System-Level Estimation of Prevaling Levels of EM Fields of Mobile Phones Considering Near-Field Zone Limitations of Their Antennas

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Abstract— **Free-space radiowave propagation model, used at short-distance EMC system analysis, is inadequate for the reactive near-field zone at the radiating source vicinity. It results to errors at the analysis of an electromagnetic background intensity in situations with high terrestrial density of mobile transmitters which capable to bring nearer to an observation point on distances, comparable with radius of this zone, and also at the probabilistic analysis of levels of prevaling electromagnetic fields of mobile sources near ground surface. Results of analysis of influence of the given physical limits of the spherical wave model used for representation of an electromagnetic radiation of cellular phones, on adequacy of procedures of probabilistic estimation of its electromagnetic fields dynamic range and electromagnetic background near ground surface, are resulted. It is indicated, that considering of these limitations practically does not affect on results of this estimations, but allows to simplify a procedure of a probabilistic estimation of levels of prevaling signals of cellular phones and total electromagnetic background intensity in places of heavy use of mobile communications.**

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

I. Abbreviations

CDF – cumulative distribution function.
EMB – total electromagnetic background in observation point.
EMC – electromagnetic compatibility.
EME – electromagnetic environment.
EMF – electromagnetic field.
EIRP – equivalent isotropic radiated power.
MPL – maximum permissible level.
MS – mobile station (mobile phone).
OP – observation point.
PDF – probability density function.
PFD – power flux density of EMF.
RWP – radiowave propagation.

II. Introduction

At the analysis of electromagnetic compatibility (EMC), and also at the estimation of radio systems electromagnetic ecology and electromagnetic safety of radio systems, with the use of stochastic model of an electromagnetic environment (EME) one of the major procedures is an estimation of level of a predominating signal (power flux density (PFD) Π_{Nmax} of predominating electromagnetic field (EMF); dynamic range D_{Nmax} of input signals, etc.) in ensemble of N EMF, present at an observation point (OP) [1-5]. The essence of this procedure is consist in determination of a value of power parameter D_{Nmax} or Π_{Nmax} for a predominating signal in OP, not exceeded with the specified probability p:

$$\Pi_{Nmax}(p) = arg\{F(\Pi_N) = p\}, \quad (1.1)$$
$$\Pi_N \in [\Pi_{min}, \Pi_{max}],\ \Pi_{max} >> \Pi_{min};$$

$$D_{Nmax}(p) = arg\{F(D_N) = p\}, \quad (1.2)$$
$$D_N = \Pi_N / \Pi_{min};\ D_N \in [1, \Pi_{max}/\Pi_{min}],$$

where Π_N, D_N – power parameters of the most intensive EMF from among N fields exceeding the certain threshold level Π_{min} (susceptibility level; threshold conforming to the signal attenuation at radiowave propagation (RWP) from the boundary of considered area or object, etc.); $F(\Pi_N)$, $F(D_N)$ – cumulative distribution functions (CDF) for probability of parameters Π_N, D_N. From the practical point of view the most interesting cases are conform to $p \geq 0.9$ (p=0.9-0.99).

At estimation of quantiles (1.1), (1.2) of probability distributions $F(\Pi_N)$, $F(D_N)$ of parameters of EME, created by mobile stations (MS) of cellular communications in OP near to earth's surface, it is very significant to use an adequate model of conditions of RWP to the OP from the nearest MS as a source of prevaling EMF, at determination of functions $F(\Pi_N)$, $F(D_N)$. Significance of that is defined by the high terrestrial density of MS on populous areas.

Generally at OP and MS location at some height over a surface the conditions of RWP from MS to OP can correspond to free-space RWP conditions only for MS which are placed in OP "breakpoint" vicinity, limited by some radius R_{BP}. For MS outside this vicinity the model of multipath RWP conditions must be used. In these cases the generally accepted RWP model [6] reproducing pessimistic character of an estimation of EMF attenuation at RWP in OP from the nearest MS ("worst case" RWP model for estimation of levels of undesirable EMF) is used:

$$\Pi = \begin{cases} P_e / (4\pi R^2), R \leq R_{BP}; \\ R_{BP}^2 P_e / (4\pi R^4), R \geq R_{BP}; \end{cases} \quad R_{BP} = 4 H_{OP} H_{MS} / \lambda, \quad (2)$$

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where P_e – equivalent isotropic radiated power (EIRP) of MS - source of EMF, H_{OP}, H_{MS} – heights of OP and MS above the underlying surface correspondingly; λ - wavelength (for separate relatively narrow frequency bands allocated for cellular communications it can be accepted λ≈const); R – distance between OP and MS - source of EMF.

