ENVIRONMENTAL SAFETY OF CELLULAR NETWORKS TAKING INTO CONSIDERATION ELECTROMAGNETIC BACKGROUND PRODUCED BY SYSTEMS OF PUBLIC INFORMATION SERVICE

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Abstract. The paper discusses the system analysis technique and evaluates the contribution made by the electromagnetic (EM) background, generated by cellular phones of other users, by systems of on-air radio broadcasting and diversified radio-tail objects in deterioration of environmental safety of cellular radio networks, as well as the influence of wide spreading of cellular radio communication facilities on a growing environmental risk of positioning on territories of contemporary cities of powerful transmitting centres and other-type radio-tail objects having powerful electromagnetic radiation and creating intensive EM background in densely populated places.

Introduction

Electromagnetic radiation (EMR) of a personal cellular phone or mobile station (MS) represents the greatest hazard to the human health in cellular communication. At the same time assessments of the aggregate MS EMR level and its comparison to the EMR levels of powerful television VHF-FM radio transmitters and radio transmitters of other services are of considerable interest owing to wide spreading of mobile telephony. It is evident that the greatest interest these assessments pose for the zone in the vicinity of the earth surface, where the majority of MS owners are positioned, as well as for the locations of cellular network base stations (BS), which is important in terms of evaluating the risks of enlarging BS control areas, and their service conditions on the hole.

We'll make assessments, using materials of [1-3].

MS EMR Aggregate Level in Cellular Network

If cellular network MS having their equivalent isotropic radiated power (e.i.r.p.) of P_{MS} are randomly evenly located within a circular or spherical spatial domain with a radius of R_m then in the centre of this domain the probability distribution density of power flux density (PFD) Π from MS has the form of a hyperbolic distribution [1]:

$$w(\Pi) = \frac{m\Pi_{min}^{m/\nu}}{\nu\Pi^{(m+\nu)/\nu}}\ ;\ \Pi \geq \Pi_{min} = \frac{C_\nu P_{MS}}{R_m^\nu}, \qquad (1)$$

The domain of R_m radius is a radio noticeable domain of MS EMR having e.i.r.p. of P_{MS} over the level Π_{min}; the parameters of this distribution are defined in the following manner:

– $m=3$ in case of volume positioning of the sources, $m=2$ in case of their surface (territorial) positioning, $m=1$ in case of their "linear" positioning (along a traffic artery, coast line, state border, etc.);

– Π_{min} corresponds to some minimal level, linked to values of R_m and P_{MS}; constant C_ν is referred to the nature of radiowave propagation (RWP) and may be found from a relevant RWP conditions model;

– $\nu \geq 2$ - is a parameter that characterizes the RWP type, in case of free-space RWP $\nu=2$; in case of near-earth propagation, under conditions of vegetation and urban area $2<\nu<12$ [1-3].

Using model (1) it is possible to evaluate the summary EMR level from simultaneously operated MS of all cellular networks that functionate in the spatial domain in question. This task is nontrivial as distribution (1) does not possess initial and central moments in the most interesting cases from the practical point. Distribution (1) with $m=2$ is invariant to the earth curvature and to the observation point altitude over the surface. This in particular allows evaluating the MS EMR summary level in the BS location. With the height H_{BS} of the BS antenna suspension over the surface, which allows narrowing the definitional domain of distribution (1) due to the fact, that the value of H_{BS} equals to the minimum possible distance between the BS and MS located on the surface, the average of (1) for free-space propagation has the following expression:

$$m_1(\Pi) \approx 2\Pi_{min}\ ln\left(R_m / H_{BS}\right)\ .$$

It is evident that the summary MS EMR level in the point under consideration is determined by the scalar value $\Pi_\Sigma = m_1(\Pi)N_{AV}$ of the aggregate power flux density of N_{AV} MS located in concerned domain. The average quantity N_{AV} of MS in considered area can be determined as 10^2-10^6 pers/km^2 with use of the data [4,5].

