Electromagnetic Background Created by Base and Mobile Radio Equipment of Cellular Communications

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Abstract— **A technique of estimation of the total electromagnetic background intensity created by base and mobile radio equipment of cellular communications, is offered. It is based on analysis of the total electromagnetic loading on territory, created by this equipment, and also on estimation of the traffic terrestrial density and of the local spatial concentration of subscribers. This technique is applicable for cellular radio networks of all standards and generations and provides possibility of worst-case estimation of electromagnetic compatibility of cellular radio networks and radio systems presented in the corresponding frequency bands on a secondary basis, and also provides an estimation of the compelled ecological risks related to the cellular communications use in places with high population density**

Keywords—electromagnetic background, EMC diagnostics, cognitive radio, cellular communications, s electromagnetic ecology

I. INTRODUCTION

Extremely intensive development of cellular communications accompanied by the fast increase of territorial density and power of electromagnetic radiation (EMR) of base (BS) and mobile (MS) stations of cellular radio networks, is the reason of essential growth of levels of an electromagnetic background (EMB) of UHF frequency range in places with high population density. This EMB restricts essentially the efficiency of UHF cognitive and UWB radio systems [1,2]. Moreover, the World Health Organization have been considered the radiofrequency electromagnetic fields (EMF) as a potentially carcinogenic factor [3]. Therefore the development of practical technique of an estimation of the total EMB intensity created by all types of radio transmitters of modern cellular radio networks, which is define the EMC of primary and secondary radio services in UHF frequency bands assigned for cellular communications, and also the electromagnetic ecology of human environment and the electromagnetic safety of urban population, is rather important.

In [4-6] the concept of electromagnetic loading (EML) on territory is stated and developed as an integrated system characteristic of radio-electronic environment (REE), defining possibilities of use of separate frequency bands on a secondary basis (cognitive radio, UWB systems, etc.), and also electromagnetic ecology of the given area.

EML on the territory, created by stationary or mobile radio transmitters of a cellular network, is defined as the total equivalent isotropic radiated power (EIRP) of MS or BS sets falling to the unit of area of the considered territory. In [4-6] an analytical dependences of EML on territory, created by stationary or mobile GSM radio equipment, on total intensity of separate EMB components near ground surface, and also relations between EML on territory and probability of excess of the EMB maximum permissible level (MPL) given by regulations [7-9], by the total intensity of EMB components in an observation point (OP) at a ground surface, are established. With reference to cellular network these results are received in assumption of independence of BS and MS operation.

Actually both BS and MS radiation, and EML on territory created by these kinds of EMR sources, and also EMB cumulative levels produced by stationary and mobile segments of radio equipment of cellular network are interdependent and directly connected with network traffic intensity, created by set of subscribers located in the corresponding territory and addressed to cellular services during the considered period.

The goal of this paper is to develop on basis of [4-6] a complete novel technique of the “worst-case” estimation of the total intensity of EMB, created by all stationary and mobile EMR sources of a cellular radio network near ground surface, taking into consideration the EML on territory created by cellular BS and MS in network busyhour, and also interdependence of cellular MS and BS operation.

II. TECHNIQUE OF AN ESTIMATION OF EMB INTENSITY

1. EML on territory L_T created by EMR of terrestrially distributed EMF sources with the average EIRP P_e and average terrestrial density ρ, is defined in [2-4] as follows:

$$L_T = P_e \rho \, , \ [\mathrm{W/m^2}]. \tag{1}$$

2. Random terrestrial distribution of mobile radio transmitters (MS) is described by the known Poisson model of area distribution of point objects:

$$p_k(N_{\Delta S}) = \left(N_{\Delta S}^k \, exp(-N_{\Delta S})\right)\big/ k!, \quad N_{\Delta S} = \rho \cdot \Delta S, \tag{2}$$

where $p_k(N_{\Delta S})$ is a probability that exactly k point objects (MS) are allocated in area ΔS, if average number of these objects in

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this area is $N_{\Delta S}$; ρ is an average density of area distribution of the objects. In addition we will consider that antennas of transmitters (MS) are elevated at the height H over a surface.

3. Conditions of radiowave propagation (RWP) can be specified by the worst-case branch of the “breakpoint” RWP model [10] for RWP in cities for UHF frequency range.

This model have a following important features: on small distance R between transmitter and OP the conditions of RWP are equal to free-space RWP: the EMF power flux density (PFD) Π [W/m^2] decreases in inverse proportion to a square of distance R. Since some distance R_{BP} (“breakpoint” distance) between OP and transmitters RWP conditions are changes: the envelope of PFD distance dependence decreases in inverse proportion to the fourth degree of distance R.