The MS antenna's electrical size l take an intermediate position between electrically small antennas ($l << \lambda$) and electrically large antennas ($l > 2.5\,\lambda$) at cellular communications. That's why on distances between OP and cellular MS verge towards λ, the model (2) actually loses its adequacy, taking into consideration [7-9]. And if at estimation of (1.1), (1.2) the required levels of probability $p \geq 0.9$ corresponds to so small distances between OP and MS, the procedures [1-5] also becomes to be of inadmissible inaccuracy.

The goal of the given paper is the analysis of influence of physical limits of model (2) on adequacy of procedures (1.1), (1.2) and technique [1-5] at the probabilistic analysis of predominating levels and dynamic range of EMF of cellular MS, and also at the analysis of the total electromagnetic background (EMB) created by these EMF sources near to the ground surface.

III. Reference Conditions

In [1,2,4,5] the CDF $F(\Pi_N)$ $F(D_N)$ are defined by two different ways:

1. By use of well-known Poisson model of uniform stochastic spatial m-dimensional distribution of point EMF sources of equal EIRP with average spatial density ρ in OP vicinity. As the result of analysis of statistical features of mutual spatial disposition of OP and these point EMF sources, and also taking into account their interaction according to (2), the CDF $F(D_H)$ can be received for probability of dynamic range D_H of an EMF of the point source which is the H-th on distance from OP [2,4]:

$$F(D_H)=\Gamma(H,N_a D_H^{-m/\nu})/\Gamma(H); \qquad (3)$$

$$D_H \in [0,\infty], N_a \geq 0, H>0, m>0, \nu>0;$$

$$\Gamma(H,N_a D_H^{-m/\nu})=\int_{N_a D_H^{-m/\nu}}^{\infty} exp(-x)\cdot x^{H-1}dx;$$

in these expressions ν - the parameter characterizing conditions of RWP to OP of the EMF of the point source which is the H-th nearest to OP; for free-space RWP $\nu = 2$; N_a - the conditional average amount of point EMF sources placed in some circle area of radius R_{max} round the OP (in which RWP conditions are fixed: ν = const) on condition that the average spatial density of point EMF sources in this circle area is constant and equal to its average density in OP vicinity; in this case N_a is equal to the amount of EMF in OP with levels above the threshold Π_{min} which corresponds to RWP losses on distance R_{max} between OP and point EMF source; $\Gamma(H, N_a D_H^{-m/\nu})$ – incomplete gamma-function of the second type.

2. On the basis of analysis of probabilistic characteristics of k-th order statistics $D_{(k)}$ generally in N-volume sampling of values of EMF levels which is present in OP [1,5]:

$$F_N(D_{(k)})=\frac{1-B'_{(D_{(k)}^{-m/\nu})}(H,N-H+1)}{B(H,N-H+1)}, D_{(k)} \in [1,\infty] \qquad (4)$$

$$B(H,N-H+1)=\int_0^1 t^{H-1}(1-t)^{N-H}dt=\frac{\Gamma(H)\Gamma(N-H+1)}{\Gamma(N+1)}$$ – beta-function;

$$B'_{(D_{(k)}^{-m/\nu})}(H,N-H+1)=\int_0^{D_{(k)}^{-m/\nu}} t^{H-1}(1-t)^{N-H}dt$$ – incomplete beta-function.

At $\nu = 2$ (free-space RWP), $m = 2$ (terrestrial distribution of EMF sources) the simplification of the model (3) at $H = 1$, and also of the model (4) at $k = N >> 1$, make it possible to reduce the procedure (1.2) to the following form [1,2]:

$$D_{N max}(p)=-N/ln\, p,\ lim_{p\to 1} D_{N max}(p)=N/(1-p). \qquad (5)$$

Usage of procedure (1.1), (1.2) is stipulated by the following. The probability distribution of EMF power characteristics (Π, D, etc.) in OP, which occurs at uniform random spatial distribution of EMF sources around OP and at model (2) of RWP conditions (which do not take into consideration the presence of reactive near-field region nearby EMF sources), is of hyperbolic type, and have no initial moments [1,4,5]. This circumstance defining the presence of prevaling EMF in given EMF ensemble, and also does not allow to estimate the total level of EMB intensity in OP by tradition approach as a scalar sum of EMF average intensities.

