatory presence of high levels of environmental EM pollution by CC systems.

However, taking into account the extremely high cost of the existence of a relation between the degree of environmental EM pollution and the degree of population susceptibility to similar viral infections, the presence of a relationship between the average levels of radio frequency EM background created by CC systems and the lethality rate from COVID-19 requires the most serious further research and verification.

And if the correlation between the average levels of EM background created by CC systems and the injury of population by COVID-19 will be confirmed by further in-depth studies (which is quite probable, taking into account a very large difference between the “thermal” and “non-thermal” MPL of radio frequency EM fields), this may serve as an objective motivation for the following:

- for much closer attention to the problem of EM pollution of populous areas and, in particular, a more objective critical attitude to corporate declarations like [24], and
- for making decisions similar to [21–23] at the national or regional levels, as well as for searching for reasonable system and technological alternatives to a number of declared directions for the extremely rapid development of 4G/5G/6G systems and for the upcoming extremely deep penetration of wireless technologies and services in all areas of human activities, without prejudice to progress in the field of information technology and public, industrial, educational and other information services.

The fundamental difficulties in justification of such decisions, system and technological alternatives are caused by the lack of adequate practical methods for predicting and evaluating the expected levels of EM background at different stages of the development and implementation of 4G/5G/6G systems and services, since the direct calculation of the total background intensity created by a huge number of stationary (BS) and mobile (MS) sources of EM radiation, is impossible both because of the extreme complexity of this mission, and due to significant a priori uncertainty and confidentiality of the source data.

Table 2. Results of the analysis of a correlation between the degree of severity of hygienic regulations of levels of radio frequency EM background for the population in different countries according to data [12], and the relative lethality rate from COVID-19, defined as the ratio of the number of deaths to the total number of the infected, according to [38–40]

Таблица 2. Результаты анализа корреляции между степенью жесткости гигиенического нормирования уровней радиочастотного электромагнитного фона для населения в различных странах, по данным [12], и относительным уровнем смертности от COVID-19, определяемым как отношение числа умерших к общему числу заразившихся, по данным [38–40]

Country	MPL, W/m ²	The ratio of the total number of deaths to the total number of infected					
		04.05.2020 WHO Rep. 105	%	11.05.2020 WHO Rep. 112	%	18.05.2020 WHO Rep. 119	%
Страна	ПДУ, Вт/м ²	Отношение числа умерших к общему числу заразившихся					
		04.05.2020 WHO Rep. 105	%	11.05.2020 WHO Rep. 112	%	18.05.2020 WHO Rep. 119	%
1. Azerbaijan	0.1	25/1932	1.29	32/2519	1.27	39/3274	1.19
2. Belarus	0.1	103/17489	0.59	135/23906	0.56	165/29650	0.56
3. Belgium	10	7844/49906	15.72	8656/53081	16.31	9052/55280	16.37
4. Bulgaria ¹⁾	0.01	73/1618	4.51	91/1965	4.63	110/2235	4.92
5. Canada	4	3681/59365	6.20	4728/67996	6.95	5702/76204	7.48
6. Chile ¹⁾	0.1	260/19663	1.32	312/28866	1.08	450/43781	1.03
7. China	0.4	4643/84400	5.50	4643/84450	5.50	4645/84494	5.50
8. Denmark	10	484/9523	5.08	529/10429	5.07	547/10927	5.01
9. France	10	24859/129708	19.17	26338/137073	19.21	28059/140036	20.04
10. Germany	10	6692/163175	4.10	7417/169575	4.37	7935/174697	4.54
11. UK	10	28446/186603	15.24	31855/219187	14.53	34636/243699	14.21
12. Hungary	0.1	351/3035	11.57	421/3284	12.82	462/3535	13.07
13. India	0.9	1373/42533	3.23	2206/67152	3.29	3029/96169	3.15
14. Ireland	10	1303/21506	6.06	1458/22996	6.34	1543/24112	6.40
15. Israel	0.9	227/16152	1.41	254/16492	1.54	271/16607	1.63
16. Italy	0.1	28884/210717	13.71	30560/219070	13.95	31908/225435	14.15
17. Japan	10	510/15057	3.39	621/15798	3.93	749/16305	4.59
18. Kazakhstan	0.1	27/3988	0.68	31/5138	0.60	34/6440	0.53
19. Lithuania;	0.1	46/1410	3.26	50/1479	3.38	56/1541	3.63
20. Luxembourg	0.45	96/3824	2.51	101/3886	2.60	107/3945	2.71
21. Netherlands	10	5056/40571	12.46	5440/42627	12.76	5680/43995	12.91
22. Poland	0.1	678/13693	4.95	800/15996	5.00	925/18529	5.00
23. Portugal	10	1043/25282	4.13	1135/27581	4.12	1218/29036	4.19
24. Russia;	0.1	1356/145268	0.93	2009/221344	0.91	2722/290678	0.94
25. Spain	10	25264/217466	11.62	26621/224390	11.86	27650/231350	11.95
26. Sweden;	10	2679/22317	12.00	3225/26322	12.25	3679/30143	12.21
27. Switzerland	0.1	1472/29822	4.94	1537/30222	5.09	1602/30504	5.25
28. Turkey	0.56	3397/126045	2.70	3786/138657	2.73	4140/149435	2.77
29. Ukraine	0.1	303/12331	2.48	408/15648	2.61	535/18616	2.87
30. USA	10	60710/1125719	5.39	76916/1271645	6.05	87180/1432265	6.09
31. Uzbekistan	0.025	10/2160	0.46	10/2411	0.41	12/2762	0.43
Pearson's correlation coefficient:			0.551		0.552		0.551

¹⁾ The lower limit of the range of normalized values.

