EMC 2004

17th INTERNATIONAL WROCLAW SYMPOSIUM AND EXHIBITION ON ELECTROMAGNETIC COMPATIBILITY, WROCLAW, 29 JUNE - 1 JULY 2004
www.emc.wroc.pl

ECOLOGICAL CHARACTERISTICS OF CELLULAR NETWORK: RELATIONSHIP WITH ITS RADIO FREQUENCY RECOURSE AND INTRASYSTEM EMC

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Abstract. Paper contains the basic ideas and thesis's allowing to prove the limitations set on the quantity of cellular network operators and the volume of radio frequency resource allotted for every cellular radio network aimed at ensuring all the acceptable ecological characteristics of each radio network and determining the relation of cellular radio network ecological characteristics and those of its intrasystem (intranet) EMC.

Possible ways of improving the ecological characteristics of cellular radio networks related to the limiting use of radio frequency resource and marginally accepted space density of the base network stations and the development and optimization of the methods and algorithms of the intranetwork EMC maintenance have been formulated.

On the whole the systematic considerations of the cellular network ecological characteristics, suggested in the paper, helps the quantitative determination of their relation with the capacity and quality of the radio frequency resource, dedicated to a network, parameters of the intranetwork EMC, as well as to formulate a number of trends to improve the cellular network ecological compatibility.

Keywords: ecology, cellular system, intranetwork EMC, Radio Frequency Resource

1. INTRODUCTION

The electromagnetic radiation (EMR) of cellular network mobile stations (MS) adversely affects the health of people who use mobile communication services. During the conversation through the cell phone, the latter is located in immediate proximity to the human head and its electromagnetic radiation affects the eyes, the brain, the blood and blood vessels as well as other systems of the human body [1].When mobile stations electromagnetic radiation power is high, this influence can become inadmissible. The mobile stations electromagnetic radiation power depends on a number of fundamental factors, in particular, the following ones:

a) the cell (site) sizes in the cellular network: the greater the site radius, the higher mobile stations electromagnetic radiation power is required in order to ensure the normal two-way communication quality.
b) the availability of base stations electromagnetic radiation power adjustments (downlink electromagnetic radiation power adjustments) and mobile stations electromagnetic radiation power adjustments (uplink electromagnetic radiation power adjustments): The availability of mobile stations electromagnetic radiation adjustment makes it possible to reduce the average mobile stations electromagnetic radiation power by several times and thus to mitigate the adverse effect of this factor on the health of the mobile users (this does not apply to subscribers who are forced to use mobile stations with maximum electromagnetic radiation owing to certain circumstances related to the fact that their workplaces, accommodations, recreation areas etc. are located away from the network base stations (BS) or in the area of unsatisfactory radiowave propagation from mobile stations to base stations because of shadowing caused by vegetation, terrain, buildings and constructions, etc.).
c) the actual sensitivity level of base station receivers - the higher the sensitivity, the lower mobile stations electromagnetic radiation power is required in order to ensure the normal two–way communication quality.
d) the intrasystem electromagnetic safety (EMC) parameters of the cellular network, specifically, the integral interference level for the network – the higher this level is, the higher mobile stations electromagnetic radiation power is required in order to ensure the normal two–way communication quality.

The indicated factors are nonequivalent with regard to their nature. In particular, the second and the third factor may be classified as limitations of the relevant mobile communication standard (system) - in the early cellular communication standards and in many proprietary communication systems, the power adjustment is unavailable for mobile and base stations, the field-related base station reception sensitivity is determined by the noise parameters and the reception bandwidth as well as by the receiver antenna gain and the required (minimum allowable) value of the signal-to-noise ratio.

An exception of a certain kind is represented by the CDMA mobile communication systems where the base station reception sensitivity depends on the quantity of mobile stations simultaneously operating in a single frequency channel of a single base station sector; the lowest sensitivity is at the peak load. However, as the base station load decreases its reception sensitivity increases (the minimum allowable mobile station desired signal decreases) due to the decrease of the integral interference level in the channel; this decrease is proportional to the decrease in the quantity of simultaneously operating subscribers.