Procedure (1.1), (1.2) based on models (3),(4),(5) is applied at an estimation of critical conditions of operation of radio systems and, in particular, is proposed for an estimation of forced ecological risks provided by the intensive usage of cellular MS [3]. Nevertheless, the influence of physical limits of RWP model (2) which is adequate only outside the MS near-field region, on estimation of D_{Nmax}, Π_{Nmax} values, is not investigated for the present time, although the region of small R corresponds to the concerned domain of models (3),(4),(5).

Let's use below the following conditions and limitations, traditional at analysis of EMB created by radio equipment of cellular communications:

1. Let's consider situations, when MS height H_{MS}, and also OP elevation H_{OP} above the ground surface are equal to the man's height: $H_{OP} \approx H_{MS} \approx$ 1.5-2m.

2. Let's consider the domain of EMF wavelengths $\lambda \approx$ 0.11-0.33 m of UHF frequency range, which corresponds to basic frequency bands of GSM, UMTS and LTE cellular systems. For these wavelengths and elevations above surface the radius of OP vicinity of free-space RWP from MS is equal to $R_{BP} \approx$ 25-150 m.

3. Taking into account the data [10,11] concerned the average terrestrial density ρ_{MS} and specific voice traffic

intensity E_{TR} in the cities, let's consider situations where $\rho_{MS} = 10^3$-10^5 MS/km^2 (10^{-3}-10^{-1} MS/m^2) and E_{TR} = 0.05-0.08 Erl.; in these situations, the average terrestrial density of the radiating MS $\rho_r = \rho_{MS}E_{TR} \approx 5\cdot10^{-5} \ldots 10^{-2}$ MS/m^2.

4. Taking into account the possible restrictions on types and electric sizes of antennas of cellular MS, we introduce the following restrictions on the left boundary of the domain of definition of distances R of the model (2):

$$R_{min} \le R \le R_{BP}\,, R_{min1} \le R_{min} \le R_{min3}\,; \tag{6}$$

$$R_{min1} = \lambda/2\pi;\; R_{min2} = \lambda/2;\; R_{min3} = \pi\lambda/2 \approx 1.6\lambda:$$

in connection with rather small electrical sizes of MS dipole antennas, it is interesting to investigate the following alternatives of this restriction [7-9]:

- "Pessimistic" alternative of estimation of prevaling EMF levels and EMB created in OP at $R_{min1}=\lambda/2\pi$; in this case the domain of R cover the full radiating region of electrically small antennas and corresponds to the conditional boundary between reactive near-field and transition (radiating near-field) regions of these antennas,
- The alternative at $R_{min2}=2l^2/\lambda$, which correspond to the restrictions often used in practice;
- "Optimistic" alternative of estimation of prevaling EMF levels and EMB created in OP at $R_{min3}=\pi\lambda/2$; in this case on the left boundary of the R definition domain the radiated power density will be ≈30 dB greater than the reactive power density (for electrically small antennas).

IV. Results

Restriction alternatives (6) make it possible to get over the most significant difficulties in usage of models (3), (4), associated with the absence of the initial moments of these distributions.

1. At the terrestrial random uniform distribution of radiating MS (m = 2) with average density ρ_r [MS/m^2],

- the ensemble of N_{ar} of EMF of these MS allocated in OP free-space RWP (ν = 2) vicinity of radius R_{max} ($R_{BP} \ge R_{max} >> R_{min}$), is observed in OP, and
- the hyperbolic probability density functions (PDF) of absolute $w(\Pi)$ and relative $w(B)$ power parameters corresponds to this EMF ensemble:

$$w(\Pi)=\frac{\Pi_{min}Q_0}{\Pi^2}, m_1(\Pi)=\Pi_{min}Q_0 ln\frac{\Pi_{max}}{\Pi_{min}}, \Pi_{min} \le \Pi \le \Pi_{max}; \tag{7.1}$$

$$w(B)=Q_0/B^2, B=\Pi/\Pi_{min}; m_1(B)=Q_0 lnB_{max}, ; \tag{7.2}$$

$$1 \le B \le B_{max}=\Pi_{max}/\Pi_{min}=(R_{max}/R_{min})^2;$$

$$\Pi_{min}=P_e/\left(4\pi R_{max}^2\right), \Pi_{max}=P_e/\left(4\pi R_{min}^2\right);$$

