LIMITING THE RF RESOURCE ALLOCATED TO A CELLULAR NETWORK AS A MEANS TO ENSURE ITS ECOLOGICAL SAFETY

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Abstract: The paper offers a method to determine the tolerance limit radio frequency resource (RFR) capacity, dedicated to a cellular communication radio network, ensuring development tendencies, essential from the ecological point of view. The results of the study of the cellular network ecologic characteristics relationship with the its RFR and intrasystem EMC are presented. The suggested systematic considerations of the cellular network ecological characteristics helps the quantitative determination of their relation with the capacity and quality of the RFR, 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.

I. INTRODUCTION

The electromagnetic radiation (EMR) of subscriber stations (SS) in a cellular radio network has negative influence on the health of people using mobile communication services. When used for communication a mobile phone is in the immediate proximity to the human head, affecting by its electromagnetic radiation the eyes, the brain, the blood and blood vessels, as well as other systems in the human body. In cases when the SS EMR power is high, this influence may become inadmissible. The SS EMR power depends on a number of basic factors, particularly on those, reviewed below:

1. Size of cells (sites) in the cellular network: the greater is the site radius, the higher SS EMR power is required to ensure the regular quality of the two-way communication.
2. Availability in the network of EMR power adjustments for base stations («Downlink») and SS EMR («Uplink»): the SS EMR adjustments allow for a reduction in the mobile SS EMR power and thus for a weakening in the negative impact of this factor on the human health (it is not applicable to subscribers who have to use the SS with its maximal EMR owing to certain circumstances, associated with their working place, dwelling, rest, and current stay locations, being far away from the network base stations (BS) or within zones of unsatisfactory radio wave propagation in the SS-BS direction due to shading by vegetation, relief, urban build-up, etc.
3. Level of the BS radio receiver (RR) actual susceptibility – the higher is the susceptibility, the lower SS EMR levels are required to ensure the regular two-way radio communication quality.
4. The cellular network intrasystem electromagnetic compatibility (EMC) parameters, in particular, the aggregate network interference level – the higher is this level (concerning a sensitivity level of the BS receiver), the greater SS EMR power is required to ensure the regular two-way radio communication quality.
5. Network structure regularity level – in case of random BS location their responsibility zones cease to be symmetric hexagonal and may have relatively remote from BS regions; networks featuring random spatial structure are characterized also by enhanced level of intra-system summary interference [4], that totally leads to a rise in the average power used by SS EMR in these networks.

The factors enlisted are unequal in their nature. To be more precise, the second and the third ones out of them may be attributed to the restrictions of the adopted mobile communication standard (system) – in earlier cellular communication standards and in many industrial communication systems are lacking of the SS and BS power adjustments; the BS radio reception susceptibility «in the field» is defined by the noise parameters and the reception bandwidth, as well as by the receiving antenna gain and the required (minimal admissible) signal-to-noise ratio.

The CDMA-based mobile communication systems make an exception of a certain kind, as in them the BS radio reception susceptibility strongly depends on the number of simultaneously operated SS within a single frequency channel of a single BS sector and in case of the peak loading is the worst. However with decrease in the loading on the BS its radio reception susceptibility increases (the minimal possible useful SS signal level drops) resulting from the degradation in the aggregate interference level within the channel, proportionally to the decrease in the number of simultaneously operating subscribers.

As far as the first, the forth and the fifth factors are concerned, these are related to the network structure and to the particulars of the RFR allocated for the network utilization, namely to the options of its intrasystem EMC support accepted on the basis of the network frequency planning. In what follows this issue shall be considered in more details.

II. THE BASIC CONSIDERATIONS

A multi-zone radio network (cellular, trunking network, etc.) is usually designed to cover the territory and its dwellers (or personnel, working on it) by appropriate radio communication services. When designing a radio network it is the loading (traffic) that is to be planned first of all, and based on this forecast the necessary RFR (the number of physical radio channels) is allocated and the required alternative of the frequency and territory planning is selected (cluster dimension, frequency repetition factor in key territory fragments of the network).