As far as the first and the fourth factors are concerned, they are related to the network structure and the specific factors with regard to usage of the spectrum allocated to this network, in particular, to the relevant network frequency planning and intrasystem EMC provision scenarios. Let us discuss this issue in more detail below.

A multicell network (cellular network, trunking network etc.) is implemented so as to cover an area and provide the corresponding communication services to the population (staff) in this area. When the network is designed, the load (traffic) prediction is carried out first. In accordance with this prediction, the required spectrum (a number of physical radio channels) is allocated and the required network frequency planning scenario (cluster size, frequency reuse ratio for the primary spatial network segments) is selected.

If unlimited spectrum may be allocated for the network development, then the network may be implemented with the use of the minimum possible number of sites and the maximum possible site size (area). In this case:

a) the maximum mobile stations electromagnetic radiation power is required, and this is the most unfavorable solution from the standpoint of ecology;
b) the required network capacity is provided using a large number of physical radio channels (sufficient for processing of the predicted traffic load) for each site (the quantity of site sectors is irrelevant in this case);
c) minimum infrastructure expenses are required (intersite data streams are maximal for this network configuration, but modern fiber networks and microwave relay stations may provide almost any required data transmission rates for site interconnections without a substantial increase in cost of communication lines);
d) the largest payments for spectrum usage are required, which is insubstantial when the spectrum is underpriced or the spectrum cost is initially included in the license payment.

However, if the limited spectrum is allocated for network development then smaller site sizes in combination with multiple frequency reuse (whose ratio is sufficient to process the predicted traffic load) for different sites should be used in order to provide the required communication quality. In this case

a) the less spectrum is allocated for network implementation, the smaller site sizes are to be used in order to process the predicted traffic load (for any given finite spatial density of mobile stations, the traffic intensity decreases as the site size becomes smaller), the lower is the required mobile stations electromagnetic radiation power and the better is the network from the standpoint of ecology;
b) if the same frequencies must be used for different network sites then the selection of a network frequency planning scenario (cluster type and dimension) becomes very important. This parameter is related to the spectrum amount available for an individual site and determines the frequency reuse ratio for the primary spatial network segments as well as the integral interference level for the network. The last mentioned factor determines the requirement for a certain additional increase in mobile stations electromagnetic radiation power;
c) the network infrastructure costs are significantly increased and the smaller is the site size, the higher are the costs;
d) the payments for allocated spectrum usage are decreased, which is significant when the spectrum price is high.

2. THE BASIC MODELS AND EXPRESSIONS

2.1 The mobile station equivalent radiated power

The site radius $\mathbf{R_{MAX}}$ determines the threshold value of base losses for propagation from a mobile station to a base station $\mathbf{S_{MAX} = \Phi(R_{MAX})}$ which relates the mobile station equivalent radiated power (ERP) $\mathbf{P_{AS}}$ and the base station receiver sensitivity $\mathbf{P_0}$ [2]:

$$\mathbf{P_{AS}}[\mathrm{dBW}]=\mathbf{P_0}[\mathrm{dBW}]+\mathbf{S_{MAX}}[\mathrm{dB}]+\mathbf{G_{ABS}}[\mathrm{dB}], \quad (1)$$

where $\mathbf{G_{ABS}}$ is the base station receiving antenna gain. Hence it is necessary to determine the actual value of the base station receiver sensitivity $\mathbf{P_0}$ for the site whose radius is $\mathbf{R_{MAX}}$ in order to estimate the maximum value of the mobile station equivalent radiated power. The actual value of the base station receiver sensitivity depends on the base station receiver internal noise level at the receiver input $\mathbf{P_N}$ as well as on the given integral intranetwork input interference level $\mathbf{P_{\Sigma\ INT}}$ (it is generally determined taking into account interference for the main and adjacent receiving channels). The integral intranetwork input interference level is determined by the cluster parameters employed in the process of network frequency planning.

