Reduction of the Radiated Power of Cellular Base Stations on Urban Area at High Intrasystem EMC Requirements

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***Abstract*—Results of estimation of necessary and sufficient levels of radiation power of base stations of cellular communications on urban area are resulted. Analysis is made on the basis of results of behavior simulation of the fragment of a GSM network executed with the use of multibeam radiowave propagation model X3D and the topological model of a fragment of urban area of the central part of Minsk. The results indicate that a high communication quality with blocking probability 0.01 and frequency sharing with SNIR≥12dB can be achieved at levels of BS equivalent isotropic radiated power 43-47 dBm per frequency channel that is essentially less than EIRP levels actually used by GSM/UMTS operators in considered territory. The received results testify that in conditions of excessive BS radiated power the insufficient QoS is caused only by lacks of intrasystem EMC of cellular network, in particular, insufficient quality of network frequency planning and high levels of intranetwork interference. In these cases improvement of intrasystem EMC make it possible to decrease EIRP levels of BS and to improve the electromagnetic safety of population on corresponding areas without degradation of cellular QoS**

Keywords—Intrasystem EMC, cellular communications, EIRP, base stations, GSM, electromagnetic safety

I. INTRODUCTION

In conditions of constant growth of terrestrial density of base stations (BS) of cellular communications and corresponding reduction of BS coverage areas a problem of BS electromagnetic radiation (EMR) safety for the population is of the great interest. The BS equivalent isotropic radiated power (EIRP) of GSM-900/1800 in urban areas in some countries [1, 2, et al.] is limited only by BS technical specifications or is defined at level 53-58 dBm per GSM frequency channel that is essentially above the EIRP levels actually necessary for normal operation of GSM cellular communications in densely populated areas.

The overrated EIRP of BS on urban areas can absolve the defects of frequency planning and intranetwork EMC, but also can be a reason of the essential environmental risks for population, whereas cellular radio networks are not the unique EMR sources in populous areas. The overrated BS EIRP is an evident reason of an overrated EIRP of user's radio devices (URDs - cellular phones, IP modems, etc.) and really can be a reason of expansion of sanitary-protective zones of operating of radio transmitting objects (radio- and television transmitting centers, local multi-radar systems, etc.): these zones are defined under the estimation of the total intensity of man-made electromagnetic fields (EMF) [3,4]. Under the well-known features of frequency planning of cellular radio networks caused by multiple repetition of usage of the same frequency channels in territorially separated network sites, really used EIRP levels of BS and URDs may be essentially overrated because of the problem of intrasystem EMC, i.e. owing to presence of the intranetwork interference.

The question on determination of science-based lower bound of a range of possible levels of EIRP BS, sufficient for normal operation of cellular communications in urban and suburban areas is of special urgency because of the following.

In some countries owing to imperfection of techniques of collection of duties for usage of a radio-frequency spectrum by cellular BS [5, et al.] these duties are proportional to BS EIRP. The given disposition contradicts as the idea of cellular communications (a territory covering not at the expense of growth of EIRP BS, but at the development of a network cellular structure with multiple repetition of usage of the same frequency channels by low-power BS under the condition of their territorial sharing), and also with requirements of electromagnetic safety of the population.

Moreover, the given disposition hinders the Licensor's decisions on decreasing the EIRP BS up to the minimum necessary levels because such decisions lead to decreasing the monetary arrivals. Change of current situation is possible only on the basis of determination of the science-based minimum necessary levels of EIRP BS on urban and suburban areas, promoting also to decrease of the average EIRP of URDs and to provide low levels of forced ecological risks for population.

Earlier the estimations [1] of BS EIRP levels in GSM 900/1800 frequency channels necessary and sufficient for support of an effective utilization of a radio-frequency spectrum assigned to a network, at various heights of BS antennas, various population density, various levels of radio reception real sensitivity, various cluster dimensionality of a frequency planning, and at various specific traffic intensity have been performed. But these estimations need to be

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qualified because they have been executed with the use of model of radiowave propagation (RWP) in urban area on the basis of Okamura-Hata modified empirical model [6,7] with its interpolation on distances less than 1 km for which its accuracy essentially depends on parameters of city housing.