Table 3. Results of the analysis of a correlation between the degree of severity of hygienic regulations of levels of radio frequency EM background for the population in different countries according to data [12], and the relative lethality rate from COVID-19, defined as the ratio of the number of deaths according to [38–40], to the total country population in millions of people ¹⁾

Таблица 3. Результаты анализа корреляции между степенью жесткости гигиенического нормирования уровней радиочастотного электромагнитного фона для населения в различных странах, по данным [12], и относительным уровнем смертности от COVID-19, определяемым как отношение числа умерших, по данным [38–40], к общей численности населения в миллионах чел. ¹⁾

Country	MPL, W/m ²	The ratio of the total number of deaths to the country population					
		04.05.2020 WHO Rep. 105	Total	11.05.2020 WHO Rep. 112	Total	18.05.2020 WHO Rep. 119	Total
Страна	ПДУ, Вт/м ²	Отношение числа умерших к общей численности населения					
		04.05.2020 WHO Rep. 105	Всего	11.05.2020 WHO Rep. 112	Всего	18.05.2020 WHO Rep. 119	Всего
1. Azerbaijan	0.1	25/10.139	2.47	32/10.139	3.16	39/10.139	3.85
2. Belarus	0.1	103/9.449	10.9	135/9.449	14.3	165/9.449	17.5
3. Belgium	10	7844/11.590	677	8656/11.590	747	9052/11.590	781
4. Bulgaria ²⁾	0.01	73/6.948	10.5	91/6.948	13.1	110/6.948	15.8
5. Canada	4	3681/37.742	97.5	4728/37.742	125	5702/37.742	151
6. Chile ²⁾	0.1	260/19.116	13.6	312/19.116	16.3	450/19.116	23.5
7. China	0.4	4643/1439.324	3.23	4643/1439.324	3.23	4645/1439.324	3.23
8. Denmark	10	484/5.792	83.6	529/5.792	91.3	547/5.792	94.4
9. France	10	24859/65.274	381	26338/65.274	403	28059/65.274	430
10. Germany	10	6692/83.784	79.9	7417/83.784	88.5	7935/83.784	94.7
11. UK	10	28446/67.886	419	31855/67.886	469	34636/67.886	510
12. Hungary	0.1	351/9.660	36.3	421/9.660	43.6	462/9.660	47.8
13. India	0.9	1373/1380.004	0.995	2206/1380.004	1.60	3029/1380.004	2.19
14. Ireland	10	1303/4.938	264	1458/4.938	295	1543/4.938	312
15. Israel	0.9	227/8.656	26.2	254/8.656	29.3	271/8.656	31.3
16. Italy	0.1	28884/60.462	478	30560/60.462	505	31908/60.462	528
17. Japan	10	510/126.76	4.03	621/126.476	4.91	749/126.476	5.92
18. Kazakhstan	0.1	27/18.777	1.44	31/18.777	1.65	34/18.777	1.81
19. Lithuania	0.1	46/2.722	16.9	50/2.722	18.4	56/2.722	20.6
20. Luxemburg	0.45	96/0.626	153	101/0.626	161	107/0.626	171
21. Netherlands	10	5056/17.135	295	5440/17.135	317	5680/17.135	331
22. Poland	0.1	678/37.847	17.9	800/37.847	21.1	925/37.847	24.4
23. Portugal	10	1043/10.197	102	1135/10.197	111	1218/10.197	119
24. Russia;	0.1	1356/146.796	9.24	2009/146.796	13.7	2722/146.796	18.5
25. Spain	10	25264/46.755	540	26621/46.755	569	27650/46.755	591
26. Sweden;	10	2679/10.099	265	3225/10.099	319	3679/10.099	364
27. Switzerland	0.1	1472/8.655	170	1537/8.655	178	1602/8.655	185
28. Turkey	0.56	3397/84.339	40.3	3786/84.339	44.9	4140/84.339	49.1
29. Ukraine	0.1	303/42.156	7.19	408/42.156	9.68	535/42.156	12.7
30. USA	10	60710/331.003	183	76916/331.003	232	87180/331.003	263
31. Uzbekistan	0.025	10/33.469	0.299	10/33.469	0.299	12/33.469	0.359
Pearson's correlation coefficient:			0.577		0.593		0.60

¹⁾ Country population is given according to <https://www.worldometers.info/world-population/>
²⁾ The lower limit of the range of normalized values.

These difficulties can be effectively overcome by using my technique [41–51] of worst-case system analysis of EM background created by CC, which allows to perform the pessimistic estimation of EM background average intensity near the ground surface with the use of integral system CC parameters, given in Table 1.

The adequacy of this technique is confirmed by its verification [49, 52] using a numerous results [1–11] of measurements of EM background created by 2G/3G CC in many countries.