In a case when an unlimited RFR may be allocated for the network development, it is possible to implement the network design based on a minimal number of sites having maximal cluster possible. Then

- The required SS EMR power is maximal, and this solution is the most unfavourable from the ecological point of view;
- The required radio network carrying capacity is maintained by means of using in each site a large number of physical RF channels, necessary to process the expected traffic density (quantity of sectors, into which the site is divided plays no significant role);
- Minimal expenses for the infrastructure are needed (in case of this radio network design the intersite information streams are maximal, however modern fiber-optic lines and microwave radio relay stations (RRS) are capable to maintain practically any necessary data transmission rates in intersite links without any considerable increase in the communication line cost);
- The greatest expenses are required to pay for the RFR utilization that may be neglected in cases, when the RFR cost is deliberately understated or in principle taken into account in the license fee amount.

When the RFR to develop the network is limited, in order to provide the required communication quality the site sizes need to be reduced in combination with multiple frequency reuse in various sites to the level, essential to process the traffic of the expected density. In this case

- The less is the RFR allocated for the network implementation, the more reduction is required in the site sizes to process the traffic of expected density (the traffic density drops with a decrease in the site size at any finite SS space density), the lower is the required SS EMR power and the better is the network from the ecological point of view;
- When it is necessary to use similar frequencies in different network sites, the choice of the network frequency and territory planning alternative plays a crucial role (cluster type and dimension). This parameter is associated with the RFR capacity, accessible for a single site, and is determined as the frequency repetition factor in the basic territory fragments of the network, and the aggregate interference level in the network. The latter factor determines a need for an additional SS EMR power increase;
- The network infrastructure expenses significantly grow and are the higher, the lower is the site size;
- Costs to utilize the allocated to the network RFR shrink, being important in cases, when the RFR cost is high.

The present paper suggests the following approach to determine the limiting RFR capacity, dropped to the cellular communication operator that will cater for essential from the ecological point trends in the network development:

1. To fix a maximum site size, within which the SS EMR does not exceed the ecologically acceptable level. This size depends on the radio wave propagation (RWP) conditions (urban (large city, medium/small city), suburban, open area), minimal useful signal level employed at the SS EMR and BS inputs, availability and radiation power adjustment parameters for basic and subscriber's stations and on the SS EMR adopted limiting level (LL). The SS EMR LL value varies in divergent frequency bands, owing to the dependence on the radiation absorption extent by the head tissues on the frequency, as well as changes in different states. In view of unavailability of unified restrictions for the SS EMR LL, preliminary estimates may be done using the SS EMR LL values such as 0.1W for frequencies 1.8-2.2GHz; 0.2W for frequencies 0.8-1.0GHz and 0.3W for frequencies 0.3-0.5GHz. Calculations for the limiting site sizes in the ranges of 450, 900 and 1800MHz, obtained by applying Okhamura-Khata for divergent radio wave propagation conditions with the following parameters: SS height over the surface is 1.5m, the BS antenna suspension height is 60m, SS antenna gain – 0dB, the BS antenna gain – 15dB taking into account attenuations in the feeder, the BS radio receiver susceptibility – 107dBm, communication probability – 0.9 (0.95*0.95); are reviewed below. It is evident, that for a dual band network, (GSM 900/1800) it is recommended to make use of the data, acquired for the 1800MHz range.
2. Both the prediction of the maximal network user space density during the maximal loading time and the calculation of the planned for this instant limiting number of subscribers in the limiting-size site, in case of which the SS EMR LL is maintained, are supported.
3. Based on the well-known data regarding the average loading, created by a single network user (0.025 Erl.), the RFR capacity **V** is estimated, minimally needed to provide services to a single limiting-size site user and to the network on the whole during the time of its maximal loading and determined

reckoning with the dimension of a cluster, employed for its frequency planning. The RFR capacity allocated to a network is not supposed to exceed the value of **V**. With respect to a GSM network the said evaluation may be done using the data, given in the table below.