The purpose of the given paper is updating the estimations [1] of necessary levels of EIRP BS on urban area on the basis of behavior simulation of GSM 900/1800 network with the use of model of real urban area of a central part of Minsk and the multipath RWP model, implemented with application of [8], and also taking into account the specified requirements of intrasystem EMC and characteristics [6,7,9] of EMF attenuation in buildings.

II. Characteristics of the Behavior Simulation of GSM Network

The models and initial data, used at behavior simulation of an urban fragment of GSM network, are given below.

A. Model of city area

Model of a fragment of city housing of a central part of Minsk represented on Fig. 1 is used, its size is 1.5x1.5 km. In this model the topology of allocation and height of buildings are considered. The given territory is a central part of a city with the compact planning. In this model the following characteristics determining the RWP peculiarities in considered conditions are accepted:

Fig. 1. Model of an urban area used at behavior simulation of cellular system

- The main material of walls of buildings - a brick, type of a covering of an earth surface – asphalt.
- Weather conditions of two types: low humidity (sunny and dry) and high humidity (rain).
- Height of houses is 8-30 m in terms of number of stores and architecture of buildings; width of the main traffic artery (avenue) is 50 m, width of streets is 20-30 m depending on an amount of traffic lanes (2-8) and width of sidewalks.
- The territory is divided into three conditional categories: domestic area, vehicular area, pedestrian area. Allocation of URDs on domestic area and pedestrian area is accepted uniform and random. Allocation of URDs on vehicular area is accepted uniform and random on traffic lanes. An amount of observation points (OP) or points of URD allocation is 10 000 points for each type of territory.
- Roofs of buildings are accepted as planes, the main material of roofs construction is ferroconcrete (the given assumption is caused by restrictions of functionality of the software [8] used at simulation).

B. RWP Model

Three-dimensional model X3D [8] of multipath RWP in the conditions of the compact city planning, not having restrictions on usage in the accepted conditions and considering up to *N* possible ways of propagation of EMR of BS allocated on roofs of buildings at height 25 m over an earth surface, to each of considered OP at a surface at height 1.5-2.0m, is used.

The model is based on usage of three-dimensional SBR (Shooting and Bouncing Ray) algorithm. The given algorithm is used for determination of paths of RWP rays from BS to the OP in three-dimensional space. The path of each ray in a direction to OP begins in a source of EMR (BS) and proceeds, specularly reflected from walls of buildings and an earth surface of no more then given amount of times (this amount is a parameter used for selection of rays considered at summation on an input of the URD's receiver at the OP), and diffracting at corners and edges of roofs of buildings.

Parameters of X3D model of RWP are following: an amount of reflections of each ray - up to 6, an amount of points of diffractions - no more than 1, a corner between two adjacent rays which are starting from one BS - 0.25 degrees, an amount of rays which are starting from one BS - up to 10.

C. Model of fragment of cellular network

Behavior simulation of cellular system is performed for conditions of high quality of wireless communications, corresponding to high probability of communication ("Grade of Service") B = 0.98-0.99 at various levels of channel EIRP BS and under the additional conditions given below:

- Terrestrial density of BS is approximately 3 BS/km^2 (6 BS represented by red marks Tx1 - Tx6 on Fig.1).
- The analysis is performed for BS of GSM-1800 which are using 75 % of volume of the radio-frequency spectrum, assigned for GSM networks. A range of analyzable levels of EIRP BS is 40-53 dBm per GSM frequency channel.
- The noise factor of BS and URD receivers is accepted at level 7 dB [2] that corresponds to level P_0 = -114 dBm of threshold sensitivity of the receiver, i.e. to the corresponding level of the BS receiver own noise resulted to the receiver input in a frequency band of a radio reception equal to 200 kHz.