$$Q_0=\Pi_{max}/(\Pi_{max}-\Pi_{min})=B_{max}/(B_{max}-1)\to 1;$$

$$N_{ar}=\rho_r\pi\left(R_{max}^2-R_{min}^2\right)\approx\rho_r\pi R_{max}^2.$$

2. Consequently for these conditions the average total EMF intensity (absolute $\Pi_{\Sigma a}$ and relative B_Σ) defined in the form of a scalar sum of corresponding average values of power parameters of all N_{ra} EMF of radiating MS from R_{BP} vicinity of OP, can be defined:

$$\Pi_{\Sigma a}=N_{ra}m_1(\Pi)=\begin{cases}(L_{TMS}/4)ln\left(64\pi^2H_{OP}^4/\lambda^4\right), R_{min}=\lambda/2\pi;\\ (L_{TMS}/4)ln\left(64H_{OP}^4/\lambda^4\right), R_{min}=\lambda/2;\\ (L_{TMS}/4)ln\left(64H_{OP}^4/\left(\pi^2\lambda^4\right)\right), R_{min}=\pi\lambda/2;\end{cases} \tag{8}$$

$$B_\Sigma=N_{ra}m_1(B)=N_{ra}Q_0 lnB_{max}; \tag{9}$$

$$N_{ra}=\rho_r\pi\left(R_{BP}^2-R_{min}^2\right)\approx 16\pi\rho_r H_{OP}^4/\lambda^2;\; L_{TMS}=P_e\rho_r.$$

Ex facte, $\Pi_{\Sigma a}$ and B_Σ dependence on alternatives of R_{min} definition (restriction) reduces a practical significance of estimates (8),(9). Nevertheless, availability of (8),(9) allows to extend capabilities of the approach [12,13] of an estimation of total EMB intensity created by terrestrially distributed cellular MS, on the basis of an estimation of an electromagnetic loading on territory L_{TMS}, created by these MS. This extension can be achieved by supplement the procedure (1.1),(1.2) with the procedure of a conditional estimation of the average EMB intensity, created by MS near the ground surface.

3. Further, the total average EMF intensity in OP created by similar MS set allocated randomly uniformly in the region of interference RWP ($R \ge R_{BP}$), can be also defined. At the same characteristics ρ_{AC}, P_e, E_{TP} of the terrestrial distribution and operation of these MS, the ensemble of corresponding EMF exceeding a threshold of radio reception sensitivity Π_{min} in OP, owing to model (2) peculiarity for this region (ν = 2), has the following statistical characteristics [12]:

$$w(\Pi)=\frac{\sqrt{\Pi_{max}\Pi_{min}}}{2\Pi^{3/2}\left(\sqrt{\Pi_{max}}-\sqrt{\Pi_{min}}\right)}\approx\frac{\sqrt{\Pi_{min}}}{2\Pi^{3/2}}, \Pi_{min} \le \Pi \le \Pi_{max};$$

$$m_1(\Pi)=\sqrt{\Pi_{max}\Pi_{min}}=P_e/\left(4m^2\pi R_{BP}^2\right);$$

$$\Pi_{max}=P_e/\left(4\pi R_{BP}^2\right), \Pi_{min}=P_e/\left(4m^4\pi R_{BP}^2\right);$$

$$\Pi_{\Sigma MSm}=\lim_{m\to\infty}\left(N_{arm}m_1(\Pi)\right)=\lim_{m\to\infty}\left(\frac{P_e\rho_r\left(m^2-1\right)}{4m^2}\right)=\frac{P_e\rho_r}{4}=\frac{L_{TMS}}{4}. \tag{10}$$

4. In particular, expressions (8)-(10) allow to update the radius R_{BPe} (earlier proposed in [12]) of the equivalent OP vicinity with free RWP between MS and OP, filled up randomly uniformly with average density ρ_{AC}, by MS set with parameters P_e, E_{TP}, which create in OP the total EMB of the same intensity, as the sum of intensities of the total EMB, created by the MS set from the R_{BP} vicinity with free-space RWP, and all MS allocated outside this vicinity in the region of interference RWP:

$$R_{BPe}=R_{BP}\sqrt{e}\approx 1.65R_{BP}. \tag{11}$$

5. PDF of the peak value $\Pi_{(N)}$ in N-volume sampling of PFD values distributed according to (7.1), can be defined with the use of technique [14]:

$$w\left(\Pi_{(N)}\right)=N\left[F\left(\Pi_{(N)}\right)\right]^{N-1}w\left(\Pi_{(N)}\right)=NQ_0^N\left(1-\frac{\Pi_{min}}{\Pi_{(N)}}\right)^{N-1}\frac{\Pi_{min}}{\Pi_{(N)}^2};\quad(12.1)$$

