ESTIMATION OF THE LEVEL OF THE ELECTROMAGNETIC BACKGROUND FORMED BY MASS USE OF CELLULAR COMMUNICATIONS

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Abstract. Results of the mathematical analysis and estimation of average intensity of "quasi stationary" electromagnetic background formed by sum of fields of cellular communication user's stations minus the prevailing signal of the nearest radiating station in places of a mass people congestion are included. It is shown, that the basic contribution to its average intensity on places of a mass people congestion is brought with electromagnetic radiations of user's stations, available in vicinities of a point of supervision on distances no more than 100-300m on which free propagation of radio waves takes place. This background with probability not lower than 0,1-0,2 is exceeded by level of an electromagnetic field of the nearest radiating user's station.

Introduction

It is considered, that in a cellular network the main danger to men's health is represented with electromagnetic radiation (EMR) of personal user's stations (US) or a cellular telephones. And if the owner of a cellular telephone, using it, exposes itself to voluntary ecological risk, for surrounding people EMR of his phone is the factor of the compelled ecological risk. The total electromagnetic background formed as a sum of EMR of many US in conditions of mass use of cellular communications, sometimes can be the most essential reason of deterioration of ecological conditions in places of a mass congestion of people.

Researches carried out before [1-3] have allowed to execute estimations of ecological danger of the electromagnetic background formed by personal radio equipment of information services of the population, in conditions of mass distribution of a mobile radio communication services, however in these works all basic estimations are made under the assumption that statistical characteristics of total EMR level of cellular communication USs in any chosen point of space are practically defined by corresponding EMR characteristics of the nearest US. However the big interest is represented with estimations of intensity of the electromagnetic background formed by all set of the USs, available in the certain area of space with the given territorial density of US's terrestrial distribution, for example, in places of a mass congestion of people.

Estimation of total intensity of the electromagnetic background formed by EMR of cellular US, at random uniform territorial accommodation of US in a vicinity of a point of supervision.

Basing on reasons [1-3], we shall define a vicinity around of some point of supervision, within of which a random territorial accommodation of USs - sources of EMR is occur, and it is possible to use model of radio wave propagation (RWP) in free space. The radius of this vicinity $\mathbf{R_0}$ and its area $\mathbf{S_0}$ are approximately equal correspondingly $\mathbf{R_0=0,15\text{-}0,3}$ km and $\mathbf{S_0}$=0,1-0,3 km^2 for GSM-1800, IMT-2000 and $\mathbf{R_0=0,05\text{-}0,2}$ km and $\mathbf{S_0}$=0,01 -0,1 km^2 for GSM-900. Taking into account estimations [4,5], and also the practically occurred USs terrestrial density $\boldsymbol{\rho}$ in places of a mass congestion of people in various conditions situations with $\boldsymbol{\rho}$=[$10^3 \div 2\cdot 10^6$] US/km^2 are of great interest. Taking into account the known data on the average traffic created by one subscriber of a network (0,025 Erl) with the tendency of increase up to 0,05-0,08 Erl), we are interested to study situations with $\boldsymbol{\rho}$=[$10^2 \div 2\cdot 10^5$] radiating US/km^2. Thus, in a considered vicinity of a point of supervision number of simultaneously radiating USs can be [$10^1 \div 10^5$]

At an estimation of total intensity of the electromagnetic background formed by EMR of USs at random uniform territorial accommodation of USs in a vicinity of a point of supervision a following models [6,7] of probability distributions of a dynamic range of signals in this point can be used:

a) Probability density distribution $\mathbf{w(D_P)}$ and probability density function $\mathbf{F(D_P)}$ of dynamic range $\mathbf{D_P}$ of signals radiating by USs, placed randomly with Poisson stochastic mode in a vicinity of radius $\mathbf{R_0}$ of a point of supervision:

$$w(D_P) = \frac{N_a^H m}{\nu\Gamma(H)} D_P^{-(Hm+\nu)/\nu} \exp(-N_a D_P^{-m/\nu}); \qquad (1)$$