- BS EMRs are accepted as isotropic, URD antennas are accepted as isotropic with 2 dB gain.
- It is accepted that the useful signal received by URD's receiver, is a signal of prevailing BS, for which RWP losses in a point of URD allocation are minimal.

III. Results of GSM-1800 Behavior Simulation

As a result of GSM-1800 behavior simulation the representative samples of values of levels of BS signals prevailing on an inputs of URD radio receivers (outputs of the URD receiving antennas) for various conditions are analyzed. Typical histograms of probability densities for these samples of levels of prevailing BS signals in sets of OP allocated on areas of different types, are resulted on Fig. 2-4 below.

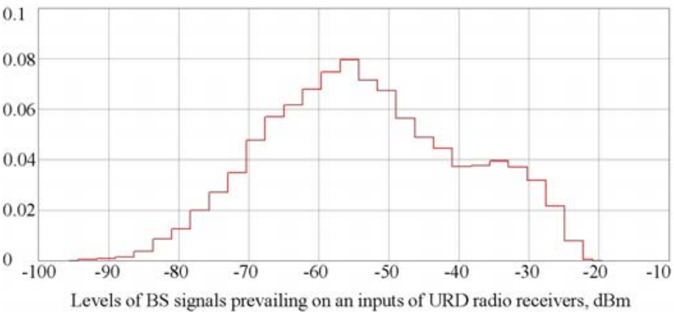

Fig. 2. Typical histogram of probability density for the sample of levels of prevailing BS signals in an ensemble of OP allocated on domestic area.

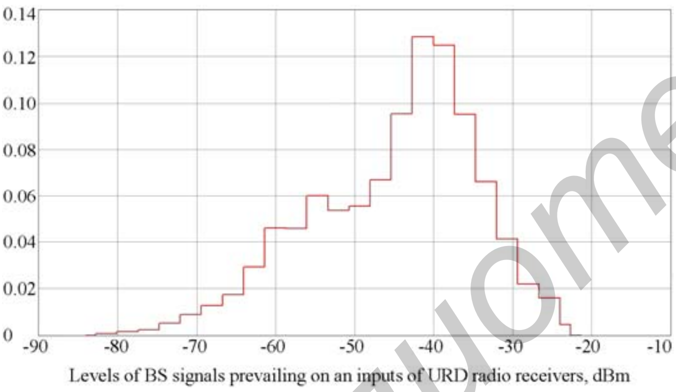

Fig. 3. Typical histogram of probability density for the sample of levels of prevailing BS signals in an ensemble of OP allocated on vehicular area.

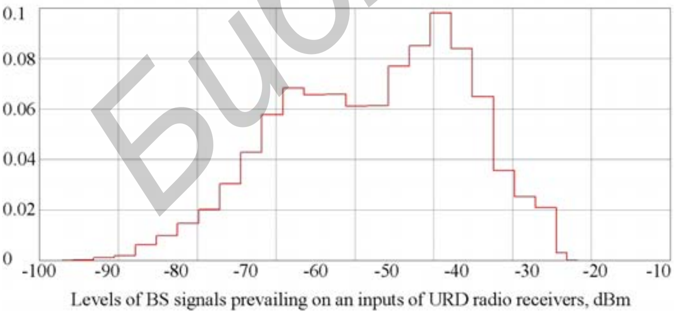

Fig. 4. Typical histogram of probability density for the sample of levels of prevailing BS signals in an ensemble of OP allocated on pedestrian area.

In Tables 1-4 the results of statistical treatment of samples of levels of prevailing BS signals on areas of different types, received at GSM behavior simulation, are resulted. In these tables the results of estimation of boundaries of ranges of levels of signals of prevailing BS on an inputs of URD receivers under various weather conditions (dry, rain), various EIRP BS levels and at URDs allocation on area of various type (domestic, vehicular or pedestrian) for communication probability ("gradeofservice") $B = 0,99$ and $B = 0,98$, are given.