PDF of the peak value $D_{(N)}$ in corresponding N-volume sampling:

$$w\left(D_{(N)}\right)=NQ_0^N\left(1-\frac{1}{D_{(N)}}\right)^{N-1}\frac{1}{D_{(N)}^2},1\le D_{(N)}\le D_{(N)max}=\frac{\Pi_{max}}{\Pi_{min}};\quad(12.2)$$

CDF of the N-th order statistics $D_{(N)}$ in N-volume sampling:

$$F\left(D_{(N)}\right)=NQ_0^N\left(B(1,N)-B_{\frac{1}{D_{(N)}}}(1,N)\right);1\le D_{(N)}\le D_{(N)max};\quad(12.3)$$

average of distribution of the N-th order statistics $D_{(N)}$ in N-volume sampling:

$$\begin{aligned}m_1\left(D_{(N)}\right)&=\int_1^{D_{(N)max}}D_{(N)}w\left(D_{(N)}\right)dD_{(N)}=\\&=NQ_0^N\int_1^{D_{(N)max}}\left(1-\frac{1}{D_{(N)}}\right)^{N-1}\frac{dD_{(N)}}{D_{(N)}}.\end{aligned}\quad(13)$$

In extreme case, taking into account [15, Item 9.558]

$$lim_{D_{(N)max}\to\infty}\left(m_1\left(D_{(N)}\right)\right)=N\cdot ln\left(D_{(N)max}\right).\quad(14)$$

Thus, at a large dynamic range of signals in OP expressions (9) and (14) are coincide, i.e. the average total relative intensity (9) of EMB is determined by the average relative intensity of the most powerful EMF in OP (and, of course, this conclusion is also reasonable for absolute average total EMB intensity and absolute intensity of prevaling EMF in OP). It confirms a conclusion [2] that at random spatial distribution of EMF sources, the total intensity of EMB created by these sources in OP is determined by the level of predominating EMF.

On Fig. 1,2,3 curves reproducing dependences of quantile (1.2) on average terrestrial density ρ_r of radiating MS for uniform conditions of EME creation in OP ($\lambda = 0.15$ m, $H_{OP} \approx H_{MS} \approx 2$ m) and for different physical limits of RWP model (2) $R_{min} = R_{min1} = \lambda/(2\pi)$ (Fig.1), $R_{min} = R_{min2} = \lambda/2$ (Fig.2) и $R_{min} = R_{min3} = \pi\lambda/2$ (Fig.3) are given. These curves are received for distribution (12.3) considering the existing of MS reactive near-field zone (solid lines), and for distribution (3) in reduced form (5) which are ignoring the existing of near-field zone (dotted lines). They are calculated for $p = 0.9$ (curves No.1) $p = 0.99$ (curves No.2) $p = 0.999$ (curves No.3) and $p = 0.9999$ (curves No.4).

Comparison of solid and dotted lines for different probabilities p testifies that in cases of the greatest practical interest ($\rho_r \le 10^{-2}$ MS/m^2 , $0.9 \le p \le 0.99$), taking into account the existing of MS reactive near-field zone in a form of limiting the minimally possible distance between OP and radiating MS, does not result in appreciable differences in estimations (1.1),(1.2) with the use of models (3), (4), (5) with the definitional domain, not restricted on the right (or with the use of RWP model (2) with the definitional domain, not restricted on the left).

6. Equating (5) and (9), and also equating (5) and (14), it is possible to become sure, that probability of non-exceeding of the average total relative EMB level in OP by the relative level of a predominating signal (i.e. by dynamic range D_N of a signal of the nearest radiating MS, or by a value of N-th order statistics $D_{(N)}$ in N-volume sampling of relative values of EMF levels) practically does not depend on a sample size (or on EME complexity) and is determined by an expression

$$\begin{aligned}&p\left(D_{Nmax}\le B_\Sigma\right)\approx p\left(D_{(N)}\le B_\Sigma\right)\approx exp\left(-1/\left(Q_0 ln\left(D_{(N)max}\right)\right)\right)\approx\\&\approx exp\left(-1/ln\left(D_{(N)max}\right)\right).\end{aligned}\quad(15)$$

This probability is no less than 0.90-0.93 for UHF frequency bands of cellular communications (0.8-3.0 GHz) and 1.5-2.0 m of OP and MS elevation above surface. Thus, if sufficient system level of EMC and electromagnetic safety in OP is ensured at non-exceeding of accepted EMB maximum permissible level (MPL) by MS EMF level with probability $p \ge 0.9$, the accounting of contribution of EMF of MS in total EMB intensity, created in OP both by base and mobile radio equipment of cellular communications, can be effected by direct summation of an average values (8).