Table 1

SS EMR power, W	The maximum permissible sizes of a site					
	450MHz		900MHz		1800MHz	
	Extreme range of two-way radio communication, km	Site area, sq.km	Extreme range of two-way radio communication, km	Site area, sq.km	Extreme range of two-way radio communication, km	Site area, sq.km
Open area						
0,1	15,250	604,20	10,770	301,35	7,750	156,04
0,2	17,930	835,22	12,870	430,32	9,120	216,09
0,3	19,610	999,07	14,230	526,08	10,150	267,65
0,5	21,850	1240,34	16,060	670,09	11,580	348,38
0,7	23,400	1422,56	17,345	781,61	12,596	412,20
1,0	25,105	1637,42	18,766	914,92	13,740	490,47
1,5	27,115	1910,11	20,462	1087,77	15,115	593,55
2,0	28,593	2124,02	21,715	1225,06	16,140	676,78
Suburban area						
0,1	5,070	66,78	3,190	26,44	1,970	10,08
0,2	6,200	99,87	3,920	39,92	2,420	15,21
0,3	6,959	125,82	4,415	50,64	2,730	19,36
0,5	8,035	167,73	5,126	68,26	3,179	26,26
0,7	8,820	202,10	5,652	82,99	3,510	32,01
1,0	9,720	245,45	6,262	101,87	3,899	39,50
1,5	10,832	304,83	7,026	128,25	4,392	50,11
2,0	11,680	354,43	7,617	150,73	4,776	59,26
Urban area						
0,1	2,885	21,62	1,615	6,78	0,864	**1,94**
0,2	3,545	32,65	1,985	10,24	1,063	2,94
0,3	3,995	41,46	2,240	13,04	1,200	3,74
0,5	4,643	56,01	2,610	17,70	1,399	5,08
0,7	5,122	68,16	2,885	21,62	1,548	6,23
1,0	5,680	83,82	3,207	26,72	1,722	7,70
1,5	6,382	105,82	3,616	33,97	1,944	9,82
2,0	6,928	124,70	3,936	40,25	2,119	11,67

Table 2

Sector (network structural element)		Circular BS antenna beams		Three-sector BS			
Number of radio channels **n** /traffic channels	Admissible traffic density at max. loading time under the call blocking probability of 1%, Erl.	Max. number of subscriber in site	Required number of radio channels in the network, cluster 7·1·**n**	Admissible traffic density at max. loading time, Erl.	Max. number of subscriber in site	Required number of radio channels in the network	
						Cluster 4·3·**n**	Cluster 3·3·**n**
2/15	8,11	324	14	24,33	973	24	18
3/23	14,50	580	21	29,00	1740	36	27
4/31	21,20	848	28	63,60	2544	48	36
5/38	27,30	1092	35	81,90	**3276**	60	45
6/46	34,30	1372	42	102,90	4116	72	54
7/54	41,50	1660	49	124,50	4980	84	63
8/62	48,80	1952	56	146,40	5856	96	72

4. The RFR capacity, allocated to a cellular communication operator is not supposed to exceed the value, obtained when estimating as per Cl.3, in this case the following shall be ensured

– Ecologically safe development trends (required splitting of elements) in the radio network to cover the pre-planned number of subscribers;
– Risk of loss by the operator of a number of po-

tential users owing to the deterioration in the communication quality during the maximal loading periods and a consequent drop in the network economic indicators in case of permanent violation of the "ecologic" recommendations concerning the site sizes reduction to gain a safe level.

The relation of an RF resource dedicated to a GSM operator (a number of radio channels in the BS radiation/reception sector) with the territorial subscriber density in the site, pers/sq.km, minimally required to ensure ecological compatibility of the network that adheres to this mobile communication standard, is illustrated with the data in Table 3.