$$P(D_P) = \frac{\Gamma(H, N_a D_P^{-m/\nu})}{\Gamma(H)};$$

$$D_P \geq 0,\ N_a \geq 0,\ \nu > 0;\ m > 0; \qquad (2)$$

$\Gamma(H, N_a D_P^{-m/\nu}) = \int\limits_{N_a D_P^{-m/\nu}}^{\infty} \exp(-x)\cdot x^{H-1} dx$ - incomplete Gamma - function of the second kind. At terrestrial type of USs spatial accommodation and free space RWP it is necessary to use **m=2**, **ν =2**.

Parameter N_a of this distribution is meaningful an average amount of EMR sources in some vicinity of a point of supervision. According to [6,7] it can make sense an average amount of EMR sources with equivalent isotropic radiated power (EIRP) P_{etr} in spherical area of potential interfering interaction of radius $R_{max} = (P_{etr}/(4\pi\Pi_{min}))^{1/2}$, limited by US radio reception sensitivity Π_{min} of on the main channel of reception in case the average spatial density of sources in all this area is constant and equal to average density ρ of random spatial accommodation of sources in vicinity of supervision point:

$$N_a = GR_{max}^m = \rho\pi^{m/2}R_{max}^m \big/ \Gamma(1+m/2) \geq 0\,; \qquad (3)$$

In this case dynamic range D_P (level Π_H normalized to sensitivity value Π_{min}) of **H**-th signal on signal strength range in a point of supervision is defined as ratio $D_P = \Pi_H/\Pi_{min}$.

However in a considered case it is more convenient to normalize dynamic range D_P of signals in a point of supervision to intensity Π_0 of an US signal in this point if the US it is removed from this point on distance R_0. In this case $D_P = \Pi_H/\Pi_0$, and the ratio (3) for parameter N_a of distribution (1), (2) gets the following kind: $Na = \pi\rho R_0^2$. Thus, distribution (1), (2) appears a distribution of normalized level D_P of **H**-th on US signal strength in a point of supervision.

Expression for the initial moments of distribution (1), (2) has the following kind:

$$m_n(D_P) = N_a^{n\nu/m}\frac{\Gamma(H - n\nu/m)}{\Gamma(H)}, H - n\nu/m > 0\,. \quad (4)$$

b) Probability distribution of a dynamic range of signals as distribution of range of sample of values of intensity of **N** signals distributed under the hyperbolic law [6,7].

If at a point of supervision **N** signals are present with hyperbolic distribution on power parameter, that, transforming sample of values $\Pi_1, \Pi_2..., \Pi_N$ in variational series $D_{(1)} = \Pi_{(1)}/\Pi_{min}$, $D_{(2)} = \Pi_{(2)}/\Pi_{min}...$, $D_{(N)} = \Pi_{(N)}/\Pi_{min}$, using known rules it is possible to find probability density distribution of **k**-th serial statistics $D_{(k)}$ of these series:

$$\begin{aligned} w\left(D_{(k)}\right) &= \frac{m\Gamma(N+1)}{\nu\Gamma(k)\Gamma(N-k+1)}\times \\ &\times\left[1 - D_{(k)}^{-m/\nu}\right]^{k-1} D_{(k)}^{-\frac{m}{\nu}(N-k+1)-1} = \\ &= \frac{m\Gamma(N+1)}{\nu\Gamma(H)\Gamma(N-H+1)}\times \\ &\times\left[1 - D_{(k)}^{-m/\nu}\right]^{N-H} D_{(k)}^{-\frac{m}{\nu}H-1}, k = N - H + 1; \end{aligned} \qquad (5)$$

$$F_N\left(D_{(k)}\right) = 1 - I_{\left(D_{(k)}^{-m/\nu}\right)}(H, N-H+1); \qquad (6)$$

$I_{\left(D_{(k)}^{-m/\nu}\right)}(H, N-H+1)$ - неполная бета-функция.