The dominant-level of MS EMR

Absence of initial and central moments of distribution (1) in case of $(m+\nu)/\nu \leq 2$ means, that in the random Π sample, there is as a rule, the largest dominant value, defined by the closest MS, belonging to a different user. In this case it may be assumed that the summary EMR level at the observation point practically corresponds to the closest MS EMR level, thus allowing to make appropriate assessments using approach [2,3], developed in application to statistical estimations of an expected signal dynamic range in space-scattered groupings of radio devices.

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Dynamic range $D=\Pi_{max}/\Pi_{min}$ of signals at the observation point is the relation of the PFD of the predominant in level signal to some threshold level. The probability p_D that the value of D will not be exceeded may be described by a ratio:

$$p_D = exp\left(-N_0 D^{-m/\nu}\right). \quad (2)$$

Here the parameter N_0 means conditional average number of MS EMR sources within some hypothetical circular (spherical) domain having the radius as below:

$$R_m = \sqrt{\frac{P_{MS}}{4\pi\Pi_{min}}}.$$

This domain may be defined as a conditional radio-noticeable domain of MS, restricted by the susceptibility Π_{min}, the MS e.i.r.p. value P_{MS} and the conditions of RWP to the observation point in space from the closest MS. The latter is a distinctive feature of this domain from the domain having R_m in radius, within which RWP conditions and MS spatial density are assumed constant (limits of adequacy in model (1)). And N_0 may be determined under the two conditions:

– Provided that the average MS EMR sources spatial density within the entire domain is constant and equals to the average density ρ [MS/km^2 in case of $m=2$] of random spatial location of MS EMR sources in the vicinity of the observation point in space (in the vicinity of the centre of the domain of radius R_m);

– On condition, that the value R_m is specified on the basis of RWP model, which is adequate for RWP between the observation point in space and the closest to this point MS EMR source (it is obvious, that specified in this manner value R_m shall be considerably greater than the true radius r_m of the radio noticeable domain of MS).

We shall now explain the latter condition and refer to Fig.1, illustrating the limits of applicability of different RWP models in case of MS surface positioning ($m=2$). Point A in the centre of the Figure is some randomly selected point, where EMR characteristics are of interest for us. MS EMR sources are located randomly in its vicinity with the average density of $\rho=const$. In our case the situation when the MS density ρ in the considered domain is high, is of special interest. At some distance R_1 of point A from MS, comparable with the wavelength λ, a plane wave is generated [6,7]; it is possible to neglect probability that some MS are present in the vicinity of radius $R_1\approx\lambda\approx$15…50cm. At the distances of MS from the point of interest $R>R_2$, exceeding the distance to the first interference maximum Vvedensky's RWP model may be utilized [7], for which ν=4. At the distanced, overcoming R_3=1km, Okhamura-Khata RWP models may be applied (ν=3,5…4) as well as a number of other models, specified in ITU Recommendations (№№ 370, 1146, 1546, and others). The site radius $R_4=R_{max}$ may exceed the value R_3 (as shown in the Figure), or stay within this domain (for micro- and picocellular structures), However, in any case RWP models having ν=3,5…4 turn out to be applicable for calculations, related to definition of the value R_{max} and to estimations of the limits of BS responsibility zones.

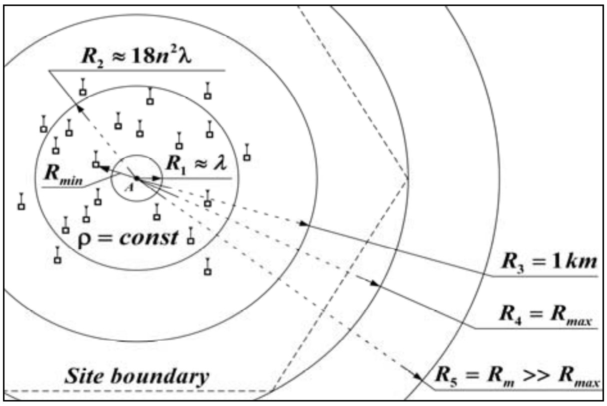

Fig.1. Conditional boundaries of application of the RWP models for the cellular radio communication frequency ranges; the value R_2 is determined for equal altitudes of the observation point H_A and MS location H_{MS} over the surface: $H_A=H_{MS}=n\lambda$