2.2 Impact of the FDMA/TDMA network frequency-spatial structure (cluster) on the minimum utilized desired signal level

To provide normal communication quality for the network, the minimum utilized desired signal level at the base station receiver input $\mathbf{P_{U\ MIN}}$ [W] should be higher than the equivalent integral interference power $\mathbf{P_N} + \mathbf{P_{\Sigma\ INT}}$ [W] by the assigned number of times which is equal to the protection ratio $\mathbf{S}$:

$$\frac{\mathbf{P_{U\,MIN}}}{\mathbf{P_N} + \mathbf{P_{\Sigma INT}}} \geq \mathbf{S}\ . \quad (2)$$

If the required minimum protection ratio $\mathbf{S}$ is lower than the value of protection ratio for the integral intranetwork interference $\mathbf{S_{CL}}$ characteristic of the selected cluster type

$$\mathbf{S} < \mathbf{S_{CL}} = \frac{\mathbf{P_U}}{\mathbf{P_{\Sigma INT}}}\ , \quad (3)$$

where $\mathbf{P_U}$ is the minimum utilized desired signal level in the net for the intranetwork interference whose level is $\mathbf{P_{\Sigma\ INT}}$, then we can determine the minimum utilized desired signal power $\mathbf{P_{U\ MIN}}$ which is related to the base station receiver internal noise and is equal to the receiver sensitivity:

$$\mathbf{P_{\Sigma INT}} = \frac{\mathbf{P_{U\,MIN}}}{\mathbf{S_{CL}}}\ ; \qquad \frac{\mathbf{P_{U\,MIN}}}{\mathbf{P_N} + \dfrac{\mathbf{P_{U\,MIN}}}{\mathbf{S_{CL}}}} \geq \mathbf{S}\ , \quad (4)$$

hence

$$\mathbf{P_{u\,min}} \geq \mathbf{P_N}\frac{\mathbf{S\,S_{CL}}}{\mathbf{S_{CL}} - \mathbf{S}} = \mathbf{P_0}\ , \quad \mathbf{S} < \mathbf{S_{CL}}\ . \quad (5)$$

(The values of $\mathbf{S}$, $\mathbf{S_{CL}}$ are expressed in units rather than decibels in expressions (2)-(5)).

The expression (5) represents the dependence of the maximum attainable base station reception sensitivity on the relationship of values of **S** and $\mathbf{S_{CL}}$. If $\mathbf{S_{CL}} >> \mathbf{S}$ then the base station receiver sensitivity approaches the value $\mathbf{P_0 = P_N\, S}$ determined by the internal receiver thermal noise. When $\mathbf{S_{CL}}$ approaches **S**, the attainable base station reception sensitivity abruptly deteriorates because the value of the minimum utilized desired signal power $\mathbf{P_{U\,MIN}}$ must be sharply increased in order to provide the protection ratio value **S** required for the network so that the influence of internal noise $\mathbf{P_N}$ is decreased equally to the difference between the values of (2) and (3) owing to the proportional increase of the integral intranetwork interference $\mathbf{P_{\Sigma\ INT}}$. For $\mathbf{S_{CL} \le S}$, the required network communication quality is unattainable owing to the high integral intranetwork interference level.

Thus the expressions (1) and (5) make it possible to relate the equivalent mobile station radiated power $\mathbf{P_{AS}}$ [W] to the base parameter of the cluster $\mathbf{S_{CL}}$ via the base station receiver sensitivity $\mathbf{P_{U\ MIN} = P_0}$ which is attainable for the selected cluster and to actually relate (by and large) the network ecological safety to the requirements for the communication quality and the employed frequency-spatial network structure (cluster).

The following points should be noted which allow one to substantially extend the scope of discussion in this field:

a) the cluster type characterized by its parameter $\mathbf{S_{CL}}$ determines the spectrum usage procedures and efficiency for the network. Hence the expression (5) may be used in order to investigate the relation between the ecological network characteristics and the spectrum usage efficiency characteristics for the spectrum allocated to this network;

b) the value of $\mathbf{S_{CL}}$ depends on the randomness of base station locations within the network [3]. Therefore the expression (5) may be used in order to investigate the impact of network structure irregularity on its ecological safety.