Expression for the initial moments of this distribution has the following kind:

$$\begin{aligned} m_n\left(D_{(k)}\right) &= \frac{\Gamma(N+1)\Gamma(H-\nu n/m)}{\Gamma(H)\Gamma(N-\nu N/m+1)} = \\ &= \prod_{i=1}^{\nu n/m}\frac{N+1-i}{H-i}, \quad H > \nu n/m \end{aligned}, \qquad (7)$$

At big $N=N_a$ estimations (4) and (7) practically coincide, however even for the most favorable case corresponding to USs random territorial accommodation **(m=2)** and free-space RWP **(ν =2)** these estimations exist only for the 2-d, 3-rd and other signals on intensity, and are absent for a highest-level (prevailing) signal in a point of supervision. Estimations of danger of excess in this point of the defined threshold level by intensity of a prevailing signal are given in [1-3]. Expressions (4), (7) allow to calculate total intensity of all other signals in a point of supervision, summing average values of signals intensity of all others N_a**-1** (using (4)) or **N-1** (using (7)) signals accept prevailing signal intensity.

Thus, at constant density **ρ** of USs in a vicinity of a point of supervision total intensity of an electromagnetic background in this point as scalar sum $\Pi_{\Sigma 1}$ of values of power flux density expressed in W/m^2 on the given point from EMR of ambient USs, except for the nearest US, is defined by an expressions:

$$\Pi_{\Sigma 1} = \frac{P_{etr}\rho}{4}\sum_{H=2}^{int[N_a]}\frac{1}{H-1}\,; \qquad (8)$$

$$\Pi_{\Sigma 1} \approx \frac{P_{etr}}{4R_0^2}N_a^{1,12}, \quad N_a = \pi R_0^2\rho\,; \qquad (9)$$

In these expressions for $\Pi_{\Sigma 1}$, given in W/m^2, value **ρ** should be expressed in US/m^2, radius of vicinity R_0 - in meters, and average EIRP of US P_{etr} - in watts. Dependences (8), (9) are illustrated by curves on fig. 1, received for R_0**=300m**, P_{etr}**=0,1W**. In this figure the continuous line corresponds (8), a dashed line - to approximation (9). It is easy to notice, that in the given special case at **ρ**>0,3 calculated average intensity of an electromagnetic background exceeds size of a maximum permissible level of -20 dBm/sm^2 (0,1 W/m^2), regulated by effective standards [8].

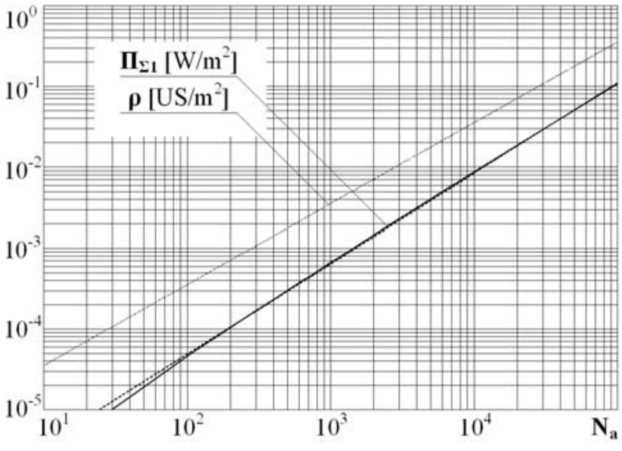

Fig. 1.