Distance R_{BP} between transmitter and OP allocated near ground surface on which changes of RWP conditions occurs, depends on a wavelength λ of transmitter’s EMR, antenna height H, and height H_{OP} of OP over a surface:

$$R_{BP} = 4H_{OP}H/\lambda\,. \tag{3}$$

Consequently the worst-case model of RWP conditions (as an envelope of values of real RWP losses) between transmitter and OP on distance R can be represented as

$$\Pi = P_e/4\pi R^2, \quad R \le R_{BP}: \tag{4}$$

$$\Pi = R_{BP}^2 P_e/\left(4\pi R^4\right), \quad R \ge R_{BP}, \tag{5}$$

where P_e is an EIRP of transmitter, Π is an EMF power flux density (PFD) created by transmitter in OP.

This model, as a rule, gives the underestimated propagation losses at multipath RWP in urban area [10] and therefore provides the worst-case character of estimation procedure for EMB created by REE of urban and suburban areas.

4. It is possible to divide all situations of OP allocation near to the ground surface, in relation to stationary (BS) and mobile (MS) EMR sources, on following two groups:

- Situations of the 1st group, typical for mutual random location of OP and BS antennas at a ground surface: in these cases considerable difference of heights H_{BS} of BS antennas elevation, and height H_{OP} of OP over a surface, takes place: $H_{BS} >> H_{OP}$.
- Situations of the 2nd group, typical for mutual random location of OP and MS at a ground surface - in these cases approximate equality of heights H_{MS} of MS, and height H_{OP} of OP over a surface, take place: $H_{MS} \approx H_{OP}$.

5. The total EMB intensity in OP is defined as the scalar sum of PFD values of all set of EMF, defined with use of (4), (5) and created by corresponding sets of radiating BS and/or MS located in the corresponding OP vicinity.

6. The separate frequency bands allocated for cellular communications, are rather narrow; it is possible to ignore the differences of EMR wavelengths of separate kinds of cellular radio equipment and consider $\lambda \approx$ const.

7. For situations of the 1st group (see item 4) covering possible variants of OP and BS mutual random location, it is necessary to define two following separate components of the total EMB intensity created in OP by BS [4,6]:

- For BS set located inside the OP breakpoint vicinity randomly and uniformly with terrestrial density ρ_{BS}, the average total EMB intensity created by these BS on height $H_{OP} << H_{BS}$ over the ground surface, is actually independent from the BS antenna height and EIRP of separate BS, and defined by the EML on territory created by these BS in OP breakpoint vicinity of radius $R_{BP\,BS} = 4H_{OP}H_{BS}/4$:

  $$\Pi_{\Sigma 1BS} = \left(L_{TBS}/2\right)ln\left(4H_{OP}/\lambda\right), \quad L_{TBS} = \rho_{BS}P_{BS}; \tag{6}$$

  where P_{BS} is an average EIRP of BS, $R \le R_{BP\,BS}$;
- For BS set located outside the OP breakpoint vicinity ($R \ge R_{BP\,BS}$) randomly and uniformly with terrestrial density ρ_{BS}, the average total EMB intensity created by these BS on height $H_{OP} << H_{BS}$ over the ground surface, is actually independent from the BS wavelength, antenna height and EIRP of separate BS, and defined only by the EML on territory:

  $$\Pi_{\Sigma 2BS} = L_{TBS}/4\,. \tag{7}$$

Full average EMB intensity $\Pi_{\Sigma\,BS}$ in OP on height H_{OP}, created by all BS, is defined by summation (6) and (7):

$$\Pi_{\Sigma BS} = \frac{L_{TBS}}{2} ln\left(\frac{4\sqrt{e}H_{OP}}{\lambda}\right) \approx \frac{L_{TBS}}{2} ln\left(\frac{6.6H_{OP}}{\lambda}\right) \tag{8}$$