2.3 Statistical characteristics of mobile station equivalent radiated power

If mobile stations are randomly and uniformly (with the constant average density ρ [stations per square kilometer]) located within the site whose radius is $\mathbf{R_{MAX}}$, then the distances to mobile stations from the base station at the site center are random. If we ignore the angular shape of the site and consider it to be circular, then the probability distribution density for the distance **R** from a mobile station to a base station is [4]:

$$\mathbf{w(R) = \frac{2R}{R_{MAX}^2}, \quad 0 \le R \le R_{MAX}}\,. \tag{6}$$

The mobile station equivalent radiated power $\mathbf{P_{AS}}$ [W] required for communication at the distance from the base station **R** is determined by the known relationships:

$$\mathbf{\Pi_0 = P_0 S_{ABS} = \frac{c_\nu P_{AS}}{R^\nu}},$$

hence
$$\mathbf{P_{AS} = \frac{\Pi_0 R^\nu}{c_\nu}}, \tag{7}$$

where

$\mathbf{\Pi_0}$ [W/m^2] is the field-related base station receiver sensitivity which is expressed in power flux density units and related to the base station receiver sensitivity value $\mathbf{P_0}$ discussed above in (5) via the effective base station receiving antenna area $\mathbf{S_{ABS}}$;

ν**≥2** is the parameter which characterizes the propagation type; for the case of free-space propagation ν**=2**, for the case of interaction between the direct and the reflected rays (Vvedensky models, Okumura-Hata models etc.) ν**=4**;

$\mathbf{c_\nu}$ is the constant which depends on $\boldsymbol{\nu}$ and is determined on the basis of the corresponding propagation model.

If the network provides mobile station equivalent radiated power adjustment depending on the distance from a mobile to a base station then $\mathbf{P_{AS}}$ is a random variable functionally related to the random variable **R**. The form of mobile station equivalent radiated power probability distribution density may be determined with the use of the known technique (6), (7):

$$\mathbf{R = \left(\frac{c_\nu P_{AS}}{\Pi_0}\right)^{\frac{1}{\nu}}, \quad \left|\frac{dR}{dP_{AS}}\right| = \frac{(c_\nu/\Pi_0)^{1/\nu}}{\nu P_{AS}^{1-1/\nu}}};$$

$$\mathbf{w(P_{AS}) = w(R = \Phi(P_{AS}))\left|\frac{dR}{dP_{AS}}\right| = \frac{2}{\nu P_{AS\,MAX}^{2/\nu} P_{AS}^{1-2/\nu}}}, \tag{8}$$

$$\mathbf{0 < P_{AS} \le P_{AS\,MAX}; \quad \nu \ge 2;}$$

$$\mathbf{P_{AS\,max} = \frac{\Pi_0 R_{MAX}^\nu}{c_\nu}}.$$

<u>Example 1:</u> ν=2 (free space propagation). In this case (8) becomes a uniform distribution:

$$\mathbf{w(P_{AS}) = \frac{1}{P_{AS\,MAX}}}. \tag{9}$$

<u>Example 2:</u> ν=4 (Vvedensky model, Okumura-Hata model, etc.). In this case (8) becomes a hyperbolic distribution:

$$\mathbf{w(P_{AS}) = \frac{1}{2\sqrt{P_{AS\,MAX} P_{AS}}}, \quad 0 < P_{AS} \le P_{AS\,MAX}} \tag{10}$$

Eq.(8) may be used to determine the expected mobile station equivalent radiated power value:

$$\mathbf{m_1(P_{AS}) = \int_0^{P_{AS\,MAX}} P_{AS} w(P_{AS}) dP_{AS} = \frac{2P_{AS\,MAX}}{2+\nu}, \quad \nu \ge 2.} \tag{11}$$

It's obvious that in cases where the network does not provide mobile station ERP adjustment the probability distribution density functions (6), (8) degenerate into Dirac delta functions at the points $\mathbf{R_{MAX}}$ and $\mathbf{P_{AS\,MAX}}$ correspondingly and the average mobile station ERP value (11) for the site also becomes equal to $\mathbf{P_{AS\,MAX}}$.