TABLE I. Ranges of levels of signals of prevailing BS on an input of URD receivers at low humidity (dry weather conditions) for communication probability ("gradeofservice") B = 0,99

EIRP of BS frequency channels, dBm	**Ranges of levels of signals of prevailing BS on an input of URD receivers, dBm**		
	Domestic area	***Vehicular area***	***Pedestrian area***
40	-83,8…-22,1	-73,2…-22,9	-76,2…-23,3
43	-80,8...-19,1	-70,2...-19,9	-73,2...-20,3
47	-76,8...-15,1	-66,2...-15,9	-69,2...-16,3
50	-73,8...-12,1	-63,2...-12,9	-66,2...-13,3
53	-70,8...-9,1	-60,2...-9,9	-63,2...-10,3

TABLE II. Ranges of levels of signals of prevailing BS on an input of URD receivers at low humidity (dry weather conditions) for communication probability ("gradeofservice") B = 0,98

EIRP of BS frequency channels, dBm	**Ranges of levels of signals of prevailing BS on an input of URD receivers, dBm**		
	Domestic area	***Vehicular area***	***Pedestrian area***
40	-81,2…-22,1	-70,2…-22,9	-73,6…-23,3
43	-78,2…-19,1	-67,2…-19,9	-70,6…-20,3
47	-74,2…-15,1	-63,2…-15,9	-66,6…-16,3
50	-71,2…-12,1	-60,2…-12,9	-63,6…-13,3
53	-68,2…-9,1	-57,2…-9,9	-60,6…-10,3

TABLE III. Ranges of levels of signals of prevailing BS on an input of URD receivers at yigh humidity (rain) for communication probability ("gradeofservice") B = 0,99

EIRP of BS frequency channels, dBm	**Ranges of levels of signals of prevailing BS on an input of URD receivers, dBm**		
	Domestic area	***Vehicular area***	***Pedestrian area***
40	-83,9…-20,8	-73,7…-21,5	-76…-22,5
43	-80,9…-17,8	-70,7…-18,5	-73…-19,5
47	-76,9…-13,8	-66,7…-14,5	-69…-15,5
50	-73,9…-10,8	-63,7…-11,5	-66…-12,5
53	-70,9…-7,8	-60,7…-8,5	-63…-9,5

TABLE IV. Ranges of levels of signals of prevailing BS on an input of URD receivers at yigh humidity (rain) for communication probability ("gradeofservice") B = 0,98

EIRP of BS frequency channels, dBm	**Ranges of levels of signals of prevailing BS on an input of URD receivers, dBm**		
	Domestic area	***Vehicular area***	***Pedestrian area***
40	-81,3…-20,8	-70,3…-21,5	-73,4…-22,5
43	-78,3…-17,8	-67,3…-18,5	-70,4…-19,5
47	-74,3…-13,8	-63,3…-14,5	-66,4…-15,5
50	-71,3…-10,8	-60,3…-11,5	-63,4…-12,5
53	-68,3…-7,8	-57,3…-8,5	-60,4…-9,5

Results of GSM-1800 behavior simulation in accepted conditions testify the following:

1) At EIRP BS level 53 dBm/channel (200 W/channel), used by GSM/IMT operators in some countries on urban areas [1], the lower bounds P_D of values of the level of useful signal on an input of URD receivers are following:

- For domestic area P_D = -70.9 ...-68.2 dBm, i.e. on 43.1-45.8 dB above the threshold sensitivity of the URD's receiver.
- For vehicular area P_D = -60.7...-57.2 dBm, i.e. on 53.3-56.8 dB above the threshold sensitivity of the URD's receiver.
- For pedestrian area P_D = -63.2...-60.4 dBm, i.e. on 50.8-53.6 dB above the threshold sensitivity of the URD's receiver.

2) If the communication quality requirements increases (B increases on 1% from 0,98 to 0,99) then the lower bounds of values of levels of the useful signal on the URD receiver inputs decreases on 2.6 … 3.4 dB, change of weather conditions changes this boundary on 0.1 … 0.5 dB.