8. For situations of the 2nd group (see item 4) covering possible variants of mutual random location of OP and of MS set distributed on considered area randomly according (2) with average density ρ_{MS}, it is necessary to define three following separate components of the total EMB intensity created in OP by MS [5,6]:

a) EMF of prevailing intensity (stochastic component) Π_{MS1}*:* probability distribution function $P(\Pi_{MS1})$ of PFD of this EMF in OP is

$$P\left(\Pi_{MS1}\right) = \Gamma\left(1, L_{TMS}/4\Pi_{MS1}\right) = exp\left(-L_{TMS}/4\Pi_{MS1}\right),$$
$$\Gamma\left(\alpha, x\right) = \int_x^\infty e^{-t}t^{\alpha-1}dt; \tag{9}$$

for tolerance probability $p \le 0.1$ (probability of that the intensity of prevailing EMF created by the nearest MS will exceed the level Π_{MS1}) the Π_{MS1} value is defined by average EML on territory L_{TMS}, created in OP vicinity by set of MS with average EIRP $m_1(P_{MS})$, and does not depend on wavelength of prevaling EMF:

$$\Pi_{MS1} \approx L_{TMS}/4p,\ p \le 0.1; \quad L_{TMS} = m_1(P_{eMS})\rho_{MS}\ ; \tag{10}$$

b) average intensity $\Pi_{\Sigma MS2}$ of “quasistationary” EMB component created by all other EMF (except the prevaling one) generated by MS allocated in OP breakpoint vicinity (3):

$$\begin{gathered}\Pi_{\Sigma MS2} = L_{TMS} Z/4, \quad Z = \sum_{H=2}^{int\{N_A\}} (H-1)^{-1}, \\ N_A = \pi\rho_{MS} R^2_{BP\,MS}, \quad R_{BP\,MS} = 4H^2_{OP}/\lambda;\end{gathered} \tag{11}$$

c) average intensity $\Pi_{\Sigma MS3}$ of “stationary” EMB component created by EMF set generated by MS allocated outside the OP breakpoint vicinity ($R \ge R_{BP\,MS}$):

$$\Pi_{\Sigma MS3} = L_{TMS}/4\,. \tag{12}$$

III. EMB Created by Radio Equipment of Cellular Network

It is essentially important, that the territorial density ρ_{MS} of radiating MS can be considered as the network traffic terrestrial density, or as the specific terrestrial loading of a cellular radio network. This parameter is defined by territorial density of subscribers ρ_S (actually – by population density) and specific traffic intensity E [Erl.]: $\rho_{MS} = \rho_S E$. During the periods of the highest voice traffic intensity (in busyhours) $E = 0.025 \ldots 0.08$ Erl. Taking into account existing tendencies in the market of cellular communications, as average value of specific traffic intensity it is expedient to accept $E = 0.05 \ldots 0.055$ Erl.

EIRP of MS is random because of the availability of forced EMR power adjustment of MS (in a range 30 dB with 2-3 dB steps in GSM networks and in a range more than 70 dB with steps >1 дБ in UMTS/CDMA networks [11,12]), average value $m_1(P_{MS})$ of MS EIRP is defined by a range of distances and by RWP conditions between the MS and BS and can be accepted equal to 1/2 … 1/3 of the maximum MS EIRP value [13].

Each radiating MS uses the corresponding communication channel (the traffic channel) of BS. EIRP level P_{cBS} of BS, used in this channel, essentially exceeds the MS EIRP level P_{MS}:

$$\begin{gathered}P_{cBS}[dBW] = P_{MS}[dBW] + \Delta_{BM}[dB], \\ \Delta_{BM} = G_{ABS}[dB] - G_{AMS}[dB] + D_{UD}[dB],\end{gathered} \tag{14}$$

where G_{ABS}, G_{AMS} – BS and MS antenna gains, D_{UD} – difference in power of "downlink" and "uplink" radio lines, necessary for normal network operation. As a rule, in cellular radio networks BS and MS antenna gains differ on 15-18 dB, and total difference Δ_{BM} of average BS EIRP, and of average EIRP MS, can reach 20 – 40 dB.

Using (8) - (14), it is possible to receive expressions for worst-case estimation of the total EMB intensity created by the joint set of radiating BS and MS of cellular network.

1. Component $\Pi_{\Sigma BS}$ of the total EMB intensity in OP on height H_{OP} over the ground surface created by set of BS in busyhour, is defined by the following expression:

$$\begin{gathered}\Pi_{\Sigma BS} \approx \frac{L_{TBS}}{2} ln\left(\frac{6.6H_{OP}}{\lambda}\right) = \frac{L_{TMS}\Delta_{BM}}{2} ln\left(\frac{6.6H_{OP}}{\lambda}\right), \\ L_{TBS} = L_{TMS}\Delta_{BM}\,.\end{gathered} \tag{15}$$