Table 3

Parameters of site			Minimally required to ensure ecological compatibility of the GSM network territorial subscriber density in the site, pers/sq.km.								
Number of radio channels **n** /traffic channels	Admissible traffic density at max. loading time under the call blocking probability of 1%, Erl.	Max. number of subscriber in site	450 MHz (SS EMR LL=0,3 W)			900 MHz (SS EMR LL=0,2 W)			1800 MHz (SS EMR LL=0,1 W)		
			Open area	Suburban area	Urban area	Open area	Suburban area	Urban area	Open area	Suburban area	Urban area
Circular BS antenna beams											
2/15	8,11	324	0,32	2,58	7,81	0,75	8,17	31,64	2,08	32,14	167,0
3/23	14,50	580	0,58	4,61	13,99	1,35	14,53	56,64	3,72	57,54	299,0
4/31	21,20	848	0,85	6,74	20,45	1,97	21,24	82,81	5,43	84,13	437,1
5/38	27,30	1092	1,09	8,68	26,34	2,54	27,35	106,6	6,70	108,3	562,9
6/46	34,30	1372	1,37	10,90	33,09	3,19	34,37	134,0	8,79	136,1	707,2
7/54	41,50	1660	1,66	13,19	40,04	3,86	41,58	162,1	10,64	164,7	855,7
8/62	48,80	1952	1,95	15,51	47,08	4,54	48,90	190,6	12,51	193,7	1006,2
Three-sector BS											
2/15	24,33	973	0,97	7,73	23,47	2,26	24,37	95,02	6,24	96,53	501,5
3/23	43,50	1740	1,74	13,83	41,97	4,04	43,59	169,9	11,15	172,6	896,9
4/31	63,60	2544	2,55	20,22	61,36	5,91	63,73	248,4	16,30	252,4	1311,3
5/38	81,90	3276	3,28	26,04	79,02	7,61	82,06	319,9	20,99	325,0	1688,7
6/46	102,90	4116	4,12	32,71	99,28	9,56	103,1	402,0	26,38	408,3	2121,6
7/54	124,50	4980	4,98	39,58	120,1	11,57	124,7	486,3	31,91	494,0	2567,0
8/62	146,40	5856	5,86	46,54	141,2	13,61	146,7	571,9	37,53	581,0	3018,6
Six-sector BS											
2/15	48,66	1946	1,95	15,47	46,94	4,52	48,75	190,0	12,47	193,1	1003
3/23	87,00	3480	3,48	27,66	83,94	8,09	87,17	339,8	22,30	345,2	1794
4/31	127,20	5088	5,09	40,44	122,7	11,82	127,5	496,9	32,61	504,8	2623
5/38	163,80	6552	6,56	52,07	158,0	15,23	164,1	639,8	41,99	650,0	3377
6/46	205,80	8232	8,24	65,43	198,6	19,13	206,2	803,9	52,76	816,7	4243
7/54	249,00	9960	9,97	79,16	240,2	23,15	249,5	972,7	63,83	988,1	5134
8/62	292,80	11712	11,72	93,09	282,5	27,22	293,4	1143,8	75,06	1161,9	6037

III. SS EMR POWER ADJUSTMENT IMPACT

Influence of power adjustment in SS and BS on the EMR average power is possible to evaluate by the following approach. We shall suppose that "ideal" SS and BS power adjustment is achieved in the system (regardless of the SS location within the coverage zone the useful signal minimal level, required for regular quality of two-way radio communication, is ensured at the SS and BS inputs). Then the SS radiated power level $\mathbf{P_{AS}}$ as a function of the distance **r** between SS and BS may be determined (with a certain degree of approximation) as follows:

$$\mathbf{P_{AS}(r) = P_{MAX} + 40\log(r/R)}; \quad \mathbf{r \le R}, \quad (1)$$

where $\mathbf{P_{MAX}}$ – is the maximum radiated power, required to ensure regular radio communication quality in case SS is located at the BS coverage zone boundary; **R** – is the distance to the BS coverage zone boundary.

The average value of $\mathbf{P_{ASA}}$ SS radiated power may be found with an equiprobable AS location assumed within the BS coverage zone:

$$\mathbf{P_{ASA}} = \int_{0}^{\mathbf{R}} \mathbf{P_{AS}(r)W(r)dr}, \qquad (2)$$

where $\mathbf{W(r)=2r/R^2}$, $\mathbf{r=R}$ – is the probability distribution density for the SS remote from BS.

By integrating, we obtain $\mathbf{P_{ASA}}$=0.333$\mathbf{P_{MAX}}$. Thus ideal radiation power adjustment enables to diminish the EMR average power three times.

In case of step-by-step radiation power adjustment with a 2dB step (GSM) and 0.5dB step (CDMA) the average radiation power equals to $\mathbf{P_{ASA}}$=0.415$\mathbf{P_{MAX}}$ and $\mathbf{P_{ASA}}$=0.363$\mathbf{P_{MAX}}$ accordingly (the advantage of CDMA over GSM in terms of ecologic safety under next to equal conditions is nothing but 0.6 dB). The ratio $\mathbf{P_{ASA}/P_{MAX}}$ as a function of the step in case of step-by-step radiation power adjustment is plotted in Fig.1.