From the point of view of environment the greatest interest is posed by the inner part of the domain $R_1<R<R_2$, within which the closest MS EMR sources are located and the closest MS are found within the line-of-sight of the point A. Predominant EMR level at the point A is generated by the closest MS, remote by a certain distance of R_{min} from this point (ref. Fig.1). Thus in this case it is deemed logical to use at least within the domain $R_1<R\leq R_{min}$ the free-space RWP model (ν=2, C_ν=1/4π). For this domain $N_0 = \pi R_m^2 \rho$, and

$$p_D(P_{MS}) = exp\left(-\frac{N_0}{D}\right) = exp\left(-N_{MS}(r_{min})\right) \quad (3)$$

where N_{MS} means the average number of MS EMR sources having e.i.r.p. of P_{MS} in some vicinity of point A having its radius of r_{min} ; the probability $p_D(P_{MS})$ represents the probability that the closest to the point A MS having e.i.r.p. of P_{MS} is located beyond this vicinity, namely, the probability that $R_{min}>r_{min}$.

When the MS EMR power is controllable, the value P_{MS} appears to be random and in our case ($R_{max}>R_2$, ν=4) :

$$w(P_{MS}) = 1\Big/2\sqrt{P_{MS\,max}P_{MS}}, \quad 0 < P_{MS} \leq P_{MS\,max}.$$

with the average of distribution $m_1(P_{MS})=P_{MSmax}/3$. Taking into account randomness of MS e.i.r.p. we shall obtain an expression that describes the probability of non-exceeding the level Π_{max} by the level predominant in PFD of MS EMR

$$p_D = \frac{2\sqrt{\Pi_{max}}}{\sqrt{\rho P_{MSmax}}} \int_0^{\sqrt{\frac{\rho P_{MSmax}}{4\Pi_{max}}}} exp\left(-t^2\right)dt. \quad (4)$$

A case when the territory on which a cellular radio network is functioning, is additionally irradiated ("illuminated”) by one or several powerful radio transmitters. For instance, this is the case when there is a radio television broadcasting centre with a high-rise TV tower on the territory of a city, or when groups of powerful radio transmitters of TV and FM broadcasting are located on high-rise building within urban area.

If there is some EM background having its intensity of Π_0, not reaching maximum permissible levels (MPL) set forth by the Standards [9-11] at the point of space under study, statistical characteristics of the aggregate PFD $\Pi_m = \Pi_0 + \Pi_{max}$ pose principle interest as a scalar sum of the EM background intensity and MS EMR predominant in its power level. By replacing $\Pi_{max} = \Pi_m - \Pi_0$ in (4) we shall obtain the expression for the probability distribution function of the aggregate EMR PFD Π_m at some arbitrary instant of time at some randomly selected point of the service zone for the cellular radio network (arbitrary number of cellular radio networks) with the preset EM background intensity Π_0 :

$$p_D(\Pi_m) = \frac{2\sqrt{\Pi_m - \Pi_0}}{\sqrt{\rho P_{MSmax}}} \int_0^{\sqrt{\frac{\rho P_{MSmax}}{4(\Pi_m - \Pi_0)}}} exp\left(-t^2\right)dt . \quad (5)$$

For conclusion we shall consider the EM background level, generated at the point A (ref. Fig.1) by MS, located in its vicinity of R_2 radius, within the domain $R_1<R<R_2$ to be precise. For this domain $\nu=2$, and considering (1) the aggregate EMR level of MS located in this domain with an average density of ρ [MS/m^2], the following is defined:

$$\Pi_\Sigma\left(R < R_2\right) \approx \frac{\rho}{2} m_1\left(P_{MS}\right) ln \frac{R_2}{R_1} . \quad (6)$$