3) At EIRP BS 43 dBm/channel (20 W/channel, that is 10 times less than EIRP BS levels used today on urban areas by GSM/IMT operators in some countries), the lower bounds of values of level of the useful signal on an URD receiver inputs for territories of various type exceeds the URD receivers threshold sensitivity on $D_P = P_D - P_0$ = 33.1-35.8 dB for domestic area, D_P = 43.3-46.8 dB for vehicular area, and D_P = 40.8-43.6 dB for pedestrian area.

4) With a view of high quality of communication the difference P_D-P_0 between the level of URD useful signal and URD threshold sensitivity should be sufficient for overcoming the RWP losses at their penetration in buildings. In this case the difference $D_P = P_D - P_0$ [dB] has three components and is connected to minimum necessary ratio «signal/self-noise» on an input of receiver Q_N and attenuation of radio-waves in building S_B as follows:

$$D_P[\text{dB}] = P_D[\text{dBm}] - P_0[\text{dBm}] \geq Q_N[\text{dB}] + S_B[\text{dB}], \quad (1)$$

$$Q_N[\text{dB}] = Q[\text{dB}] + \Delta Q[\text{dB}].$$

where Q is a minimum necessary protection ratio on an URD receiver input, equal to the ratio of the minimum used power of the useful signal $P_{u\,min}$ [W] on an URD receiver input to the power of a total noise ($P_0 + P_{\Sigma\,int}$) [W], depending both on the level of URD receiver self noise P_0, and on the total level of intranetwork interference $P_{\Sigma\,int}$:

$$\frac{P_{u\min}}{P_0 + P_{\Sigma\text{int}}} \geq Q; \quad Q_N = \frac{P_{u\min}}{P_0}; \quad (2)$$

$$Q[dB] = 10\lg Q, \quad Q_N[dB] = 10\lg Q_N;$$

ΔQ is the complementary component of (1) specified by a quality of frequency sharing of cellular network (or quality of intranetwork EMC design).

5) The necessary minimum protection ratio in cellular network Q must be less than the value Q_{CL} of protection ratio defined by a total intranetwork interference $P_{\Sigma\text{int}}$ created at the selected cluster dimensionality of the network frequency planning

$$Q < Q_{CL} = \frac{P_u}{P_{\Sigma\text{int}}}, \quad (3)$$

where P_u is the level of useful signal provided in cellular network at the level $P_{\Sigma\,int}$ of an intranetwork interference. If the term (3) is satisfied then it is possible to find the minimum used power $P_{u\,min}$ of the desired signal received by URD, depended on the self noise of URD receiver and defining the actual value of URD's actual sensitivity of radio reception implemented in cellular network:

$$P_{\Sigma\text{int}} = \frac{P_{u\min}}{Q_{CL}}, \qquad \frac{P_{u\min}}{P_0 + \dfrac{P_{u\min}}{Q_{CL}}} \geq Q.$$

Hence

$$P_{u\min} \geq P_0 \frac{Q\,Q_{CL}}{Q_{CL} - Q}, \quad Q < Q_{CL}, \quad (4)$$

$$Q_N = \frac{P_{u\min}}{P_0} \geq \frac{Q\,Q_{CL}}{Q_{CL} - Q_0}, \quad Q < Q_{CL}, \quad (5)$$

The last expression allows to estimate ΔQ values in (1) at various quality of the network frequency planning. On Fig. 5 plots of Q_N dependence on value Q for four Q_{CL} values taken with the step 0.5 dB in a range 16.5 … 18 dB; on Fig. 6 plots of ΔQ dependence on value Q for four Q_{CL} values pointed above, are resulted. The specified Q_{CL} values are appropriate for the frequency planning with cluster dimensionality 4 - 7 [10] of regular cellular network. Curves on Fig. 5,6 testify to the following:

