COMPARATIVE ANALYSIS OF ENVIRONMENTAL SAFETY OF CELLULAR RADIO NETWORKS WITH FDMA/TDMA AND CDMA

VLADIMIR MORDACHEV, VIKTOR KOZEL, REPUBLIC OF BELARUS
Belarusian State University of Informatics and Radioelectronics, nilemc@bsuir.edu.by

Abstract. The paper contain the results of comparative analysis of environmental safety of cellular radio networks with FDMA/TDMA and CDMA. The relations and dependences given above ensure a possibility of a comprehensive qualitative and quantitative evaluation of the influence of the presence and the value of the mobile stations electromagnetic radiated power (MS EMR) adjustment step, requirements to the probability of call blockage in the network, as well as of the base stations antenna suspension heights in the cellular communication networks, that use various multiple access technologies, on their environment safety, determined by the average MS EMR power. These may be directly applied when justifying the requirements to the parameters of the existent mobile communication networks and those showing much promise, that ensure acceptable for users level of the average emission power.

Introduction

In contemporary networks of land mobile service that use the CDMA technology, the power of the electromagnetic field, generated by the MS, depend on the distance of the abonent from the base station and on the traffic intensity of this base station (BS). In view of the instability and random nature of these factors the direct evaluation of the power level of the MS electromagnetic field does not make sense. In this case to assess the influence of the MS EMR on the human body it is reasonable to apply a MS EMR average power level.

The basic models and equations

Since in the case under study we shall consider general regularities that determine the influence of individual factors on the average MS EMR power, we shall use the well-known hyperbolic approximation of the signal power dependence at the receiver input $\boldsymbol{P}$ on the distance $\boldsymbol{R}$ to the electromagnetic field source:

$$\mathbf{P} = \mathbf{C}\frac{\mathbf{P_e}}{\mathbf{R}^{\nu}} \qquad (1)$$

where $\boldsymbol{P_e}$ is the equivalent isotropically radiated power (e.i.r.p.) of the emission source, $\boldsymbol{C}$ is a constant, ν is the parameter, defining the attenuation «rate» of the electromagnetic field as the distance to the electromagnetic field source increases (ν=2 in case of radio wave propagation (RWP) in free space; ν=4 in case of RWP with the direct and echo beams' interference in the far-region zone for the VHF range and in the lower part of the UHF range; ν=3,5÷4,0 for the Okhumura-Hata model. When defining the RWP conditions by model (1) applicably to the problem in consideration we shall neglect the additional multipliers that describe different kinds of fading.

We shall now use a typical spatial cellular radio network model, implying:

- Multiple access regular idealized network structure with hexagonal in shape cells (sites) of equal sizes with base stations (BS), having identical heights of antenna suspensions in centers of cells, the circumradius of each of them (the site radius) being equal to $\boldsymbol{R_{max}}$;
- Positioning of the network on a plain terrain, from which radio wave model of class (1) can be used;
- Random uniform location of abonents over the area and, hence, of the MS in the network.

The average value of the MS EMR power in the land mobile service network, based on the CDMA technology, may be described by the below expression:

$$\langle \mathbf{P_{AC}} \rangle = \sum_{\mathbf{n=0}}^{\mathbf{N_{max}}} \mathbf{P_n} \int_0^{\mathbf{R_{max}}} \mathbf{P_{AC\,n}(R) W(R) dR}\,, \qquad (2)$$

where $\mathbf{N_{max}}$ stands for the maximal number of simultaneously attended abonents within a single frequency channel; $\mathbf{P_n}$ is the probability of the simultaneous operation of $\mathbf{n}$ users within a single frequency channel; $\mathbf{R_{max}}$ - the distance to the boundary of the service zone in case of maximal traffic in the frequency channel; $\mathbf{P_{AC\,n}(R)}$ is the distance to the base station as a function of the MS EMR power under simultaneous operation of $\mathbf{n}$ MS within a single frequency channel; $\mathbf{W(R)}$ - the probability distribution density of distance between user and BS.

On condition of uniform spatial distribution of abonents within the base station service zone, $\mathbf{W(R)}$ has the following expression:

$$\mathbf{W(R)} = \frac{\mathbf{2R}}{\mathbf{R_{max}^2}}, \quad \mathbf{R \le R_{max}} \qquad (3)$$

Considering well-known "Erlang-B" service model the probability of simultaneous operation of $\mathbf{n}$ MS may be defined as follows:

DOI:10.1109/EMCECO.2007.4371724

$$P_n = \frac{E^n / n!}{\sum_{k=0}^{N_{max}} E^k / k!} \qquad (4)$$

where E is the present user traffic, Earl. per one frequency channel. The present user traffic together with the maximal number of traffic channels N_{max} in a single frequency channel directly describes the call blocking probability P_b of due to the absence of a free traffic channel.