7. The level $p \ge 0.99$ accepted in [3], approximately correspond to the level of the total EMB intensity

$$B_{\Sigma(p=0.99)}\approx 2\pi N_{ra}m_1(B)\approx 2\pi N_{ra}lnB_{max};\ R_{min}=\lambda/2.\quad(16)$$

$$\Pi_{\Sigma(p=0.99)}=\pi L_{TMS}ln\left(2R_{BP}/\lambda\right)\approx 25L_{TMS}.$$

This level can be compared directly with an accepted MPL value (in related form) in cases when contribution of EMF of cellular base stations is rather insignificant, and EMB level in OP is determined by the prevaling EMF of the nearest MS, for example, in concourse areas.

Inaccuracy of usage of (16) instead of quantiles of level $p \ge 0.99$ of distributions (12.3),(3) can be evaluated, using following ratios:

a) The ratio (17) of an estimated value (16) of the total relative EMB intensity created in OP by EMF of MS, and of an estimated value of a quantile (1.2) for $p = 0.99$ of distribution (12.3) of the N-th order statistics $D_{(N)}$ in N-volume sampling, received with a glance of physical restrictions (6) on an existence domain of RWP model (2):

$$U_S=B_{\Sigma(p=0.99)}/D_{(N)}(p=0.99),\quad(17)$$

$$D_{(N)}(p=0.99)=arg\left\{F\left(D_{(N)}\right)=0.99\right\}.$$

b) The ratio (18) of an estimated value (16) of the total relative EMB intensity created in OP by EMF of MS, and of an estimated value (5) of the dynamic range of these EMF in OP, received for the random Poisson MS terrestrial distribution of radiating MS at $p = 0.99$ without a glance of physical restrictions (6) on an existence domain of RWP model (2):

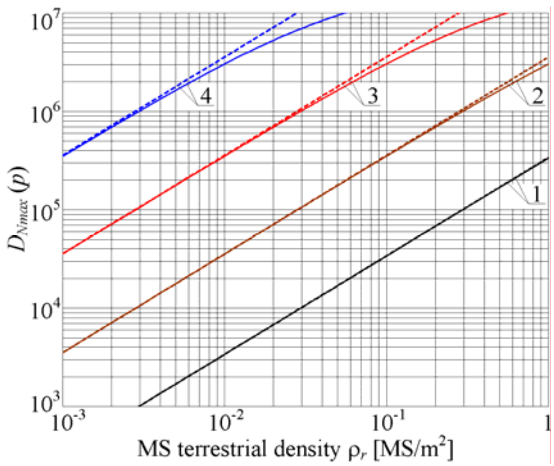

Fig. 1. Dependences of related levels $D_{Nmax}(p)$ of prevaling EMF of radiating MS nearest to OP, on average terrestrial density ρ_r of radiating MS, for $R_{min1} = \lambda/(2\pi)$ and different p, considering MS reactive near-field zone (solid lines) and ignoring it (dotted lines)

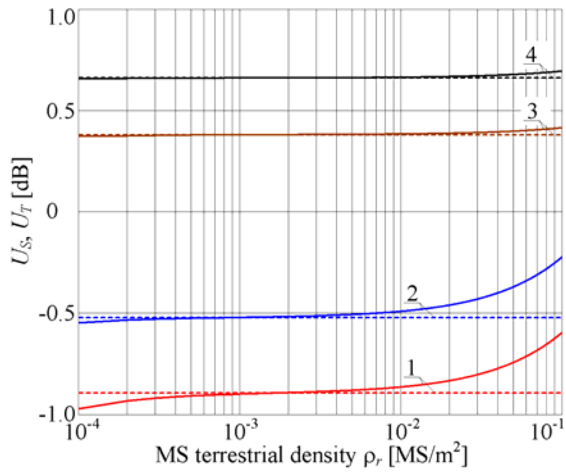

Fig. 4. Dependences of ratios U_S (solid lines) и U_T (dotted lines) on average terrestrial density ρ_r of radiating MS, for different elevation $H_{OP} \approx H_{MS}$ over the ground surface, different working frequencies, and $R_{min1} = \lambda/(2\pi)$