- In the range $Q_{CL} - Q \geq 5$ dB appropriate to the high quality of the network frequency planning, the necessary addition ΔQ to the level of the useful signal to ensure the desired communication quality, does not exceed 2 dB.
- At $Q << Q_{CL}$ it is evident that Q is approximately equal to Q_N.
- Addition ΔQ to the level of the useful signal provide the appropriate "synchronous" growth of level of an intranetwork interference $P_{\Sigma\,int}$ and corresponding reduction of influence of the self noise of URD's receiver on Q value (reducing up to the acceptable level of the P_0 contribution in a denominator (2)).
- At degradation of a cellular network frequency planning the addition ΔQ increases sharply and can reach 10-15 dB and more.
- At poor quality of cellular network frequency planning for some areas of the network coverage zone condition $Q_{CL} > Q$ can not be fulfilled, and in these areas owing to

the unsatisfactory level of intranetwork EMC the required communication quality remains unsatisfactory at any expansion of level of the URD's desired signal (realized by the growth of EIRP BS).

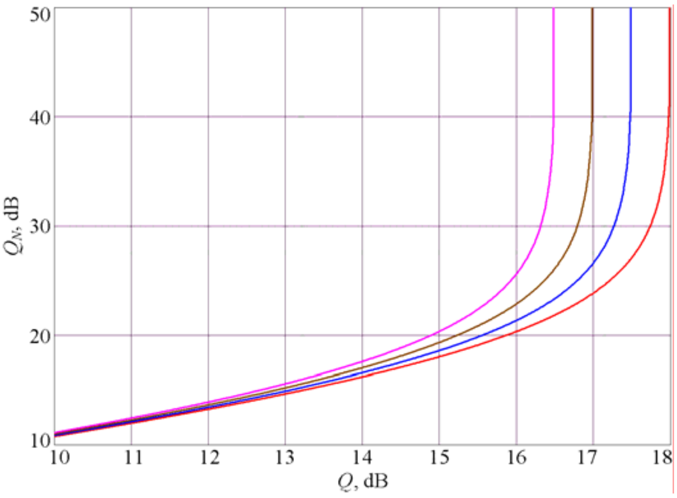

Fig. 5. Plots of the Q_N dependence on Q value for Q_{CL} = 16.5 dB (left pink curve), Q_{CL} = 17 dB (brown curve), Q_{CL} = 17.5 dB (blue curve) and Q_{CL} = 18 dB (right red curve)

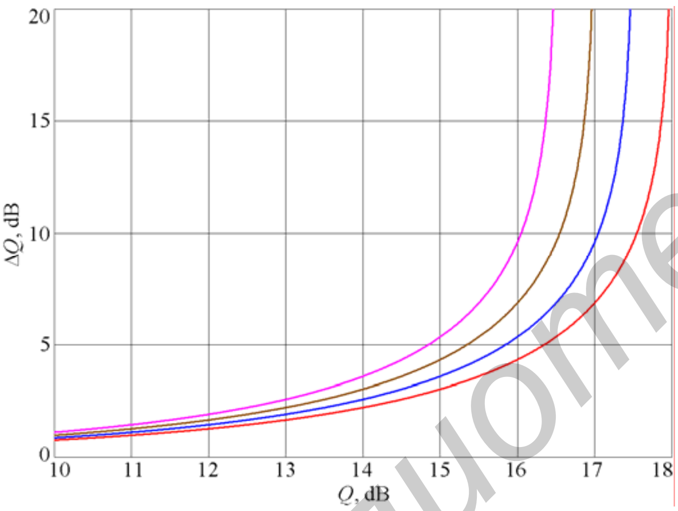

Fig. 6. Plots of the dependence of $\Delta Q = Q_N - Q$ on Q value for Q_{CL} = 16.5 dB (left pink curve), Q_{CL} = 17 dB (brown curve), Q_{CL} = 17.5 dB (blue curve) and Q_{CL} = 18 dB (right red curve)

As a result it is possible to estimate the following: is a reserve on level of the desired signal on an input of an URD radio receivers, marked above in section III, is really necessary and sufficient for ensuring of required quality of cellular communications, or not. To find out a reply it is necessary to take into consideration the following.