The maximal number of traffic channels available in a frequency channel may be derived from the relation of the energy per bit of data transferred to the spectral-noise density at the receiver input, to be rated for each communication system individually.

$$\frac{E_b}{N_0} = \frac{P_{rx}/C}{(P_{noise} + (n-1)P_{rx})/\Delta f} = \frac{P_{rx}B}{(P_{noise} + (n-1)P_{rx})} \qquad (5)$$

where P_{rx} is the useful signal power (actual sensitivity) at the BS receiver input on condition of simultaneous operation of n MS in one frequency channel; C stands for the data transmission rate, bps; Δf - the required frequency bandwidth, Hz; $B = \Delta f / C$ - processing acceleration (effective signal base).

Deriving P_{rx}, from the condition $P_{rx} \geq 0$, we shall obtain $B - \left(E_b / N_0\right)(n-1) > 0$ and, hence:

$$N_{max} = \mathrm{Int}\left\{ \frac{B}{E_b / N_0} + 1 \right\} \qquad (6)$$

Based on the accepted radio wave propagation model (1) the MS EMR power on condition of maximal user traffic of the frequency channel, may be defined in the following manner:

$$P_{AC\,N_{max}} = P_{AC\max N_{max}} + 10\nu \lg\left(\frac{R}{R_{max}}\right),$$

or in power units:

$$P_{AC\,\text{Вт}\,N_{max}} = P_{AC\max\text{Вт}\,N_{max}} 10^{\nu \lg(R/R_{max})} = P_{max}(R) \qquad (7)$$

where $P_{AC\,N_{max}}$ is the abonent station power (dBW) with the distance R from the base station; $P_{AC\max N_{max}}$ is the MS power (dBW), that ensures the link of the preset quality at the service zone boundary.

Considering expressions (5) and (7) it is possible to obtain the dependence for the MS EMR power on the distance to the base station R on condition of simultaneous operation of n MS in one frequency channel, W

$$P_{AC\,n}(R) = P_{max}(R) \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max} - 1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)} \qquad (8)$$

Rewriting expression (2) taking into account (3), (4), (7) and (8) we shall obtain an evaluation of the mean MS EMR power on condition of ideal continuous power adjustment:

$$\langle P_{AC} \rangle = \sum_{n=0}^{N_{max}} \frac{E^n / n!}{\sum_{k=0}^{N_{max}} \frac{E^k}{k}} \int_0^{R_{max}} P_{AC\max\text{Вт}\,N_{max}} \times$$

$$\times 10^{\nu \lg\left(\frac{R}{R_{max}}\right)} \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max} - 1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)} \frac{2R}{R_{max}^2} dR$$

After necessary conversions we shall have:

$$\langle P_{AC} \rangle = P_{AC\max\text{Вт}\,N_{max}} \frac{2}{2+\nu} \times$$

$$\times \sum_{n=0}^{N_{max}} \frac{E^n / n!}{\sum_{k=0}^{N_{max}} \frac{E^k}{k}} \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max} - 1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)}.$$

In case if discrete adjustment of the MS EMR power is presupposed in the system with a step of St, dB, the average MS EMR power may be described as below:

$$\langle P_{AC} \rangle = \sum_{n=0}^{N_{max}} P_n \sum_{i=1}^{\infty} P_{i\,n}^{AC} \int_{R_{i+1}}^{R_i} W(R)dR \,, \qquad (9)$$

where $P_{i\,n}^{AC}$ is the MS power at i-th step of power adjustment with n simultaneously operating MS within a single frequency channel; R_i and R_{i+1} are distances to the BS, within which the MS has the power described as $P_{i\,n}^{AC}$. The power adjustment step is St and the distances are R_i and R_{i+1} are interrelated by the following relation: $10^{\nu \lg\left(\frac{R_{i+1}}{R_i}\right)} = 10^{-\frac{St}{10}}$. Then

$$P_1^{AC} = P_{AC\max\text{Вт}\,N_{max}} \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max} - 1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)}$$

and $P_i^{AC} = P_{i+1}^{AC}(Dp)$, $R_i = R_{max}(Dr)^{i-1}$;

we shall have:

$$P_i^{AC} = P_{\text{ACmaxBт}\,N_{max}} \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max}-1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)} (Dp)^{i-1},$$

and where $Dp = 10^{-\frac{St}{10}}$; $Dr = \frac{R_{i+1}}{R_i} = 10^{\frac{-St}{10\gamma}}$.