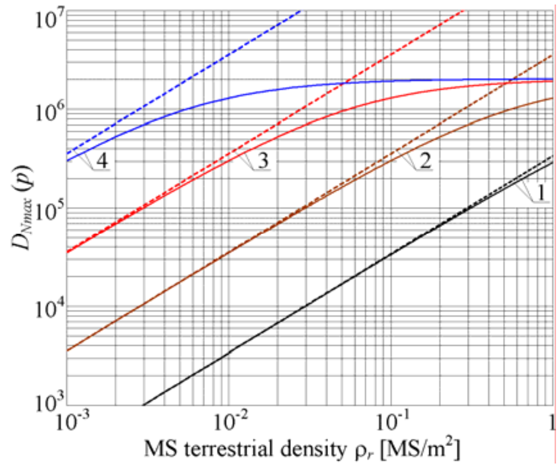

Fig. 2. Dependences of related levels $D_{Nmax}(p)$ of prevaling EMF of radiating MS nearest to OP, on average terrestrial density ρ_r of radiating MS, for $R_{min2} = \lambda/2$ and different p, considering MS reactive near-field zone (solid lines) and ignoring it (dotted lines)

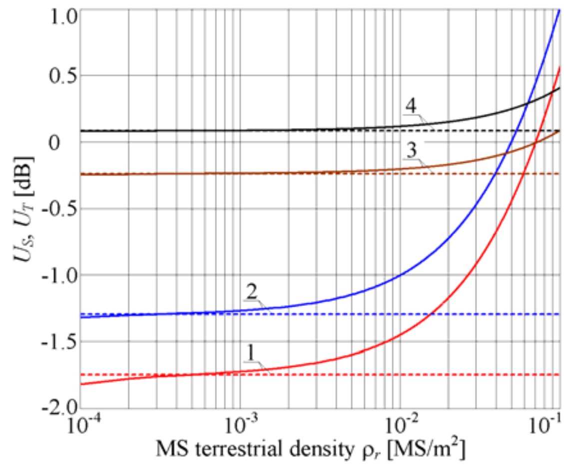

Fig. 5. Dependences of ratios U_S (solid lines) и U_T (dotted lines) on average terrestrial density ρ_r of radiating MS, for different elevation $H_{OP} \approx H_{MS}$ over the ground surface, different working frequencies, and $R_{min2} = \lambda/2$

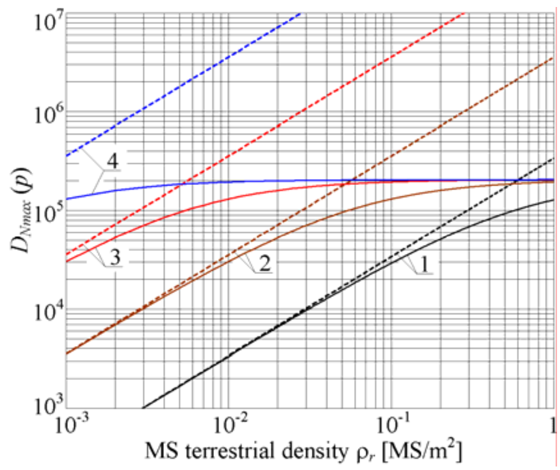

Fig. 3. Dependences of related levels $D_{Nmax}(p)$ of prevaling EMF of radiating MS nearest to OP, on average terrestrial density ρ_r of radiating MS, for $R_{min3} = \pi\lambda/2$ and different p, considering MS reactive near-field zone (solid lines) and ignoring it (dotted lines)

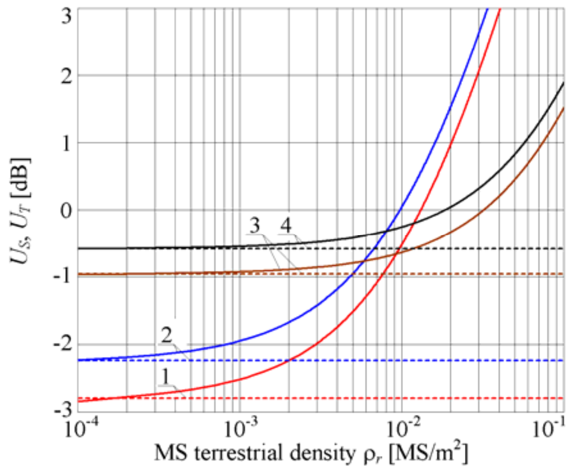

Fig. 6. Dependences of ratios U_S (solid lines) и U_T (dotted lines) on average terrestrial density ρ_r of radiating MS, for different elevation $H_{OP} \approx H_{MS}$ over the ground surface, different working frequencies, and $R_{min3} = \pi\lambda/2$