- In GSM networks we have $Q \geq 9$ dB [2];
- In typical quasiregular three-sector structure of cellular GSM radio networks, in which the number of the radio channels assigned to a network, in 4-7 times exceeds the number of frequency channels used in a three-sector site [10], intrasystem EMC is provided at level Q_{CL} = 15-20 dB. Determination of the GSM URD receiver's sensitivity at level -104 dBm [2] is conformed with circumstances mentioned above because this level on 10 dB exceeds the self-noise level P_0 of the GSM URD receiver.
- At an estimation of necessary EIRP BS level of GSM network on urban area it is necessary to consider the attenuation of BS signals in buildings. According to [7] attenuation of radio waves in buildings at ground level is about 18-19 dB for GSM-900 and about 16-17 dB for GSM-1800, according to [9] the median value of this attenuation for locations at ground level can be about 11 dB for GSM-900/1800 at 6 dB of mean square deviation, according to [6] main losses on penetration of UHF radio waves on building floors depend on a floor number and take on values in the range 2.5 … 16.5 dB. In all cases a particular character of the resulted estimations is marked, these estimations are reasonable only for certain conditions: for certain types and number of stores of buildings, character and parameters of city housing, etc. However, at terrestrial density 3-5 BS/km^2 it is necessary to take into consideration that [a)] indoors a signals from several surrounding BS are present, and connection is executed on the "best" channel, and [b)] the estimations resulted above in Tables I-IV, are made for small height over an earth surface (not above the ground floor level). Therefore the real upper limit of radio waves attenuation in buildings with regard to the conditions given above for behavior simulation of cellular communications, can be accepted equal to 18-20 dB.

Taking into account the simulation results given above in Section III, and the upper limit of radio waves attenuation in buildings accepted above, it is possible to come to the following:

1) At EIRP BS 53 dBm/channel (200 W/channel), used by IMT/GSM operators in considered area and also in some countries on urban areas, a store ΔQ on level of the desired signal on an inputs of URD radio receivers, created for compensating the influence of an intranetwork interference on quality of cellular communications, take on the following values:

- For domestic area $\Delta Q \approx$ 13-15 dB,
- For vehicular area $\Delta Q \approx$ 22-26 dB,
- For pedestrian area $\Delta Q \approx$ 20-22 dB.

So large reserve on level of the desired signal on URD receiver inputs, on the one hand is a reason of the overrated levels of URD's radiation, and on the other hand admits poor quality of the network frequency planning on urban area.

2) At EIRP BS 43 dBm/channel (20 W/channel) a store ΔQ on level of the desired signal on an URD receiver inputs created for compensating of influence of an intranetwork interference on communication quality, take on a value 3-5 dB for URDs allocated in domestic area, 12-16 dB for URDs allocated in vehicular area, and 10-12 dB for URDs allocated in pedestrian area. Such reserve is oriented on expected, but quite achievable quality of the network frequency planning on urban area, provided with the extension of volume of a radio-frequency resource used by a network, and with the network development and optimization that allows to increase the Q_{CL} value.

3) Results of the analysis specifies the obvious ways of reduction of the average level of intranetwork interference and increase the Q_{CL}, or reduction of the necessary ΔQ value:

- Reduction of dimensions of the network sites (decrease the areas of service zones of separate BS) at fixed traffic terrestrial density in busy hours allow to reduce the traffic volume processed by separate BS and decrease a number of frequency channels necessary for corresponding BS. At fixed volume of the radio-frequency spectrum assigned to the cellular network it allow to increase the cluster dimensionality of the network frequency planning (or to increase the a ratio of the total network quantity of frequency channels to number of frequency channels used by separate BS, at usage of optimization methods of frequency planning of cellular networks with the irregular space structure) and to increase Q_{CL}.
- Restriction of the requirements to quality of cellular communications at some rational standard level; excessive strictness of these requirements can be an obvious reason of necessary expansion of ΔQ and of application by cellular operators the essentially overrated levels of EIRP BS that is extremely undesirable from the point of view of electromagnetic ecology of urban areas and electromagnetic safety of population.