2. Component $\Pi_{\Sigma MS}$ of the total EMB intensity in OP on height H_{OP} over the ground surface created by set of MS in busyhour, is defined by the following expression:

$$\Pi_{\Sigma MS} \approx \frac{L_{TMS}(Z+1)}{4} + \frac{L_{TMS}}{4p} = \frac{L_{TMS}}{4}\left(Z + 1 + \frac{1}{p}\right). \tag{16}$$

The total EMB intensity $\Pi_{\Sigma BG}$ in OP on height H_{OP} over the ground surface created by joint set of MS and BS in busyhour, is defined by the following expression:

$$\begin{gathered}\Pi_{\Sigma BG} = \Pi_{\Sigma BS} + \Pi_{\Sigma MS} \approx \\ \approx \frac{L_{TMS}}{2}\left(\Delta_{BM}\, ln\left(\frac{6.6H_{OP}}{\lambda}\right) + \frac{1}{2}\left(Z + 1 + \frac{1}{p}\right)\right),\ p \le 0.1\end{gathered} \tag{17}$$

3. In cases of small tolerance probability and comparatively small Z (or small R_{BP} values, or comparatively small ρ_{MS}), and also taking in consideration that in some cases the local MS spatial density (local L_{TMS}) in OP immediate neighborhood can be M times greater than on the average in OP breakpoint vicinity or in BS service zone (OP in crowds, etc.), expression (17) can be submitted as follows:

$$\Pi_{\Sigma BG} \approx \frac{L_{TMS}}{2}\left(\Delta_{BM}\, ln\left(\frac{6.6H_{OP}}{\lambda}\right) + \frac{M}{2p}\right),\ p \le 0.1\,. \tag{18}$$

The difference between (17) and (18) is equal to $L_{TMS}(Z+1)/4$ and at values of practical interest ($L_{TMS} \le 10^{-4}$, $Z<10$, $M \ge 1$) it does not exceed 1% of $\Pi_{\Sigma BG}$, or (1 … 2) 10^{-4} W/m^2.

IV. Calculated Values of EMB Intensity Created by Cellular Radio Networks

On Fig. 1-6 sets of calculated curves illustrating dependences of estimated values of total EMB intensity, created jointly by BS & MS of cellular communications, on the average EML on territory created MS, on the level of tolerance probability p at estimations of the compelled ecological risks for population (ecological risks in considered busyhour time point for $(1\text{-}E)\cdot 100\%$ of people who don’t use mobile phones in present time, but nevertheless are in danger of EMF exposure created by surrounding MS and BS; personal voluntary risks for MS users are not considered), and also on accepted excess of EIRP BS channel over the average EIRP MS. Calculations are executed for $\lambda = 0.167$ m (GSM-1800).

On Fig.1 curves illustrating dependences of total EMB intensity $\Pi_{\Sigma BG}$ [W/m^2] and its separate components on tolerance probability p, calculated for $L_{TMS} = 10^{-4}$ W/m^2, $\Delta_{BM} = 100$ (20 dB) and $M = 1$, are presented. Red curve No.1 correspond to expressions (17),(18) for the total EMB intensity $\Pi_{\Sigma BG}$, blue horizontal line No.2 correspond to component (15)

– the EMB intensity $\Pi_{\Sigma BS}$ created by BS; pink curve No.3 correspond to component (10) – the intensity Π_{MS1} of prevaling EMF of MS in OP; brown curve No.4 correspond to component (16) – the total EMB intensity created by set of MS.

On Fig.2 curves illustrating dependences of total EMB intensity on tolerance probability p, calculated for $\Delta_{BM} = 100$, $M = 1$, and different levels of EML on territory, created by MS, are placed. Blue curve No.1 is calculated for $L_{TMS} = 10^{-4}$ W/m^2 (urban area), brown curve No.2 correspond to $L_{TMS} = 10^{-5}$ W/m^2 (suburban area), black curve No.3 correspond to $L_{TMS} = 10^{-6}$ W/m^2 (countryside), red horizontal line correspond to MPL 10 μW/cm^2 (0.1 W/m^2) accepted in [7-9].

Estimated values of EML on territory L_{TMS} at various conditions (various terrestrial density of subscribers) described in [14], at various specific traffic intensity in busyhour and at average MS EIRP $m_1(P_{MS}) = 0.04$-0.08 W, are given in Table 1.

The analysis of curves of Fig. 1,2 and data of Table 1 allows to make a conclusion, that MS influence on total EMB level in OP at man's height over the ground surface becomes essential at levels of tolerance probability $p \le 10^{-2}$. At the same time, difference between (10) and (16) is appreciable only at $p > 10^{-2}$. Therefore, at MS uniform random terrestrial distribution, and at essential excess Δ_{BM} of BS EIRP over the average MS EIRP, it is possible to ignore the contribution of MS EMR, except for the contribution of the prevaling EMF of MS, in creating of the total EMB intensity.