Technique of worst-case system analysis of EM background created by CC

This technique offers a number of useful expressions and procedures for worst-case estimation of the average level of EMB created by radio frequency EM fields that are generated by sets of BS and/or MS of CC at the observation point (OP) at a height of $H_{OP} = 1 \dots 2$ m near the earth's surface (Fig. 1, 2).

In accordance with this technique, the total EM background intensity Z_{Σ} [W/m²] in OP means the scalar sum of values of power flux densities Z_n of EM fields created by N sources of these fields located in an area of radio visibility of these sources from the OP:

$$Z_{\Sigma} = \sum_{n=1}^N Z_n. \quad (1)$$

EM background Intensity created by BS of CC

The average total intensity $Z_{\Sigma BS}$ [W/m²] of EM background created in OP near the ground surface by a set of BS located randomly uniformly (with respect to the OP position) in the area of BS radio visibility from the OP, is determined by the following expression [44, 46, 47]:

$$Z_{\Sigma BS} = Z_{\Sigma BS1} + Z_{\Sigma BS2} = \frac{B_{BS}}{2} \ln \left(\frac{4H_{OP}\sqrt{e}}{\lambda} \right) \approx \frac{B_{BS}}{2} \ln \left(\frac{6.6 \cdot H_{OP}}{\lambda} \right), \quad H_{OP} \geq \frac{\lambda}{4}, \quad (2)$$

$$Z_{\Sigma BS1} = \frac{B_{BS}}{2} \ln \left(\frac{4H_{OP}}{\lambda} \right), \quad Z_{\Sigma BS2} = \frac{B_{BS}}{4}, \quad (3)$$

where λ is the wavelength of BS radiation, B_{BS} [W/m²] is the average specific electromagnetic loading on area (SEMLA) created by BS in the considered area.

The SEMLA B_{BS} [W/m²] created by the set of K BS which are EMR sources, distributed over the area S , is defined as a sum of covering total radiated powers P_{ek} of these BS per unit area:

$$B_{BS} = \frac{\sum_{k=1}^K P_{ek}}{S}, \quad P_{ek} \approx Q_k P_{EIRPk}, \quad (4)$$

where P_{EIRPk} is the equivalent isotropic radiated power (EIRP) of k -th BS in the main lobe of its antenna; $Q_k = P_{ARK}/P_{EIRPk} \leq 1$ is the system parameter of EMR directivity of k -th BS; in this ratio P_{ARK} and P_{EIRPk} are the values of this BS average total radiating power which reaches an observation area by the real BS antenna with horizontal and vertical selectivity, and by the ideal isotropic antenna with the same antenna gain, correspondingly. In particular, if CC radio network is regular with N_S sectors on each BS, then for worst-case estimations $Q_k \approx 1/N_S$ can be used. For separate k -th BS with a sector antenna with $\Delta\alpha_k$ [rad] of main beam width that is usually inclined 5–10 degrees to the earth's surface, it is possible to use $Q_k \approx \Delta\alpha_k/2\pi$.

The average EMB intensity (2) created by BS consists of two components (3): frequency dependent component $Z_{\Sigma BS1}$ corresponds to the contribution of BS located in the OP vicinity of free-space radio waves propagation (RWP) between BS and OP (breakpoint vicinity [53]), and frequency independent component $Z_{\Sigma BS2}$ corresponds to the contribution of BS located outside the breakpoint vicinity in the area of interference (multipath) RWP.

In cases when sources with the same EIRP P_e [W] of non-directional EM radiation are distributed over the area uniformly with average density ρ , the average SEMLA created by these sources, will be $B = \rho P_e$. The latter, in particular, can be used when evaluating the SEMLA created by MS, and also by BS in CC networks of a regular cellular structure.

Estimates (2) significantly depend on the wavelength λ . Taking into account the relative narrowness of the frequency bands allocated for EM radiation of BS of CC (the ratio of the width of the allocated frequency band to the value of its left border is 2.7 % for GSM-900, 4.2 % for GSM-1800, 2.8 % for UMTS, less than 5 % for each of the LTE frequency bands [15]), these estimates using (2) for each frequency band, can be performed for a fixed value of λ corresponding

to its middle. As a result, the total average intensity $Z_{\Sigma BS}$ of EM background generated by the set of BS of all J frequency bands allocated for the BS EM radiation, can be determined in an obvious way:

$$Z_{\Sigma BS} = \sum_{j=1}^J Z_{\Sigma BSj} = \sum_{j=1}^J \frac{B_{BSj}}{2} \ln \left(\frac{4H_{OP}\sqrt{e}}{\lambda_j} \right), \quad H_{OP} \geq \max \left\{ \frac{\lambda_1}{4}, \frac{\lambda_2}{4}, \dots, \frac{\lambda_J}{4} \right\}, \quad (5)$$

where $Z_{\Sigma BSj}$ is the total average EM background intensity, created in OP at a height H_{OP} above the Earth's surface by the set of BS radiating in the relatively narrow j -th frequency band, for which the wavelength of BS radiation is taken equal to λ_j .