IV. Conclusion

The results given above testify that EIRP of GSM BS at the rate of about 50-55 dBm/channel and more, used today by GSM/IMT operators of considered territory and also in some countries on urban areas, is essentially superfluous and is oriented on poor quality of the network frequency planning and intrasystem EMC design.

These results reflect the competitiveness of the “Cellular communications” medium from the point of view of the Licensor and Licensees of cellular communication services. ΔQ is that reserve which allows Licensees to economize on investments into a cellular communication infrastructure. Unfortunately, this saving is received at the expense of electromagnetic ecology of cellular communications and electromagnetic safety of the population on those territories where this saving takes place.

Reduction of EIRP of GSM BS in urban areas up to 43-45 dBm/channel can be accepted as quite real in conditions that the corresponding investments into a cellular networks infrastructure are directed at following:

- At simultaneous extension of the volume of radio-frequency resource used by cellular network (at the expense of conversion of a radio-frequency spectrum, of new frequency ranges granted for cellular communications, etc.).
- At further development of network infrastructure at the expense of increase of BS terrestrial density on urban areas taking into account requirements of networks optimization.

As an effect of these efforts a required reserve on levels of the desired signal on inputs of URD receivers, created for compensating of influence of an intranetwork interference on communication quality in GSM networks, can be essentially reduced.

The presented results provide an estimation the acceptability of reduction the radiated power of cellular BS on urban area at high requirements to the intrasystem EMC. They testify that essentially overrated average levels of EIRP BS can be considered as one of essential symptoms taken into account in diagnostics of quality of an intranetwork EMC in cellular communications.

The quantitative results placed above are valid for GSM cellular communications. However the watched technological evolution of cellular communications is associated with increasing usage of UMTS and LTE technologies of the 3rd (3G) and 4th (4G) generations at the considerable reduction of a contribution of 2G cellular technologies in implementation of services of mobile communications. Therefore authors arrange to continue efforts concerning the quantitative analysis of the required and sufficient levels of EIRP BS of cellular communications of 3rd and further generations on urban and suburban areas.

References

[1] V.I.Mordachev, A.S.Svistunov, “Required and sufficient level of GSM base stations electromagnetic radiation power”, Doklady BGUIR, No. 7(77), 2013, pp.44-50 (in Russian).

[2] “Digital Cellular Telecommunications System (Phase 2+). Radio Transmission and Reception (GSM 05.05 version 8.5.1 Release 1999)”, ETSI EN 300 910, V8.5.1 (2001-11).

[3] “Hygienic requirements to installation and operation of systems of cellular communication”, authorized by the Decision of Ministry of Health of Belarus №14 dt. 01.02.2010 (in Russian).

[4] “Estimation of risk for health of the population provided by influence of the electromagnetic fields created by base stations of cellular communications and broad-band wireless access. Application instructions”, dt.28.06.2010, No. 093–0610 (in Russian).

[5] “About determination of the order of an annual payments, single payments and a payments for assign of a radio-frequency spectrum”, Decision of the Council of Ministers of the Republic of Belarus No.890 dt.15.07.2006.

[6] J.D.Parsons, The Mobile Radio Propagation Channel, 2nd Edition, John Wiley & Sons Ltd, 2000, 433 p.

[7] K.Siwiak Radiowave Propagation and Antennas for Personal Communications, 2nd ed., Boston: Artech House, 1998, 418 p.

[8] Wireless InSite: Site-specific Radio Propagation Prediction Software. Reference Manual, Version 2.7.1.- REMCOM, February 2014,

[9] Rec. ITU-R P.1812 A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands.

[10] A.Mehrotra, “Cellular radio: analog and digital systems”, Artech House, 1994, 460 p.