2.4 Statistical characteristics of electromagnetic radiation absorbed by the human body

The mobile station electromagnetic radiation power absorbed by the human body (mainly the head tissues) $\mathbf{P_A}$ amounts to 10-50% of $\mathbf{P_{AS}}$ and essentially depends on the network operating frequency range; it reaches maximum at the frequencies near 2 GHz [1]. Therefore and taking into account that $\mathbf{P_A = k\, P_{AS}}$ **,** $\mathbf{k \approx const < 1}$**,** we obtain the probability distribution density form and the expected value of absorbed power $\mathbf{P_A}$:

$$\mathbf{w(P_A) = w(P_{AS} = \Phi(P_A))\left|\frac{dP_{AS}}{dP_A}\right| = \frac{2}{\nu k^{2/\nu} P_{AS\,MAX}^{2/\nu} P_A^{1-2/\nu}}}, \tag{12}$$

$$\mathbf{0 < P_A \le kP_{AS\,MAX}; \nu \ge 2;}$$

$$m_1(P_A) = \int_0^{kP_{AS\,MAX}} P_A w(P_A) dP_A = \frac{2kP_{AS\,MAX}}{2+\nu} = \frac{2k\Pi_0 R_{MAX}^{\nu}}{c_\nu(2+\nu)}, \ \nu \geq 2. \quad (13)$$

It is obvious that in cases where the network does not provide mobile station ERP adjustment the probability distribution density (12) degenerates into a Dirac delta function at the point $P_{A\,MAX}=kP_{AS\,MAX}$ and the average value of mobile station ERP absorbed by the human body (13) for the site also becomes equal to $P_{A\,MAX}$.

If k is a random variable with the known probability distribution law for which the first ordinary moment $m_1(k)$ is available then (13) may be refined and expressed as:

$$m_1(P_A) = m_1(k)m_1(P_{AS}) = \frac{2\Pi_0 R_{MAX}^{\nu}}{c_\nu(2+\nu)} m_1(k). \quad (14)$$

2.5 Ecological restrictions on network structure parameters and allocated spectrum amount

The quantity $m_1(P_A)$ is related to the site area via R_{MAX}. If this quantity (which determines the average absorption of mobile station electromagnetic radiation power by the human body) is limited by a certain maximum permissible quantity $P_{A\,PM}$ then the maximum ecologically permissible site radius $R_{MAX\,P}$ and site area S_{SP} are determined with the use of the following obvious relations:

a) for mobile subscribers in the network with mobile station equivalent radiated power adjustment when the location of subscribers varies randomly:

$$R_{MAX\,P} = \left(\frac{c_\nu P_{A\,PM}(2+\nu)}{2\Pi_0 m_1(k)}\right)^{\frac{1}{\nu}}; \quad (15)$$

$$S_{SP} \approx \pi R_{MAX\,P}^2 = \pi\left(\frac{c_\nu P_{A\,PM}(2+\nu)}{2\Pi_0 m_1(k)}\right)^{\frac{2}{\nu}}; \quad (16)$$

b) for locally mobile subscribers in the network with mobile station equivalent radiated power adjustment when the subscribers use mobile phones mostly within a certain location (office, apartment, summer cottage etc.) which is situated near the site boundary or for the case of network without mobile station equivalent radiated power adjustment:

$$R_{MAX\,P} = \left(\frac{c_\nu P_{A\,PM}}{\Pi_0 m_1(k)}\right)^{\frac{1}{\nu}}; \quad (17)$$

$$S_{SP} \approx \pi R_{MAX\,P}^2 = \pi\left(\frac{c_\nu P_{A\,PM}}{\Pi_0 m_1(k)}\right)^{\frac{2}{\nu}}. \quad (18)$$