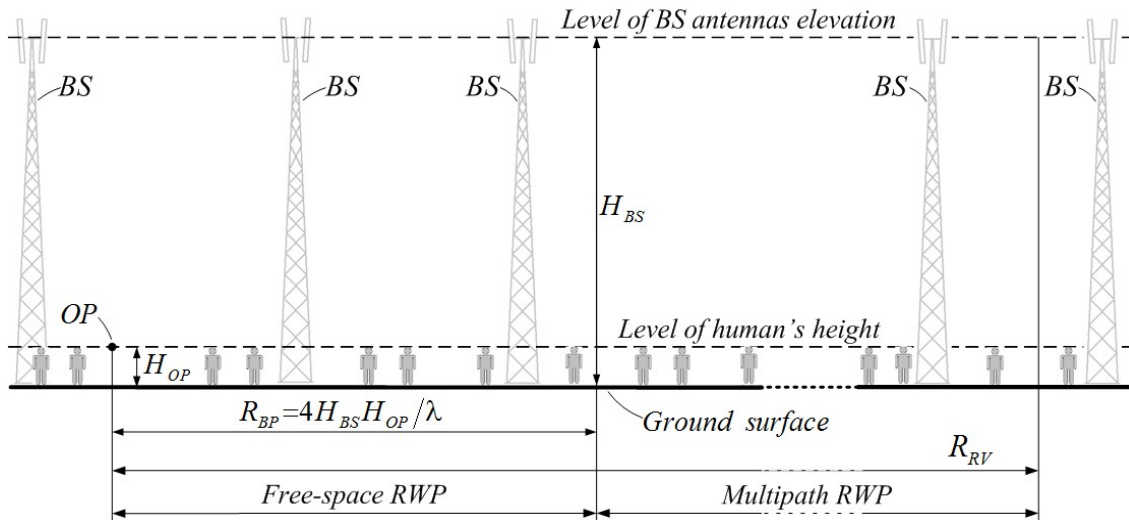


Fig. 1. Mutual terrestrial distribution of observation point (OP) and BS. Height of BS antennas above the surface $H_{BS} \geq 10$ m is significantly higher than the height $H_{OP} = 1 \dots 2$ m of the OP above the Earth's surface. Boundary between regions of free and of interference RWP corresponds to the radius of the OP "breakpoint" vicinity $R_{BP} = 4H_{BS}H_{OP}/\lambda$

Рис. 1. Взаимное территориальное размещение точки наблюдения (OP) и базовых станций (BS). Высота антенн BS над поверхностью $H_{BS} \geq 10$ м значительно превышает высоту $H_{OP} = 1 \dots 2$ м OP над земной поверхностью. Граница между областями свободного и интерференционного распространения радиоволн (RWP) соответствует радиусу «брейкпойнт»-окрестности OP $R_{BP} = 4H_{BS}H_{OP}/\lambda$

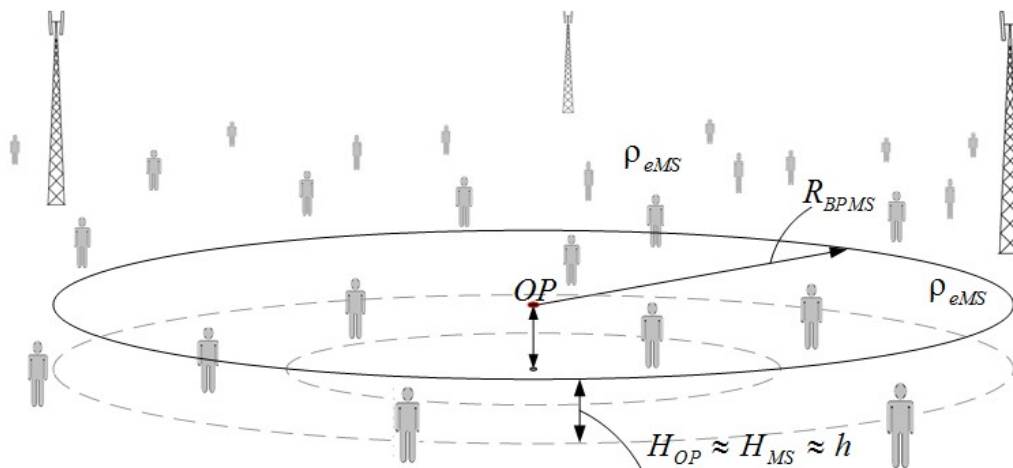


Fig. 2. Mutual terrestrial distribution of OP and subscribers with radiating MS. Elevation H_{MS} of MS and elevation of OP H_{OP} above the Earth's surface is assumed to be equal roughly: $H_{OP} \approx H_{MS} \approx h$. In this figure $R_{BPMS} = 4h^2/\lambda$ is the radius of region of free-space RWP between MS and OP

Рис. 2. Взаимное территориальное размещение OP и пользователей с излучающими мобильными станциями (MS). Высоты MS H_{MS} и OP H_{OP} над земной поверхностью приняты примерно одинаковыми: $H_{OP} \approx H_{MS} \approx h$. На этом рисунке $R_{BPMS} = 4h^2/\lambda$ – радиус области свободного RWP между MS и OP