Beyond this domain the RWP conditions become more complicated ($\nu \approx 4$), and for the case of uniform random positioning of MS EMR sources within the domain $R_2<R<R_{max}$ with the density ρ' [MS/m^2] the aggregate EM background level from the MS of this domain:

$$\Pi_\Sigma\left(R \ge R_2\right) \approx 5 R_{max}^2 \rho' \Pi_{min} . \quad (7)$$

Ratios (3), (4) allow estimating the excess by the predominant in level MS EMI of some prescribed intensity level at an arbitrary point of the cellular communication service zone; ratio (5) allows estimating the risk of the excess by the aggregate PFD at an arbitrary point of this domain of some preset MPL provided that the EM background found in this point is lower in its level than PFD; ratios (6),(7) make it possible to assess the level of additional EM background, generated by EMR of MS, located in the vicinity of the observation point and in its actual radio noticeable domain. The latter is of critical significance in terms of a possibility to give an objective estimation to the environmental risk related to construction on the territory of built-up areas of powerful radiotail objects, that generate increased EM background (in particular, radio television towers) under mass use of mobile communication facilities, as well as from the viewpoint of estimating the environmental risks of utilization of mobile radio communication facilities in electromagnetic environment of a contemporary city, formed by systems of on-air TV and radio broadcasting, radar and radio relay systems and other previously implemented powerful EMR sources.

Preliminary analysis results

The full preliminary results of the analysis contained in [14], include probability curves of non-excess of the level $\Pi_0 = 10^{-6}$, 10^{-5} W/cm^2 by the closest MS EMR intensity as functions of spatial MS EMR source density, curves for the probability distribution density of the aggregate EMR PFD $p_D(\Pi_m)$ at a random selected point of the cellular radio communication service zone (arbitrary number of cellular radio networks) with the different EM background intensity, etc. Taking into consideration, that

– according to data [12] «human-safe EM background is $\Pi_0=10^{-6}$ W/cm^2 in its intensity »;

– in compliance with [9,10] the maximum permissible for the population level of the EM background, generated by the radio-tail objects (radio and television transmitters, radar and radio relay systems, etc..), is $\Pi_0=10^{-5}$ W/cm^2;

– it follows from [11] that MS EMR MPL, that has its effects on the MS owner body, is restricted by the value such as $\Pi_0=10^{-4}$ W/cm^2,

– in case of locating powerful TV and FM broadcasting transmitting centres on the territory of large settlements, typical is the situation when over sizeable urban area the planned and / or actual EM background level is negligibly (only by 1-3dB) lower than the prescribed MPL [9,10],

the analysis of the presented curves enables to notice the following:

1. In the absence of EM background the probability of excess by the closest MS EMR intensity of the level $\Pi_0 = 10^{-5}$ W/cm^2 at an arbitrary point at an arbitrary time instant is 0.01-0.02 with $\rho=0.01$ MS/m^2 and reaches 0.05-0.1 with $\rho=0.1$. The latter means, that under the accepted conditions (public places, $\rho=0.1$) at an arbitrary time instant for each 5-10 individuals out of a hundred the closest MS EMR level will exceed the EM background MPL established for the public by [9,10].
2. In the absence of EM background the probability of excess by the closest MS EMR intensity of the level $\Pi_0 = 10^{-6}$ W/cm ^{2} is 0.01 with $\rho=0.001$ MS/m^2 and reaches 0.05 with $\rho=0.01$ and 0.1-0.2 with $\rho=0.1$. The latter means, that under the accepted conditions (public places, $\rho=0.1$) at an arbitrary time instant for each 10-20 individuals out of a hundred the closest MS EMR level will exceed the background level safe for human life.
3. For small values of the probability of exceed by the closest MS EMR intensity of the prescribed level Π_0 ($p_D \ge 0.9$) it is possible to utilize model (3) in place of complicated model (4), replacing the average MS e.i.r.p.:

$$p_D \approx 1 - - \frac{\rho P_{MS\,max}}{12 \Pi_0} . \quad (8)$$

4. Mass application of low-power radio interfaces such

as Bluetooth, Dect (PMS=10mW) also may be considered as serious environmental risk.