TABLE I. VALUES OF AVERAGE EML ON TERRITORY CREATED BY MS IN DIFFERENT CONDITIONS

Type of conditions	**Subscribers density ρ_S MS/km^2 (MS/m^2)**	**L_{TMS} [W/m^2] (ρ_{MS} [MS/km^2])**	
		E = 0.025 Erl.	***E = 0.05 Erl.***
Extremely high MS density (in crowds, in buildings, etc.)	250 000 (0.25)	$2.5 \cdot 10^{-4} – 5 \cdot 10^{-4}$ (6 250)	$5 \cdot 10^{-4} – 1 \cdot 10^{-3}$ (12 500)
Urban pedestrian areas	100 000 (0.1)	$1 \cdot 10^{-4} – 2 \cdot 10^{-4}$ (2 500)	$2 \cdot 10^{-4} – 4 \cdot 10^{-4}$ (5 000)
Urban / suburban road surface	3 000 (0.003)	$3 \cdot 10^{-6} – 6 \cdot 10^{-6}$ (75)	$6 \cdot 10^{-6} – 1.2 \cdot 10^{-5}$ (150)

On Fig.3 curves illustrating dependences of total EMB intensity $\Pi_{\Sigma BG}$ on average EML on territory created by EMR MS, calculated for $\Delta_{BM} = 100$, $M = 1$, and different levels of tolerance probability, are given. Black curve No.1 correspond to $p = 10^{-1}$, blue curve No.2 correspond to $p = 10^{-2}$, brown curve No.3 correspond to $p = 10^{-3}$, pink curve No.4 correspond to $p = 10^{-4}$; horizontal red line No.5 correspond to MPL 0.1 W/m^2. Critical levels L_{TMSK} of average EML on territory created by EMR of MS set, at which the total EMB intensity created by all set of radio equipment of cellular communications, reaches MPL, appropriate for the levels of tolerance probability given above, are resulted in Table 2.

Curves of Fig. 3 and data of Table 2 confirm validity of [13] regarding a choice of value of the tolerance probability defining the population electromagnetic protection rate, at level $p = 10^{-2}$. The choice $p \ge 10^{-2}$ practically does not reduce the requirements related to the restriction of EMR levels of cellular BS & MS. At the same time at reduction of tolerance probability in relation to $p = 10^{-2}$, the abrupt decrease of critical levels of EML on territory at which the total EMB intensity created by cellular network reaches the MPL, is observed.

TABLE II. CRITICAL LEVELS L_{TMSK} OF AVERAGE EML ON TERRITORY CREATED BY MS, AT $\Delta_{BM} = 20$ DB

p	**L_{TMSK}, W/m^2**
10^{-1}	$4.52 \cdot 10^{-4}$
10^{-2}	$4.11 \cdot 10^{-4}$
10^{-3}	$2.14 \cdot 10^{-4}$
10^{-4}	$3.68 \cdot 10^{-5}$
10^{-5}	$3.97 \cdot 10^{-6}$

On Fig.4 curves illustrating dependences of total EMB intensity $\Pi_{\Sigma BG}$ on average EML on territory created by EMR MS, calculated for $p = 0.01$, $M = 1$, and different levels of Δ_{BM}, are given. Black curve No.1 correspond to $\Delta_{BM} = 10$ dB, blue curve No.2 correspond to $\Delta_{BM} = 15$ dB, brown curve No.3 correspond to $\Delta_{BM} = 20$ dB, pink curve No.4 correspond to $\Delta_{BM} = 25$ dB, horizontal red line No.5 correspond to MPL 0.1 W/m^2.

The analysis of curves of Fig. 4 allows to make a conclusion, that difference Δ_{BM} in channel BS EIRP, and in MS EIRP, is the major factor defining amount of prevalence of EMB intensity component created by stationary EMR sources of cellular network near ground surface. This difference in average power of "downlink" and "uplink", necessary for a network operation, depends on quality of frequency planning of a cellular radio network (on levels of intranetwork EMC) and can be partly reduced (roughly up to BS antenna gain) by the extension a network radio-frequency resource, optimization of a network infrastructure, etc.