If mobile stations are randomly and uniformly distributed over the site area with the average density ρ[stations/sq.km], the maximum permissible number of subscribers who can use the net under the conditions of ecological safety equals to:

a) for mobile subscribers in the network with mobile station equivalent radiated power adjustment

$$N_{S\,MAX} = \rho S_{SP} \approx \rho\pi\left(\frac{c_\nu P_{A\,PM}(2+\nu)}{2\Pi_0 m_1(k)}\right)^{\frac{2}{\nu}}; \quad (19)$$

b) for locally mobile subscribers in the network with mobile station equivalent radiated power adjustment or for the case of network without mobile station equivalent radiated power adjustment

$$N_{S\,MAX} = \rho S_{SP} \approx \rho\pi\left(\frac{c_\nu P_{A\,PM}}{\Pi_0 m_1(k)}\right)^{\frac{2}{\nu}}. \quad (20)$$

The quantity **L** of physical communication channels required in order to provide permissible communication quality within the site area (these channels may be implemented in any known way, for example, "FDMA+TDMA" for GSM) depends, along with the required spectrum amount, on the network structure (quantity of sectors in a single site n_S). In particular,,

for the "Erlang B" model (blocked calls cleared):

$$L = \arg\left\{\frac{E^L/L!}{\sum_{j=0}^{L}\left(E^j/j!\right)} = P_B\right\}, E = \frac{N_{S\,MAX}E_0}{n_S}, \quad (21)$$

where

E [Erl.] - busy hour traffic intensity for the site sector;

E_0 [Erl.] - average busy hour load per subscriber (E_0=0,025 Erl.);

P_B - permissible call blocking probability for the network; for cellular networks, $P_B \leq 1\div2\%$;

n_S - quantity of sectors for a single network site (generally n_S=3, but other values are possible, for example n_S=1,2,4,6,…);

for the "Erlang C" model (blocked calls queued and served as soon as there is free capacity; the waiting time is not limited):

$$L = \arg\left\{\frac{\frac{E^L}{L!}\frac{L}{L-E}}{\sum_{j=0}^{L-1}\frac{E^j}{j!} + \frac{E^L}{L!}\frac{L}{L-E}} = P_B\right\}. \quad (22)$$

In every mobile communication system, the quantities **L,E** are related to the corresponding amount of the spectrum used by each site and the whole system.Specifically, for FDMA/TDMA systems and given values of **L,E**, the required quantity of frequency channels for a site and for the whole network provided that the load for individual sites is equal is determined by expression

$$V_S \approx \text{int}\left\{\frac{L+1}{M}\right\} + 1, \quad V_N = V_S N_{CL}, \quad (23)$$

where

V_S , V_N are numbers of frequency channels for a site and for the whole network correspondingly;

int{…} is the transformation into an integer number (digits after the decimal separator are neglected);

M is the number of timeslots to implement **M** communication channels with time division in a single frequency channel; in GSM systems, **M**=8, in TETRA systems, **M**=4;

N_{CL} - is the number of frequency channels in a cluster when network frequency planning is carried out.

The relationship (23) makes it possible to determine the ecologically safe amount of spectrum to be allocated to an operator. If the number of channels allocated to an operator exceeds (23) then the number of sites deployed by an operator and sufficient to process the predicted load **E** will be lower than the ecologically required number of sites and in this case the deployed sites will have larger size. As a result of this, the network will have insufficient ecological safety. If the number of channels allocated to an operator does not exceed (23), then the limitations on the allocated spectrum will help improve the network up to the ecologically safe level.

It is clear that even with the spectrum allocation to an operator within (23), the ecological safety of a network may be violated at initial stages of its implementation; in this case, the requirements should be imposed on the operator to comply with the limitations on the network site sizes (17),(18) and use the automatic mobile station equivalent radiated power adjustment at all stages of commercial network operation.

3. EXAMPLE OF CELLULAR NETWORK ECOLOGICAL SAFETY EVALUATION

Fig. 1 below shows the calculated relationships between the maximum permissible coverage area radius for GSM 900 and 1800 base stations and mobile station equivalent radiated power. These relationships were obtained with the use of the Okumura-Hata model for urban propagation and the following parameters: the mobile station height above the surface is 1.5m; the base station antenna height is 60m; the mobile station antenna gain is 0dB; the base station antenna gain (taking into account feeder attenuation) is 15dB; the mobile station equivalent radiated power adjustment range is 0.1-0.9W; the base station receiver sensitivity is -107dBm; the probability of successful communication is 0.9 (0.95*0.95).