Thus, expression (9) may be rearranged to the below equation:

$$\langle P_{AC} \rangle = P_{\text{ACmaxBт}\,N_{max}} \sum_{n=0}^{N_{max}} \frac{E^n/n!}{\sum_{k=0}^{N_{max}} \frac{E^k}{k}} \times$$

$$\times \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max}-1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)} \sum_{i=1}^{\infty} (Dp)^{i-1} \int_{(Dr)^{2i}}^{(Dr)^{2(i-1)}} dx \qquad (10)$$

After a number of conversions, taking into account the power adjustment step St and the RWP constant ν expression (10) may be rewritten as follows:

$$\langle P_{AC} \rangle = P_{\text{ACmaxBт}\,N_{max}} 10^{\frac{St}{10}} \frac{10^{\frac{St}{5\nu}} - 1}{10^{\frac{St(2+\nu)}{10\nu}} - 1} \times$$

$$\times \sum_{n=0}^{N_{max}} \frac{B - \left(\frac{E_b}{N_0}\right)(N_{max}-1)}{B - \left(\frac{E_b}{N_0}\right)(n-1)} \frac{E^n/n!}{\sum_{k=0}^{N_{max}} \frac{E^k}{k}}.$$

Considering that the MS power in case of max traffic in the frequency channel $P_{\text{ACmaxBт}\,N_{max}}$ taking into account propagation model (1)) is relat the BS receiver susceptibility in case if the frequ channel is loaded with the only traffic channel P_{01} by the following relation:

$$P_{\text{ACmaxBт}\,N_{max}} = P_{01} \frac{B}{B - \left(\frac{E_b}{N_0}\right)(N_{max}-1)} \frac{R_{max}^{\nu}}{C},$$

we shall rewrite expression (11) in the following manner:

$$\langle P_{MS} \rangle = \frac{P_{01} R_{max}^{\nu}}{C} K_{\nu,\Delta P}\, K(B, E, \frac{E_b}{N_0}),$$

where the contribution into reduction of the MS EMR average power is determined by the multiplier as below due to the discrete MS EMR power adjustment:

$$K_{\nu,\Delta P} = 10^{\frac{\Delta P}{10}} \frac{10^{\frac{\Delta P}{5\nu}} - 1}{10^{\frac{\Delta P(2+\nu)}{10\nu}} - 1},$$

and the influence on the MS EMR average power of the traffic intensity, processed by the BS, may be described through the multiplier

$$K(B, E, \frac{E_b}{N_0}) = \sum_{n=0}^{N_{max}} \frac{E^n/n!}{\sum_{k=0}^{N_{max}} \frac{E^k}{k}} \frac{B}{B - \left(\frac{E_b}{N_0}\right)(n-1)}.$$

The basic analysis results

Fig.1 shows the dependences on the traffic intensity the relations of the average MS EMR power of the GSM-1800 standard and the MS with typical analogue PM (NMT, etc.) to the average MS EMR power in Cdma2000 and UMTS systems for sites of equal sizes. To plot the curves basic parameters of mobile radio communication networks [1,2], reviewed in the table below, were used.

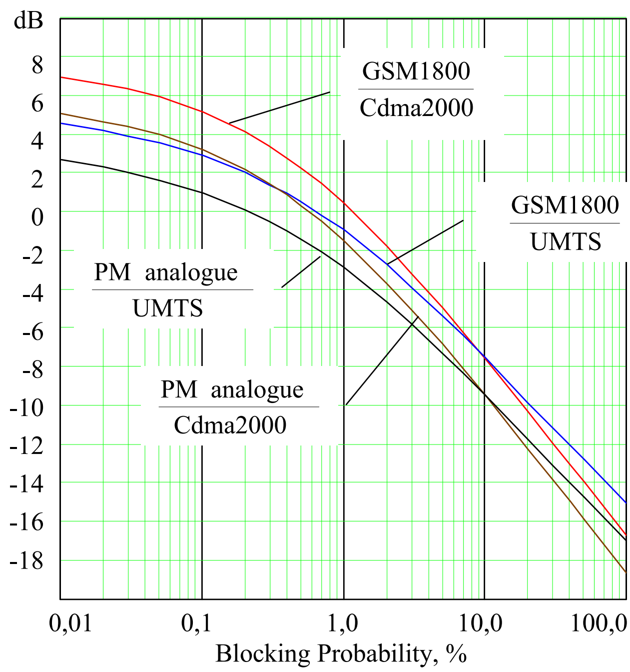

Fig.1. Ratio of the average MS EME power of different standards of mobile communication systems for typical conditions (BS traffic and Blocking Probability).