Outside a vicinity of radius $\mathbf{R_0}$ of a conditions of radio waves propagation changes; here it is required to take into account influence of the beams direct and reflected from a surface. Using models [9], it is possible to receive the following expression for average intensity of an electromagnetic background in a point of the supervision formed by EMR of USs, located with average density $\boldsymbol{\rho_2}$ on distances from $\mathbf{R_0}$ up to distance $\mathbf{R_{max}}$ conditionally corresponding to boundary of direct visibility zone:

$$\Pi_{\Sigma 2} = \mathbf{N_2}\frac{2\Pi_\mathbf{b}\left(1-\mathbf{K}_\nu^{2-\nu}\right)}{(\nu-2)\left(\mathbf{K}_\nu^2-1\right)},\quad \mathbf{N_2} = \pi\left(\mathbf{R}_{\mathbf{max}}^2-\mathbf{R}_0^2\right)\rho_2,\quad \Pi_\mathbf{b} = \frac{\mathbf{P_{etr}}}{4\pi\mathbf{R}_0^2},\ \mathbf{K}_\nu = \frac{\mathbf{R_{max}}}{\mathbf{R_0}}. \tag{10}$$

Relationships (10) are illustrated by curves on fig.2, received at $\mathbf{R_0}$=300m, $\mathbf{P_{etr}=0,1W}$, $\mathbf{K_v}$ = 40, $\boldsymbol{\nu}$ =3,5 ($\boldsymbol{\nu}$ - parameter of RWP model for the USs, accommodated outside $\mathbf{R_0}$; the accepted value $\boldsymbol{\nu}$ corresponds to Okumura-Hata RWP model). It is easy to notice, that in this case at anyone real $\mathbf{N_2}$ the rated average intensity of an electromagnetic background formed by EMR of USs from area outside $\mathbf{R_0}$ appears significantly small in comparison with intensity of the electromagnetic background formed by EMR of USs, allocated directly in a vicinity of the point of supervision in the area of free-space RWP between the USs and a point of supervision, and also in comparison with maximum permissible value (MPV) of an electromagnetic background intensity [8].

As at **m=2**, $\boldsymbol{\nu}$ =2, **H=1** probability distribution function (2) of signals dynamic ranges in a point of supervision is exponential ($\mathbf{F(D_P)=exp(-N_a/D_P)}$), the probability of non exceeding by a prevailing signal of the nearest US the average intensity $\mathbf{\Pi_{\Sigma 1}}$ of a background equal to total intensity of other signals in the considered point of supervision, will be equal to following:

$$\mathbf{P_{\Sigma 1}} = \mathbf{P}\left(\mathbf{D_P} \le \frac{\Pi_{\Sigma 1}}{\Pi_0}\right) = \mathbf{exp}\left(\mathbf{N_a} \Big/ \frac{\Pi_{\Sigma 1}}{\Pi_0}\right), \tag{11}$$

where $\mathbf{\Pi_{\Sigma 1}}$ it is defined by expressions (8), (9). And this probability of non exceeding by a prevailing signal of the nearest US the average intensity $\mathbf{\Pi_{\Sigma 1}}$ of a background for free-space RWP is appreciable enough (0,8-0,9). It is comparable to values of probabilities of absence of radio interference (reliability of communication) not lower 0,8 (0,8-0,99), used at planning and designing of radio networks of a mobile radio communications, international legal protection of frequency allocations, calculation of zones of coverage (services) and zones of a radio interference, etc. [10]. The curve of dependence of probability $\mathbf{P_{\Sigma 1}}$ on average number $\mathbf{N_a}$ of the signals exceeding in the considered point level $\mathbf{\Pi_0}$, is given below on fig. 3.

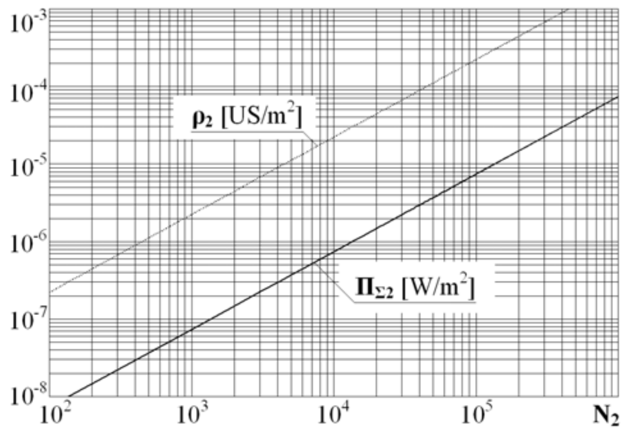

Fig. 2.