EM background Intensity created by MS of CC

The average total intensity of EM background $Z_{\Sigma MS}$ [W/m²] created in OP by a set of radiating MS located at a height $H_{MS} \approx H_{OP} \approx h$ above the Earth's surface randomly uniformly in area of MS radio visibility from the OP, is determined by the following expression [45, 48]:

$$Z_{\Sigma MS} = Z_{\Sigma MS1} + Z_{\Sigma MS2} \approx B_{MS} \ln\left(\frac{6.44 \cdot h}{\lambda}\right), \quad h \geq \frac{\lambda}{2\sqrt{2\pi}}, \quad (6)$$

$$Z_{\Sigma MS1} = \frac{B_{MS}}{2} \ln\left(\frac{8\pi h^2}{\lambda^2}\right), \quad Z_{\Sigma MS2} = \frac{B_{MS}}{4}, \quad (7)$$

where λ is the wavelength of MS radiation, B_{MS} [W/m²] is the average SEMLA created by radiating MS in the area of MS radio visibility (at least, in the OP vicinity). In (6), (7) the presence of a MS reactive near-field zone (absence of radiation at distances $R \leq \lambda/2\pi$) was taken into account.

The average SEMLA B_{MS} created by MS is defined by the average terrestrial density ρ_{eMS} [devices/m²] of radiating MS in the considered area, and by the average EIRP P_{eMS} [W] of these MS: $B_{MS} = \rho_{eMS} P_{eMS}$. The ρ_{eMS} value is determined by the total area density of MS (radiating and non-radiating) ρ_{MS} and by the specific traffic intensity G_{MS} [Erl] (the probability of the MS being in the radiation mode): $\rho_{eMS} = \rho_{MS} G_{MS}$. For CC phones, $G_{MS} = 0.08-0.1$ Erl can be reached during business-hours [14, 10, 54]. The P_{eMS} value can be taken equal to 30–50 % of the maximum power P_{MSmax} of MS radiation [43, 55]. Depending on the CC standard and MS type $P_{MSmax} = 0.1 \dots 0.25$ W; EM radiation of MS is considered to be isotropic with an antenna gain of 1.

The average EM background intensity (6) created by MS also consists of two components: the frequency dependent component $Z_{\Sigma MS1}$ corresponds to the contribution of MS located in OP vicinity of free-space RWP between MS and OP, and the frequency independent component $Z_{\Sigma MS2}$ corresponds to the contribution of MS located outside this vicinity in the area of interference RWP.

As for EM background created by BS, estimates (6) also depend on the wavelength λ . Therefore, taking into account that frequency bandwidths of the BS and MS radiation are usually the same, to determine the total average EM background intensity $Z_{\Sigma \Sigma MS}$ created by radiations of MS of all J CC frequency bands, an obvious procedure similar to (5) can be proposed:

$$Z_{\Sigma \Sigma MS} = \sum_{j=1}^J Z_{\Sigma MSj} = \sum_{j=1}^J B_{MSj} \ln\left(\frac{6.44 \cdot h}{\lambda_j}\right), \quad h \geq \max\left\{\frac{\lambda_1}{5}, \frac{\lambda_2}{5}, \dots, \frac{\lambda_J}{5}\right\}, \quad (8)$$

where $Z_{\Sigma MSj}$ is the total average EM background intensity, created in OP at a height h above the Earth's surface by the set of randomly distributed MS radiating in the relatively narrow j -th frequency band, for which the wavelength of MS radiation is taken equal to λ_j .

Ideally, if we neglect the presence of a MS near-field reactive zone where the MS EM radiation is absent, then the frequency dependence of levels of MS fields in OP can also be neglected. In this case the level Z_{MSp} of EM background in OP caused by MS radiations, which is not exceeded with probability p , is determined by the level of prevailing EM field of the nearest MS, which is also related to the average SEMLA B_{MS} created by MS set in the OP vicinity [41–43]:

$$Z_{MSp} \approx \frac{B_{MS}}{4(1-p)}, \quad B_{MS} \approx \rho_{eMS} P_{eMS}; \quad p > 0.9. \quad (9)$$

For UHF CC systems (0.3–3 GHz), the level of EM background created by MS radiations, not exceeded with probability $p \approx 0.99$, is approximately equal to $Z_{p \approx 0.99} \approx 25B_{MS}$ [48].

Comparative estimates using (2) and (6), allow us to conclude that at uniform MS terrestrial distribution, the contribution of their EM fields to the total background intensity created by CC is less by an order of magnitude or more than the contribution of BS EM fields, due to the significantly different EIRP of BS and MS at the radio link between them. However, in places of mass gathering of MS, where their area density can exceed the average density a hundred times or more (shopping and business centers, stadiums, airports, etc.), contribution of MS radiations to the total EM background intensity created by CC, turns out to be dominating.

SEMLA Estimation in 4G/5G/6G Networks

Due to the extremely intensive increase in the quantity and spatial density of sources of EM radiations, as well as the significant expansion of wireless information services at CC evolution to 5G/6G, direct SEMLA calculation based on (4) to predict total average background intensity using (2), (5), is rather difficult due to a significant complication of CC radio network infrastructure. Alternatively, the technique [50, 51] of estimation of average SEMLA and average EM background intensity created by the set of CC BS, in terms of prediction of the average ATC, can be proposed.