On Fig.5 curves illustrating dependences of total EMB intensity $\Pi_{\Sigma BG}$ on tolerance probability p, calculated for $L_{TMS} = 10^{-4}$ W/m^2 and $\Delta_{BM} = 100$ (20 dB), for different levels M of MS concentration in OP, are given. Black curve No.1 correspond to $M = 0$ dB (MS concentration is absent), blue curve No.2 correspond to $M = 5$ dB, brown curve No.3 correspond to $M = 10$ dB, pink curve No.4 correspond to $M = 15$ dB, green curve No.5 correspond to $M = 20$ dB, horizontal red line No.6 correspond to MPL 0.1 W/m^2. Critical levels of tolerance probability at which the total EMB intensity reaches MPL in OP characterized by the specified levels M of EMR MS concentration, are resulted in the second column of Table 3.

On Fig.6 curves illustrating dependences of total EMB intensity $\Pi_{\Sigma BG}$ on average EML on territory created by MS, calculated for $p = 0.01$ and $\Delta_{BM} = 100$ (20 dB), for different levels M of MS concentration in OP, are given. Black curve No.1 correspond to $M = 0$ dB (MS concentration is absent), blue curve No.2 correspond to $M = 5$ dB, brown curve No.3 correspond to $M = 10$ dB, pink curve No.4 correspond to $M = 15$ dB, green curve No.5 correspond to $M = 20$ dB, horizontal red line No.6 correspond to MPL 0.1 W/m^2. Critical levels of average EML on territory created by MS in considered area, at which the total EMB intensity reaches MPL in OP characterized by the specified levels M of EMR MS concentration, are resulted in the third column of Table 3.

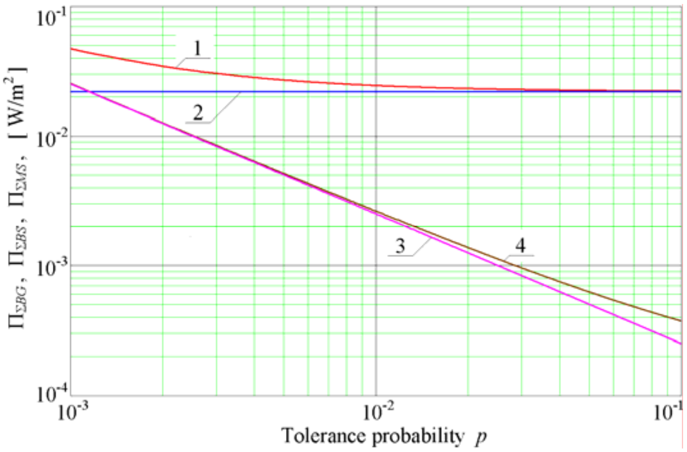

Fig. 1. Dependences of total EMB intensity and intensity of its separate components on tolerance probability p, calculated for $L_{TMS} = 10^{-4}$ W/m^2, $\Delta_{BM} = 100$ (20 dB) and $M = 1$.

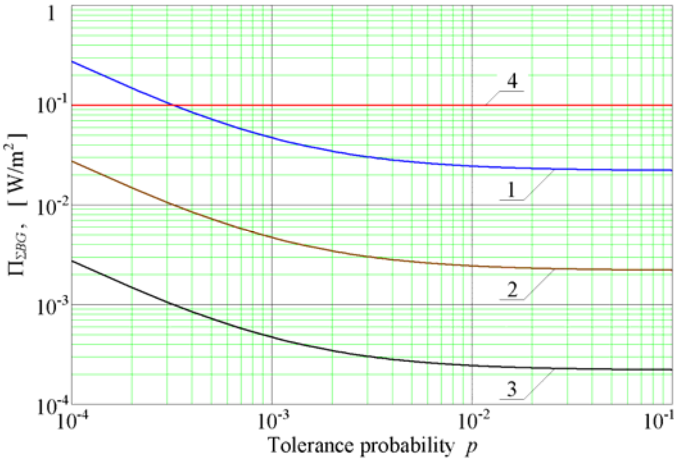

Fig. 2. Dependences of total EMB intensity on tolerance probability p, calculated for $\Delta_{BM} = 100$, $M = 1$ and different levels of average EML on territory, created by MS.