According to [1] and a number of other sources, one may take the following mobile station equivalent radiated power values as ecologically safe for mobile communication: approximately 0.2-0.3W for GSM-900 and approximately 0.1-0.2W for GSM-1800. Consequently, the ecologically acceptable site radiuses should not exceed 1.6-1.9 km (site area is 8-11 square kilometers) for GSM-900 and 0.8-1.0 (site area is 2-3 square kilometers) for GSM-1800. Hence for a typical urban scenario (a large city with the population $C_{P\Sigma}$ = 1.0-1.5 million of people and area of 300-500 square kilometers) the ecological safety of GSM networks will be ensured if every operator deploys at least 40-60 900MHz sites and/or 100-150 1800MHz sites over the city territory (the latter figure also refers to combined 900/1800MHz sites).

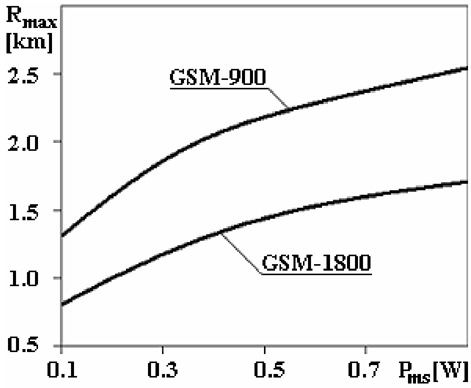

Fig. 1

An example below shows preliminary estimates of the required minimum number of subscribers $\mathbf{C_{MIN}}$ for the GSM net with three-sector 2-frequency (GSM-900) or 4-frequency (GSM-900/1800) sites; the estimates are provided for the typical urban scenario discussed above and the typical design value of network operating capacity, model "Erlang B" [5].

Network type	Busy hour traffic intensity per site, Erl.	Max. quantity of subscribers per site	Number of sites in the network	Quantity of subscribers $\mathbf{C_{MIN}}$, in thousands of people
GSM-900, 2 frequency channels per sector (15 traffic channels), three-sector sites	24.33	973	40-60	40-60
GSM-900, 4 frequency channels per sector (30 traffic channels), three-sector sites	60.9	2436	40-60	100-150
GSM-900/1800 or GSM-1800, 4 frequency channels per sector (30 traffic channels), three-sector sites	60.9	2436	100-150	240-360

In the event of substantial spatial irregularity of the network structure and relatively high levels of integral intranetwork interference, if the frequency clusters of low order are used the minimum desired signal field strength should be increased in order to achieve the acceptable network performance. Therefore the quantity of sites in relation to the data above should be additionally increased in order to ensure the ecological safety of the considered typical network segment.

The prerequisites for ecological safety of cellular network segments operating on the basis of the typical urban scenario presented above will be created in the number of network operators will be limited and each operator will have the prospective subscriber base of at least $\mathbf{C_{MIN}}$ subscribers. The maximum predicted penetration level generally amounts to 50-90% of the total population ($\mathbf{C_{A\Sigma}}$ = (0.5 … 0.9)$\mathbf{C_{P\Sigma}}$) and depends on many factors, including standards of living and paying capacity of the population. Therefore the approximate number of cellular operators $\mathbf{N_0}$ (number of issued licenses) as applied to the typical scenario discussed above should not exceed the value of

$$\mathbf{N_0} \le \mathbf{int}\left\{\frac{\mathbf{C_{A\Sigma}}}{\mathbf{C_{MIN}}}\right\}; \tag{24}$$

$\mathbf{N_0}$≤2-4 for GSM-900/1800 networks and $\mathbf{N_0}$≤4-6 for GSM-900 networks. If the amount of spectrum allocated to each of the operators varies then this estimation may be refined with the use of the data and expressions presented above.