The average total ATC S_{tr} [bit/s/m²] of CC wireless information services (one of the key 4G/5G/6G system parameters, presented in Table 1) is defined as the volume of downlink traffic over the set M of BS radio frequency channels (RFC) per unit area:

$$S_{tr} = \frac{\sum_{m=1}^M V_{tr RFC m}}{S}, \quad M = \sum_{l=1}^L k_l, \quad (10)$$

where S is the area, the wireless information services of which are provided by the total set of M downlink RFC of all of L BS located in area S ; $V_{tr RFC m}$ [bit/s] is the traffic volume of the m -th servicing downlink RFC (can be equal to its capacity or data rate).

The proposed technique is based on the following relations obtained on the basis of the well-known Shannon-Hartley theorem under the assumption that properties of the intranet interference in RFC are close to the properties of their internal thermal noise:

$$B_{\Sigma BS} = \frac{8\pi^2 mkT_0 K_N D_{\Sigma} (2^{W_{EP}} - 1) R_{\max}^2 S_{tr} Q}{\lambda^2 W_{EP}} = \frac{8\pi^2 mkT_0 K_N D_{\Sigma} CNIR \cdot R_{\max}^2 S_{tr} Q}{\lambda^2 \log_2(1 + CNIR)}, \quad (11)$$

$$\left. \begin{aligned} C_{PR} &\approx \Delta F_R \cdot \log_2(1 + CNIR), \quad CNIR = P_R / N_{\Sigma} \\ W_{EP} &= C_{PR} / \Delta F_R = m W_{ER} \approx \log_2(1 + CNIR) \\ D_{\Sigma} &= (K_{CC} + 1) L_m L_C K_H \end{aligned} \right\}, \quad (12)$$

where C_{PR} [bit/s] is the potential RFC capacity; ΔF_R is the RFC bandwidth, [Hz]; P_R is the RFC useful signal power, [W]; N_{Σ} is the RFC total noise power which is a sum of RFC internal thermal noise power N_0 and intrasystem interference power N_{INT} , [W]; $CNIR$ is the "carrier-to-(noise plus intrasystem interference)" ratio; $k=1.38 \cdot 10^{-23}$ W/K is Boltzmann's constant, K_N is radio receiver noise factor, T_0 is an ambient temperature ($T_0=290$ K); W_{EP} [bit/s/Hz] is the RFC potential spectral efficiency which is m times greater than the real RFC spectral efficiency W_{ER} ; D_{Σ} is a total necessary reserve in BS radiating power which take into account the losses L_m at RWP into buildings ($L_m \leq 100$ [56–58]), the losses L_C at RWP in street canyons (which are caused by multipath phenomenon due to the reflection from buildings and Earth's surface, and also by diffraction; $L_C \leq 100$ [53]), the necessary margin K_H in levels of receiving signals for the handover implementation ($K_H \leq 10$), and the factor $K_{CC} = N_{INT}/N_0$ which characterizes the excess of the internal thermal noise level by the intrasystem interference level. K_{CC} value is determined by the quality of the frequency-spatial planning (FSP) of CC radio network and can take values in a wide range from 0 (without intrasystem interference) to 100...1000 (20–30 dB) and even more at low FSP quality (at poor intrasystem electromagnetic compatibility (EMC)); R_{\max} is a radius of service area (cell radius of CC network), on the border of which the required level of useful signal on MS receiver's input needs the maximum BS radiated power; Q characterizes the average level of spatial selectivity of BS EM radiation of data bits in the direction of the Earth's surface; it is taken into account above when considering the expression (4).

Total necessary reserve D_{Σ} in transmitting power is different for BS of different hierarchical levels of CC radio network structure: for internal pico-BS (access points in rooms, hotspots, etc.) $D_{\Sigma} \leq 10$ –30 dB, for external micro- and macro-BS with $R_{\max} \geq 200$ m in dense urban areas [13] it can reach 70–80 dB in radio networks with poor intrasystem EMC (at high K_{CC} levels). Thus, under the requirements for RFC data rates of 4G/5G/6G CC (Table 1), it is the value of the parameter D_{Σ} that actually determines the total average SEMLA (11) and the total background intensity (2), (5) created by BS of CC. In some cases, when determining the D_{Σ} value, it is advisable to take into account some correlation between its components in (12).

Factor m in (11), (12) reflects both the ratio of potential and real RFC spectral efficiency, and the contribution of MIMO technology in its improvement. In cellular RFC without the use of MIMO technology $m \approx 2 \dots 10$. Thus, the expected increase in CC RFC spectral efficiency due to MIMO technology by 2–8 times [15] actually allows one only to compensate approximately for the imperfectness of real modulation/demodulation and coding-decoding processes. Therefore, in today's practice, predictable analysis of EM background in 4G/5G networks can be performed for $m = 1$ under the assumption that CC RFC capacity is close to the potential (use $m \approx 1$).

How to make 4G/5G/6G safe for people?