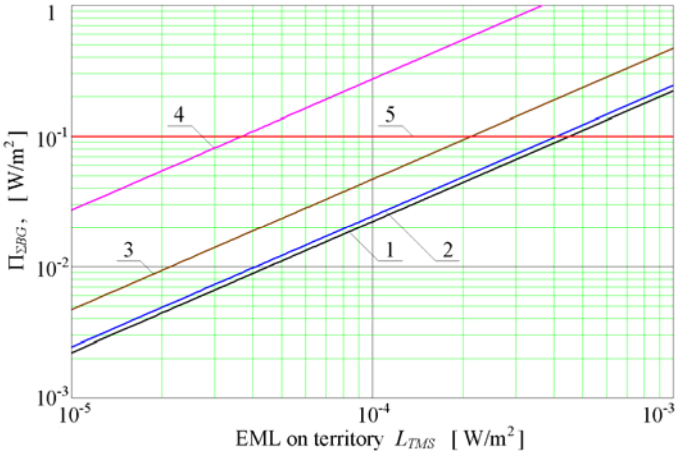

Fig. 3. Dependences of total EMB intensity on average EML on territory created by MS, calculated for $\Delta_{BM} = 100$, $M = 1$ and different levels of tolerance probability.

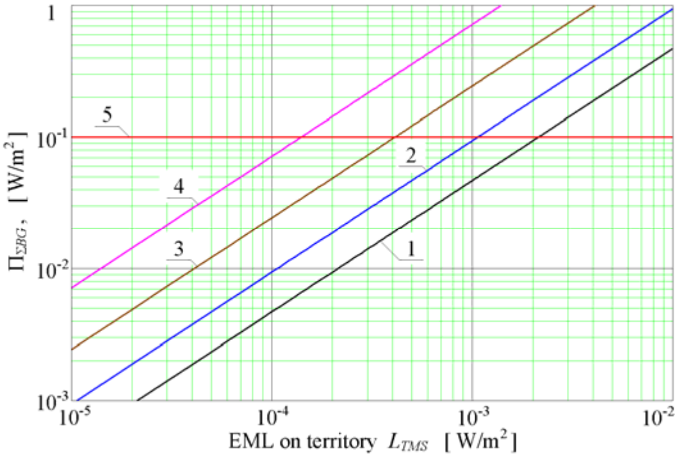

Fig. 4. Dependences of total EMB intensity on average EML on territory created by MS, calculated for $p = 0.01$, $M = 1$ and different levels of Δ_{BM}

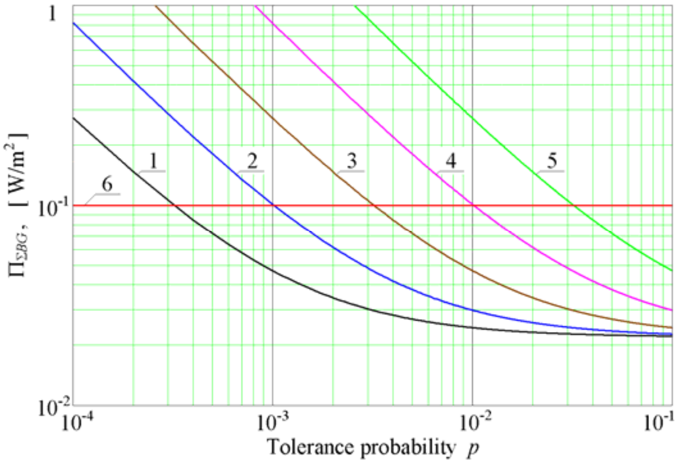

Fig. 5. Dependences of total EMB intensity on tolerance probability p, calculated for $L_{TMS} = 10^{-4}$ W/m^2 and $\Delta_{BM} = 100$ for different levels M of MS concentration in OP.

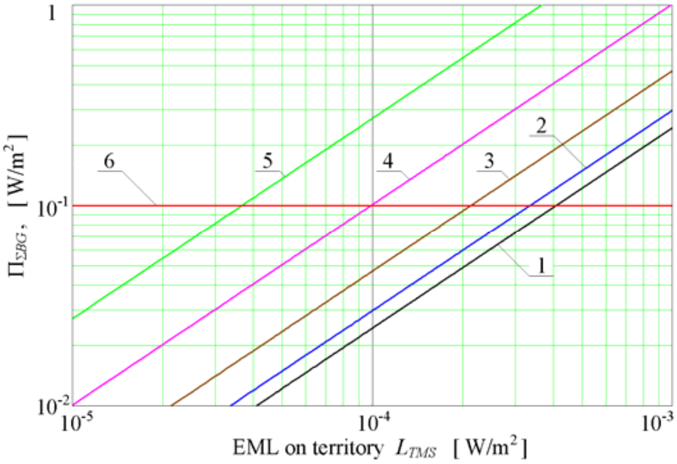

Fig. 6. Dependences of total EMB intensity on average EML on territory created by MS, calculated for $p = 0.01$ and $\Delta_{BM} = 100$ for different levels M of MS concentration in OP.