	GSM-1800	Cdma2000
P_{01}, dBm	-105*	-125*
E_b/N_0, dB	9	4
ΔP, dB	2	0,5
Δf, MHz	0,2	1,25
C_b, kbps	270,833	9,6
F, dB	5	5

	UMTS	PM-analogue
P_{01}, dBm	-125*	-117
E_b/N_0, dB	3	-
ΔP, dB	0,5	3
Δf, MHz	3,84	0,017
C_b, kbps	12,200	-
F, dB	5	-

**)Base station receiver susceptibility [dBm] may be determined as per the following equation:–174+10lg(C_b)+E_b/N_o+F, where C_b is the information modulation rate, bit/sec; F – receiver noise figure, dB [3].*

It is uneasy to notice, that MS EMR average power in UMTS or CDMA-2000 cellular network at low user traffic much less than MS EMR average power in GSM network. It may be explained first of all by the lower sensitivity of the reception devices working in GSM networks, caused by specificity of TDMA frames and time slots formation (in particular use of a plenty of the service bits which are directly not carrying the information). However this advantage is quickly lost with growth of user traffic on UMTS or CDMA-2000 network, that is a result of receivers real sensitivity decreasing because of growth of an intranetwork interference. The same situation is present at comparison of behavior of MS EMR average power in UMTS / CDMA-2000 cellular network and MS EMR average power in PM analog MS EMR with technology FDMA with growth of user traffic.

The analysis of the curves resulted on fig. 1 allows to notice, that the gap available between the peak and the actual load (traffic) in the CDMA networks is an additional «degree of freedom» from the viewpoint of ensuring the network environment: in cases of peak traffic the environmental characteristics of the CDMA networks are considerably worse in compared to similar characteristics of the GSM networks and 1st generation analog networks. However in periods, when the network load is considerably lower than the peak (which is fair for at least 80-90% of time), an additional advantage in terms of MS e.i.r.p. (due to a benefit in the actual receiver sensitivity of an «underloaded» BS in the CDMA network if compared to the actual BS receiver sensitivity of the GSM network) may achieve 4-7 dB.

In reality this additional advantage, on the data [4], a little bit less; it is possible to assume, that may be explained taking into account a high level of the intranetwork interference in CDMA network caused its simplified frequency cluster structure, in particular, by use adjacent and even the same frequency channels with code division in neighboring BS sectors of service zone, and also by neighboring BS in adjacent service areas.

Conclusion

The relations and dependences given above ensure a possibility of a comprehensive qualitative and quantitative evaluation of the influence of the presence and the value of the AS EME power adjustment step, requirements to the probability of call blockage in the network, as well as of the BS antenna suspension heights in the cellular communication networks, that use various multiple access technologies, on their environment safety, determined by the average AS EME power. These may be directly applied when justifying the requirements to the parameters of the existent mobile communication networks and those showing much promise, that ensure acceptable for abonents level of the average emission power.

Information about the authors

Vladimir Mordachev, 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. Main areas of interest: EMC and EME system analysis and synthesis, radio devices and systems behavior simulation, EMC testing and measurement.

Victor Kozel, assistant-professor of Belarusian State University of Informatics and Radioelectronics. Main areas of interest: mobile and fixed radio communication networks design, frequency planning, EMC analysis and synthesis, statistical theory of communication and signal processing

References

1. IMT-2000. Report of the Fifth Meeting of ITU-R Working Party 8F, Stockholm, 27 June – 3 July 2001.
2. ETSI EN 300 910 v.8.5.1 (2000-11). Digital Cellular Telecommunications System (Phase 2+); Radio Transmission and Reception (GSM 05.05 version 8.5.1 Release 1999).
3. Skrynnikov V.G., Skrynnikov O.V. Estimation of the radio coverage of the UMTS network at an early stage of its development.- «Mobile systems» №2, 2006, p.16-22 (in Russian).
4. Golyshko A.V., Somov A.Y. Problems related to the environmental and technical development of the cellular communication networks.- “Vestnik sviazy”, №10, 2003, p.60-69 (in Russian).