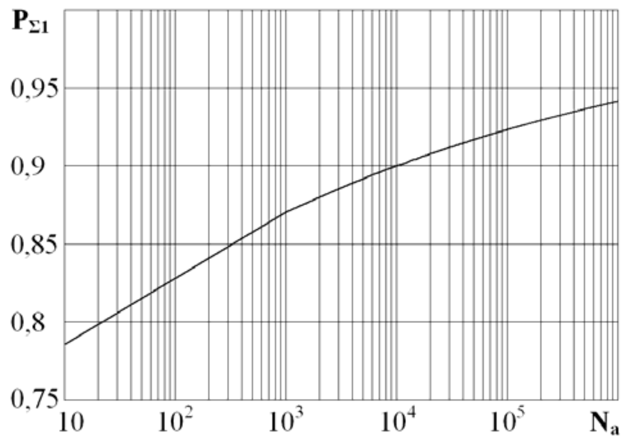

Fig. 3.

Equations (8) - (11) are received with use of models (1), (2), (5), (6) for values of a dynamic range of signals in a point of the supervision normalized not to sensitivity $\mathbf{\Pi_{min}}$ of USs on the main channel of reception, but to value of intensity $\mathbf{\Pi_0}$ of a signal of US removed from a point of supervision on distance $\mathbf{R_0}$, corresponding to radius of a vicinity of a point of supervision in which, (I) the model of RWP conditions in free space ($\mathbf{\nu}$ =2) is correct, and, (II) the terrestrial density of radiating US is appreciable and constant (**ρ =const.**).

In [11] it is shown, that when increasing of actually observable value of a dynamic range of signals the probability of that the intensity of electromagnetic field in a considered point is defined by a prevailing signal sharply grows, i.e. in the area of the big values of intensity of the electromagnetic background formed by USs EMR, the main contribution to this background is brought by prevailing EMR of the nearest US. The given position was a starting point of estimations [1-3]. However, as curves on fig. 1,3 testify, at the big US spatial density an ecological danger is defined by a cumulative electromagnetic background from all radiating USs, allocated in the place of a mass congestion of people. In this situations a total probability of excess by intensity of an electromagnetic background of value MPV regulated by effective standards [8], sharply grows.

Conclusion

The materials submitted in this paper allow to make the following conclusions:

1. The basic contribution to intensity of the electromagnetic background formed by equipment of cellular communications is injected by EMR of USs allocated in vicinity of a point of supervision on distances no more than 100-300m from this point, on which free-space RWP between a point of supervision and the USs - sources of electromagnetic fields occurs. In places of a mass congestion of people this is an EMR of the US of subscribers allocated in the given places (general purpose transport, sports action, meeting, etc.). This background with probability not lower than 0,05-0,2 is exceeded by the EMR level of the nearest active US.

2. At USs spatial density more than $\mathbf{\rho}>0{,}1\div0{,}3$ US/m^2 the average level of the "secondary" electromagnetic background formed by signals of all the USs, except a signal prevailing on a level (a signal of a nearest US), can exceed MPV [8].

3. The average intensity of an electromagnetic background formed by EMR of USs, allocated on distances more than $\mathbf{R_0}$, appears negligibly small in comparison with intensity of the electromagnetic background formed by EMR of USs, allocated in the area of free-space RWP between the US and a point of supervision, and also in comparison with MPV [8].

4. At the considerable spatial density of USs in a vicinity of a point of supervision the estimation of probability of excess of acting MPV by a cumulative electromagnetic background should be made by an approach and technique [1-3] and also taking into account a presence of "quasi-stationary" background with intensity (8),(9).

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Author is a Head of EMC R&D Laboratory of Belarusian State University of Informatics and Radioelectronics (Minsk, Belarus), Ph.D, Senior Researcher, member of IEEE. He is author of about 200 publications and patents in area of EMC and EME.

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