$$U_T = \frac{B_{\Sigma(p=0.99)}}{D_{N\,max}(0.99)}. \quad (18)$$

Curves reproducing dependences of ratio U_S (solid lines) and ratio U_T (dotted lines) on average terrestrial density ρ_r of radiating MS for different heights $H_{OP} \approx H_{MS}$ of OP and MS above ground surface and different operating frequencies f are given on Fig. 4,5,6. Curves on Fig.4 are calculated for $R_{min} = \lambda/(2\pi)$, curves on Fig.5 are received for $R_{min2} = \lambda/2$, curves on Fig.6 are received for $R_{min3} = \pi\lambda/2$. On these pictures the following pairs of curves $\{U_S(\rho_r),\ U_T(\rho_r)\}$ are placed from bottom to top: for $H_{OP} \approx H_{MS} = 1.5$ m, $f = 1$ GHz (curves No.1), for $H_{OP} \approx H_{MS} = 2$ m, $f = 1$ GHz (curves No.2); for $H_{OP} \approx H_{MS} = 1.5$ m, $f = 3$ GHz (curves No.3), and for $H_{OP} \approx H_{MS} = 2$ m, $f = 3$ GHz (curves No.4).

The analysis of these curves testifies that inaccuracies of usage of estimated value (16) instead of quantiles of level $p \geq 0.99$ of distributions (12.3),(3) at an estimation of EMC and electromagnetic safety on socially-significant objects with the use of procedure [3], based on (3)-(5), do not exceed 2-3 dB. Differences between the corresponding curves are reducing at the increase of ρ_r, and f ; these inaccuracies are smallest

- at increase of operating frequency, in particular, on frequencies of GSM-1800, UMTS and LTE, and also
- in critical situations of the highest spatial density ρ_r of radiating MS, that occurs in concourses, crowds, public transportation, etc.

It enables application of the ratio (16) at implementation of procedures [3] of diagnostics of electromagnetic ecology of socially-significant objects, at computer diagnostics of EME in areas of intensive usage of mobile communications, and also at intersystem EMC diagnostics of radio systems operating on the secondary basis on areas with high terrestrial density of mobile EMF sources of radio services operating in allocated frequency bands on the primary basis.

V. Conclusion

The considered limitations (6) on existence domain of RWP model (2) at real values of terrestrial density of radiating MS, with reference to the cellular MS which antenna's electrical sizes does not exceed $\lambda/2$, in practice

- does not affect on adequacy of procedures (1.1), (1.2) with the use of models (3),(4),(5), but
- allows to simplify significantly a probabilistic assessment of levels of predominating signals of cellular MS in places of heavy use of cellular communications, and an estimation of the total intensity of EMB component, created by subscriber radio equipment of cellular radio networks.
- in whole, it is possible to use $R_{min2}=2l^2/\lambda \approx \lambda/2$ as a conditional boundary of existence domain of model (2) for cellular MS, as it is accepted in [16,17].

In these conditions decrease of an electrical size of MS antennas, diminishing a conditional radius of a near-field region of MS radiation in comparison with $R_{min} \approx \lambda/2 \ldots \pi\lambda/2$, practically does not improve the objectivity of estimations with usage of (3),(4),(5),(8),(9),(12.1)-(15), with the exception for lower operational frequencies of cellular communications ($\geq$1.0 GHz).

At local concentration of MS in OP vicinity watched on small objects, it is necessary to use an estimate value of radius of area of MS concentration $R_{max} < R_{BP}$. (and corresponding values of Π_{min}, B_{max}) instead of radius R_{BP} of zone of free-space RWP in models resulted above. As the total level of EMB intensity in OP is determined by the level of predominating EMF of MS, decrease of the size of analyzable OP vicinity practically will not influence on results of analysis with usage of (3),(4),(7.1)-(9),(12.1)-(15); the main influence on EME component in OP created by the set of radiating MS will be rendered by values ρ_r, E_{TP}, P_e in OP vicinity.

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