5. In presence of EM background having the intensity of 10^{-6} W/cm^2 the MPL 10^{-5} W/cm^2, set forth in [9,10], is exceeded in a randomly selected point of space at an arbitrary time instant at an expense of the time interval of MS EMR presence with the probability of 0.01 for ρ=0.01 and with the probability of ≈0.05 for ρ=0.1. The level 2-3·10^{-6} W/cm^2 is accepted as the MPL by the mayor office in Moscow and in Paris [13]; level 2·10^{-6} W/cm^2 is exceeded with the probability of ≈0.01 for ρ=0.001, with the probability of ≈0.05 for ρ=0.01 and with the probability of ≈0.2 for ρ=0.1. Under these conditions level 10^{-4} W/cm^2 (MS EMR MPL) is exceeded at a randomly selected point of space owing to the presence of other MS EMR users with the probability of ≈0.001 for ρ=0.01 and with the probability of ≈0.005 for ρ=0.1.

6. In presence of the EM background of 10^{-5} W/cm^2 in intensity (MPL in [9,10]) the maximum permissible as per [11] level 10^{-4} W/cm^2 level is exceeded at any arbitrary instant of time due to the presence of EMR of adjacent MS with the probability of ≈0.01 for ρ=0.1 and with the probability of ≈0.001 for ρ=0.01.

7. In presence of the EM background of 1-3 dB lower in its intensity than the MPL of the background prescribed for the public the risk of exceeding by the aggregate electromagnetic field strength of this MPL (10^{-5} W/cm^2) appears to be very realistic. For these situations the probability $p(\Pi_m>\Pi_0)$ of exceeding by the aggregate EMR intensity of the MPL takes the values up to 0,1-0,5.

8. The average level of the EM background generated at the observation point by the mobile communication facilities, that are located at a relatively small distance (within the domain $R_1<R<R_2$ around point A in Fig.1), can also be rather significant. As an example we shall now consider a situation, when MS of the GSM-900 network are distributed in the vicinity of the point of interest: $m_1(P_{MS})$=0.67W, R_2=100m. Using (6), we shall receive $\Pi_\Sigma(R<R_2)\approx 2\rho$, if the MS territorial density is described in [MS/m^2], and the value $\Pi_\Sigma(R<R_2)$ is expressed in [W/m^2]. It is easy to prove that with ρ=0.1 MS/m^2 the average EM background level, generated at the observation pointby the mobile communication facilities in the vicinity of $R<R_2$, will exceed the MPL set forth in [9,10] in two times, and in case of ρ=0.01 MS/m^2 shall make 20% of the MPL, which undoubtedly has to be considered when estimating the boundaries of the control areas for powerful radio-tail objects.

As regards the average of the EM background, formed at the observation point by the MS, located at considerable distances (within the domain $R_2<R<R_{max}$ around point A in Fig.1), this component of the EM background may be estimated applying (7). As an example we shall consider a typical situation: $R_{max}\approx$3…4 km, $\Pi_{min}\approx 10^{-11}$ W/m^2. In this situation $\Pi_\Sigma(R_2<R<R_{max})\approx 10^{-3}\rho'$, provided the MS territorial density is described in [MS/m^2], and the aggregate PFD is expressed in [W/m^2]. Considering that the case of $\rho'\leq\rho$ is the greatest interest this component is 3-4 orders lower than $\Pi_\Sigma(R<R_2)$, however situations when the influence of this component might appear critical, are possible in principle.

Conclusion

The results and conclusions, contained in this paper, in view of estimations [14], prove the necessity to refuse placing powerful radio systems (on-air broadcasting systems, radars, etc.) on the territory of densely populated settlements in favour of transferring to alternative space scattered or cable / fiber-optic TV and broadcasting program distribution systems, space systems of air space supervision, etc., since here there is a realistic potential of alternative technical solutions, whereas mobile radio communication has in principle no alternatives.

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