TABLE III. CRITICAL LEVELS OF TOLERANCE PROBABILITY AND OF AVERAGE EML ON TERRITORY CREATED BY MS IN OP IMMEDIATE NEIGHBORHOOD, FOR DIFFERENT LEVELS M OF MS CONCENTRATION IN OP

M, dB	**p for $\Delta_{BM} = 20$ dB**	**L_{TMSK}, W/m^2, for $p = 10^{-2}$**
0	$3.19 \cdot 10^{-4}$	$4.11 \cdot 10^{-4}$
5	$1.01 \cdot 10^{-3}$	$3.36 \cdot 10^{-4}$
10	$3.19 \cdot 10^{-3}$	$2.14 \cdot 10^{-4}$
15	$1.01 \cdot 10^{-2}$	$9.92 \cdot 10^{-5}$
20	$3.19 \cdot 10^{-2}$	$3.68 \cdot 10^{-5}$

Local excess of average EML on the territory, created by MS in OP vicinity, in comparison with average EML on territory, created by MS in BS service zones, can be formed on local objects, in particular, at public transport, in trade centers and market areas, crowded meetings and in many other places of a local congestion of people. As follows from Figures 5,6 and Tables 2,3, influence of MS EMR on total EMB intensity essentially increases in such places, and in some cases the EMB component created by MS, can be prevailing.

Overall, in places with high population density the total EMB intensity, created by all set of BS and MS near ground surface, can come nearer to MPL, and even to exceed this level in places of a local congestion of people. Results presented above shows, that in urban pedestrian areas at the accepted criteria of EMF dangerous (MPL 0.1 W/m^2, $p = 0.01$) any local excess $M>>1$ of average EML on the territory, created by MS (i.e. any congestion of radiating MS), can be dangerous because in these situations the total EMB intensity appears commensurable with MPL or exceeding it.

V. CONCLUSION

Estimations illustrated by curves on Figures 1-6 and by data of Tables 1-3, conform to the real levels of the compelled ecological risks associated with mass use of cellular communications on densely populated territories. In particular, these estimations correlate with the experimental results [16] of measurements of total EMB intensity, created by cellular communications in urban area.

1. On Figure 1 at $L_{TMS} = 10^{-4}$ W/m^2 (this level correspond to data of Table 1 for urban area ($\rho_{MS} = (1\text{-}2) \cdot 10^{-3}$ MS/m^2, $m_1(P_{eMS}) = 0.05\text{-}0.1$ W) and $\Delta_{BM} = 20$ dB) and tolerance probability 0.01 accepted in [15], the point on red curve No.1 correspond to the value of $\Pi_{\Sigma BG} = 0.0244$ W/m^2; for EMB component created by BS $\Pi_{\Sigma BS} = 0.0219$ W/m^2 (line No.2).

2. On Figure 2 the point of brown curve No.2 for $p = 0.01$ calculated for $L_{TMS} = 10^{-5}$ W/m^2 (this level also correspond to data of Table 1 for urban area ($\rho_{MS} = (1\text{-}2) \cdot 10^{-4}$ MS/m^2, $m_1(P_{eMS}) = 0.05\text{-}0.1$ W) and $\Delta_{BM} = 20$ dB) correspond to the value of $\Pi_{\Sigma BG} = 0.00244$ W/m^2; for EMB component created by BS $\Pi_{\Sigma BS} = 0.00219$ W/m^2;

3. The measured levels of the total EMB intensity created by cellular systems, presented in [16], are in an interval of values [0.004-0.015] W/m^2, i.e. are encompassed within the interval [0.00244 -0.0244] W/m^2 predicted from the curves of Figures 1-2.

Results given above allow to define a ways of improvement of an electromagnetic safety of urban population. In particular, it concerns restrictions on cellular communication use in places of a people congestion, because the local growth of EML on territory, created by MS in these places, can cause corresponding inadmissible local growth of EMB intensity; and also it concerns ensuring the minimum necessary excess $min\{\Delta_{BM}\}$ of the average EIRP BS over the average EIRP MS because in whole the EMB component created by BS is the essentially prevaling component of total EMB in areas of random uniform MS distribution.

The presented technique of estimation of EMB, created both by BS and MS of cellular radio networks, is applicable for cellular radio networks of all standards and generations, and provides possibility of essential simplification of the technique [15] of an estimation of compelled ecological risks produced by cellular communications in places with high population density.

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