To illustrate the possibilities of using the proposed technique for the analysis of EM background generated by CC, the calculated dependences $Z_{\Sigma BS}(D_{\Sigma})$ of the average intensity of EM background created by BS of CC urban micro-cells ($R_{\max} = 200$ m) in the 2 GHz band ($\lambda = 0.15$ m) near the Earth's surface at a height of $H_{OP} = 1.5$ m, on the level of total necessary reserve D_{Σ} in BS radiating power, are given in Fig. 3.

These dependencies are obtained using expressions (2), (11) for various ATC levels created by CC networks: curve No. 1 is obtained for $S_{tr} = 10^3$ bit/s/m², which corresponds to the estimated ATC in 2G/3G networks; curve No. 2 is calculated for $S_{tr} = 10^5$ bit/s/m², which corresponds to the declared ATC level in 4G networks [13, 16], curve No. 3 is calculated for $S_{tr} = 10^7$ bit/s/m² which corresponds to the declared maximum ATC level in 5G networks [16, 17], the curve No. 4 corresponds to the predicted ATC limit $S_{tr} = 10^9$ bit/s/m² in 6G networks [19, 20]; the red horizontal line corresponds to MPL 0.1 W/m², accepted in many countries, taking into account the danger of non-thermal effects of radio frequency EM fields on the human body.

Curve 1 in Figure 3 is in full agreement with measurement results [1–11]: at the ATC levels created by 2G/3G networks, the average level of EM Background is below 0.1 W/m² at network energy reserve $D_{\Sigma} \leq 10^7$ (70 dB), which is more than enough to compensate for all RWP losses in urban area and for presence of intrasystem interference due to the limited radio frequency resource used in CC radio network.

Dependence 2 allows us to conclude that the average ATC level expected in 4G networks requires the CC operation with an energy reserve of $D_{\Sigma} \leq 10^5$ (50 dB). This can be reached at the high FSP quality and the widespread use of indoor hotspots, urban micro-cells to reduce RWP losses in urban areas.

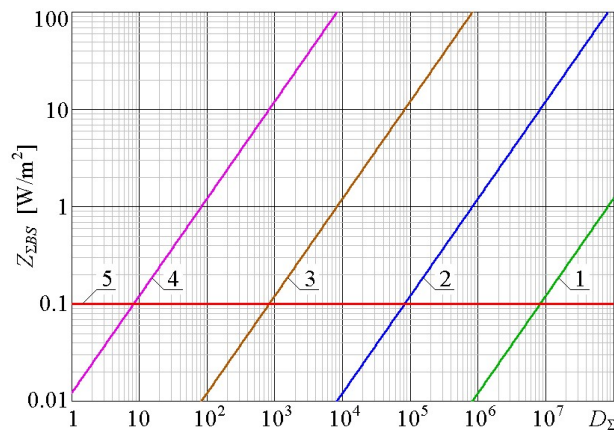


Fig. 3. The calculated dependences of the average EMB intensity created by CC urban micro-cells of UHF frequency range ($\lambda = 0.15$ m) near the Earth's surface at a height of $H_{OP} = 1.5$ m, on the total necessary reserve D_{Σ} in BS EMR power to compensate for RWP losses in street canyons and buildings, for handover implementation and for overcoming intra-network interference, at different levels of CC area traffic capacity (ATC)

Рис. 3. Расчетные зависимости средней интенсивности ЭМ фона, создаваемого городскими микро-сайтами в диапазоне УВЧ ($\lambda = 0.15$ м) вблизи земной поверхности на высоте $H_{OP} = 1.5$ м, от суммарного запаса D_{Σ} по мощности ЭМ излучения BS, необходимого для компенсации затухания радиоволн в городских «каньонах», при их проникновении в здания, для реализации хэндовера и для преодоления внутрисетевых помех, при различной территориальной плотности беспроводного трафика (АТС)

As for the total ATC levels predicted for 5G/6G radio networks, these levels of wireless information services in all areas of human activities can only be safe at CC networks energy reserves $D_{\Sigma} \leq 10^3$ in 5G systems and $D_{\Sigma} \leq 10$ in 6G systems (which requires a significant reduction in the radio communication range up to a few tens of meters or less, exclusion of the effect of any obstacles on urban RWP and also exclusion or reduction to the minimum level of intra-network interference, as well as introduction of the necessary restrictions on the volume and options of wireless public information services and various technological information processes).

Thus, the use of (2) – (11) provides the possibility of a proximate system analysis and forecast of environmental EM pollution by both operating and designed CC networks, as well as the possibility of quantitative substantiation of the requirements for possible options for ensuring their safety and environmental friendliness.

The SEMLA value in definition (4) is an integral parameter characterizing the specific average EM loading on area created by terrestrially distributed radio transmitters. Therefore, expressions (2), (3), (5) – (9) can also be used to analyze the intensity of EM background created by any other radio systems and radio services – broadcasting, fixed, navigation, etc.

In definition (11), the SEMLA value is directly and unambiguously related to the general system parameters of 4G/5G/6G networks presented in Table 1, in particular,

- with ATC (10), which defines the integral level of wireless information services and is used in (11);

- with “Connectivity density” (density ρ_{eMS} of radiating MS), which determines the average SEMLA value created by EM radiations of MS used in (6) – (9); ρ_{eMS} definition also provides the possibility of indirect estimation of ATC for subsequent use of model (11) to estimate the background level created by BS radiations;

- with “RFC spectrum efficiency” and $CNIR$ which are used in (11), (12) and determine the CC network energy efficiency;

- with RFC “Peak data rate” and “Experienced data rate” associated with ATC and along with cell’s radius R_{max} determining the average SEMLA created by BS [50, 59], as well as

- with wavelength λ describing the radio frequency resource used by the CC system.