The most controversial issue is the ecologically acceptable mobile station equivalent radiated power. The value of this parameter may differ by a factor of several units in accordance with standards and regulations in various countries and estimations provided by different sources [1]. However, the pessimistic estimations of the permissible mobile station equivalent radiated power should be used considering a number of existing trends (increased average talk time in case of mobile subscribers, higher penetration level for mobile communication services, increased market for 1.8-2.2GHz mobile communication services etc.) related to growing availability of cellular communication and consequently the rapid subscriber base expansion and dramatic integration of cellular communication into the whole society structure as well as presence of other environment pollution factors (radiation and chemical pollution) whose impact on the human body in combination with the electromagnetic radiation has not yet been investigated good enough.

It is obvious, that the results given above can be stated in the form intended to set "ecological" limitations on the radio frequency resource volume, allotted to the cellular network operator , based upon the regulated levels values $\mathbf{\Pi_0}$ [W/m^2] of EMF power flux density of the population irradiation in certain frequency ranges or values of Specific Absorbtion Rate (SAR) regulated by the international (ICNIRF) or national standards or recommendations. In particular, the maximum permissible value $\mathbf{P_{AS\ PM}}$ of the EMR AC power is proportional to the standardized irradiation reference level value: $\mathbf{P_{AS\ PM} = P_{A\ PM} / k = const \cdot \Pi_0}$. The one place relation between the value $\mathbf{P_{AS\ PM}}$ and standardized value SAR is also obvious. Although to this day there are no conventional quantitative characteristics of this relation being the object of numerous and intensive researches [6].

4. CONCLUSION

Hence the system approach to ecological characteristics of cellular networks presented above makes it possible to determine the relation of these characteristics to the amount and quality of spectrum allocated to the network (specifically, the corresponding frequency range), intrasystem (intranetwork) EMC parameters and formulate the following provisional aspects concerning improvement of ecological safety for cellular networks.

1. The spectrum allocated to an operator should be limited; in this scenario, an operator has to develop the network infrastructure with the limited available spectrum, i.e. split sites by increasing the frequency reuse ratio.
2. The minimum permissible spatial density of base stations (maximum site size) should be limited, at least in the urban building regions; limitations on the minimum permissible quantity of sites at the initial network development stages should be introduced.
3. Relatively lower frequency ranges (400-450, 800-900 MHz) should be preferred where possible, especially in rural and suburban regions; utilization of spectrum in the 1800-2200 MHz range is advisable only in scenarios where there is base station density and the high mobile station equivalent radiated power is not required (microcells and picocells).
4. When spectrum planning is carried out for prospective mobile communication networks (3G, 3G+, 4G), it is ecologically advisable to use 800/900 MHz and 2 GHz spectrum allocations and additionally try and free the spectrum earlier used by the land mobile service (300-350, 400-450 MHz etc.) for handling of voice traffic in rural regions, suburban regions, recreation areas etc.
5. The methods and algorithms for intranetwork EMC provision should be further developed which can lower the integral intranetwork interference level, in particular in networks with irregular structure.
6. The comparative systems ecological analysis of cellular communication technologies (FDMA, TDMA, CDMA) should be made in order to determine the most ecologically attractive solutions at each hierarchy level of prospective mobile communication networks (3G, 3G+, 4G).
7. Sensible limitations on the talk time and talk intensity should be introduced for locations where high (close to the maximum) mobile stations electromagnetic radiation power is required for communication. These situations take place when low base station signal level is shown at the mobile station display. This limitation may be implemented on the basis of issuing of the relevant information to subscribers and also generation of the corresponding warning signals by mobile station processors taking into account the emission level and talk time as well as cumulative nature of electromagnetic radiation impact on the human body.
8. If special low-power wireless (mobile) base stations are not available indoors, it is advisable to prefer wire communications wherever possible because the mobile station electromagnetic radiation is attenuated by building structures and the mobile station equivalent radiated power should increase correspondingly to compensate for this effect.
9. It is advisable to use combined networks, for example, DECT-GSM networks, inside large offices, business premises, educational and other areas; these networks provide indoor communication with low mobile station equivalent radiated power (not higher than tens of milliwatts).
10. The technical facilities for remote control of mobile stations should be further developed which make it possible to operate mobile stations at a distance from critical human organs (this is possible when mobile stations are used in cars, at workplaces etc.).

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