The planned widespread use of quasi-optical and optical (terahertz and laser) technologies and subsystems for ultra-fast wireless data transmission (up to 1 Tbps) at various infrastructure levels of the 5G/6G networks, as well as at the implementation of various technological information processes in industry, transportation, education and other areas, provides a significant reduction in radio-frequency ATC (10), and a corresponding decrease in radio-frequency SEMLA and in the intensity of radio-frequency EM background created by CC.

The planned increasingly widespread use of adaptive active phased-array antennas as the BS antenna systems of an adaptive multibeam operation with adaptability of directivity and power of BS radiation for each of serving MS will also reduce SEMLA levels (4), (11) and the EM background created by these systems by reducing the parameter Q of BS radiation directivity, at least, by an order of magnitude.

The influence of the planned widespread use of MIMO technology on the intensity of EM background created by 4G/5G/6G networks, is also taken into account by the presence in (11), (12) of the WEP and m parameters that determine the real spectral efficiency of RFC of CC.

Finally, a very significant expansion of the radio-frequency spectrum allocated to these networks, including allocation of numerous frequency bands in SHF and EHF ranges, which greatly simplify the solving of intra-network EMC problem and increase the spatial selectivity of BS EM radiation with a significant (by 1–2 orders of magnitude or more) decrease in the level of intra-network interference and an increase in the real sensitivity of radio reception means the corresponding increase in 4G/5G/6G network energy efficiency, and is also taken into account by the presence of parameters λ , K_{CC} and Q in expressions (2), (11) and (12).

Since the analysis of all referred CC parameters and characteristics can be performed without the use of confidential commercial information of CC operator companies, the use of this technique can provide a high degree of independence and objectivity of estimations of EM background intensity created by CC systems. Its application to estimate the expected levels of EM background at various implementation alternatives and different structure and volumes of wireless information services can

provide a justification and assessment of the effectiveness of system, technical and managerial solutions aimed at ensuring the required levels of safety and environmental friendliness of 4G/5G/6G systems in various conditions.

Conclusion

1. The validity of the hypothesis about the possible impact of the EM background created by the public wireless information systems, first of all by systems of cellular (mobile) communications, on the relative lethality rate from COVID-19 is indirectly confirmed by the results of the analysis of correlation between the degree of severity of hygienic regulation of levels of radio frequency EM background for the population in different countries according to data [12] and the lethality rate from COVID-19 in relation to the number of people infected according to [38–40].

Taking into account the extremely high cost of error in this conclusion, this hypothesis certainly requires further verification, both in terms of analyzing the reliability of data [38–40, etc.], which are the basis of the correlation analysis, and in analyzing the actual levels of EM background in places with different levels of the lethality rate from COVID-19, and in terms of accounting for the impact on the lethality rate from COVID-19 of other factors (the effectiveness of national health systems, the effectiveness of government measures against the spread of COVID-19, etc.).

2. Detected correlation between the degree of severity of hygienic regulation of levels of radio frequency EM background for the population and the lethality rate from COVID-19 in various countries requires a critical attitude to corporate declarations [24, etc.] about the harmlessness of 4G/5G/6G technologies and systems for the population, as well as possibly revising plans [15–20] for the development of these technologies and systems towards a wider, if possible, use of non-radiating wire (fiber-optic, cable, etc.) technologies and systems without any damage to the quality of public information services and to the technological level in industry, services, education, healthcare and in other sectors.

3. The calculated data contained in [41–51], as well as preliminary quantitative estimates using (2), (3), (5) – (9), (11), (12), indicate that the fulfillment of severe hygiene restrictions on the MPL of EM background 1–10 $\mu\text{W}/\text{cm}^2$, which take into account the danger of non-thermal effects of radio frequency EM fields on public health, in 4G/5G/6G networks, and the safe development of these networks to the levels indicated in Table 1, are quite possible under the following conditions:

a) reducing the distances of high-speed wireless data transmission up to a few tens of meters or less in conditions of direct visibility and lack of multipath RWP [50, 51] so that the achieved SEMLA level created by CC BS in UHF bands will be no more than half of the accepted MPL value [44];

b) using the external micro- and macro-BS of CC substantially for mobile telephony and technological low data rate services, including such wireless servicing of mobile objects, with a restriction to safe levels of data transfer rates over the RFC of these BS;

c) fast developing of 4G/5G/6G technologies and systems towards the implementation of system and technical solutions related to increasing spectral and network energy efficiency and ensuring decrease in EM background levels created by 4G/5G/6G radio networks, ensuring in them the maximum possible level of adaptation of power and directivity of EM radiation, optimization of the volume of wireless information services;

d) following the example of [21–23], introduction of reasonable restrictions on the use of wireless services in places requiring special attention – in places where children stay (kindergartens, schools, etc.), in hospitals, in vehicles, etc., providing the necessary level of public EM safety.

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