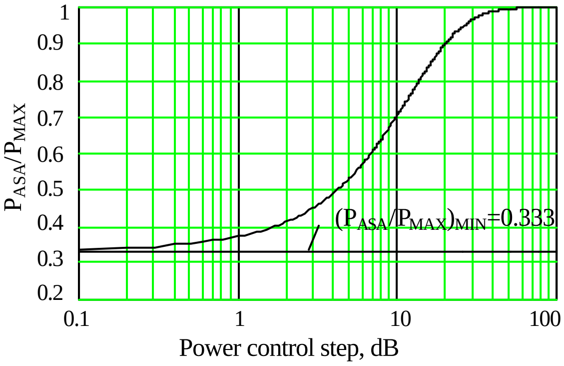

Fig.1

IV. AN EXAMPLE

There are four identical licenses granted in a region to provide GSM mobile communication services, the urban population density is 10000 pers./sq.km, 80% of population are potential cellular communication users. In this case the users' basis of each of the cellular operators is 20% of the urban population (2000 pers./sq.km).

It is obvious that in this situation we speak about double frequency range GSM 900/1800 networks, for this reason it is proposed to confine to the site area of 1.94 sq.km. (indicated with bold type, line 1-st of part "Urban area", Table 1). In this case maximal number of subscribers in sight o each network will amount to 1.94·2000=3880 units.

Let us further refer to Table 2. The alternative of a three-sector BS using 5 carriers (**n**=5) in each sector (line 4, Table 2, indicated with bold type) with the maximal number of subscribers in the site being equal to 3276 pers., seems to be acceptable. Under these conditions the maximum number of subscribers in the site is 3276. This number of users is slightly lower that the predicted one, equal to 3880, to facilitate the site size reduction to reach the required level, and enables to generate some "protective interval", allowing for the impact of the random cellular network spatial topology on its ecological compatibility if assumed to cover the territory at the given communication quality. When using 4·3·5 cluster each operator should have an allocated RFR with 60 radio channels in its capacity, for instance 24 channels in 900MHz range and 36 – in 1800MHz range. If the network space structure is regular enough, and if the resource as mentioned is available, it is possible to switch to 3·3·6 cluster; and for this reason, bearing in mind the ecologic point, it is reasonable to introduce additional recommendations, related to the site size restrictions or toughening the requirements to the communication quality (related to the aggregate intrasystem interference level).

V. REQUIRED GENERAL RFR FORECAST

The stated approach essentially allows to define the common restrictions on volume RFR allocated for development of mobile communication in appropriate region, that will cater for essential from the ecological point trends in this radio service development. With reference to networks GSM this forecast can be executed as follows:

1. The estimation of the expected spatial density of subscribers of mobile communication on categories of area (Urban, Suburban, Open) is made: $\mathbf{Q_U}$, $\mathbf{Q_S}$, $\mathbf{Q_O}$ [pers/sq.km].
2. The estimation of expedient number **N** of operators (given out licenses, radio networks) and necessary number of channels **n** in each BS sector of each network is made. Here a data of table 3, and also a lot of additional circumstances and reasons connected with it are used, in particular:
   - necessity of ensuring the requirements of the anti-monopoly law and freedom of a competition in the market of cellular communication;
   - presence of restrictions on possible number of radio channels (carriers) **n** in one BS sector;
   - preferability of use in an Open area of 900 MHz radio channels;
   - opportunity to use the basic decisions supposing the usage of three-or six-sector BS in Urban area, three-sector BS in Suburban area, and Circular or three-sector BS in Open area;
   - necessity of a selection of cluster dimension, providing high communication quality due to ensuring a required level of intranetwork EMC; in particular, for three-sector BS configuration can be recommended cluster dimension **M=4·3=12**;
   - expediency of a rounding off of values $\mathbf{Q_U/N}$, $\mathbf{Q_S/N}$, $\mathbf{Q_O/N}$ the planned average spatial density of subscribers in a site up to the nearest smaller values contained in table 3 (to how it is accepted above in an example) to facilitate the site size reduction to reach the required level.
3. RFR volume **K** for GSM service which can be recommended for allocation in considered region, is equal

$$\mathbf{K=M \cdot N \cdot n} \text{ [channels]} \qquad (3)$$

(RFR of all networks are equal)

$$\mathbf{K} = \mathbf{M} \sum_{\mathbf{(N)}} \mathbf{n} \text{ [channels]} \qquad (4)$$

(RFR of all networks are not equal)

It is obvious, that essentially similar estimations can be executed with reference to systems of mobile communication of any types and generations. However with reference to 3G networks it is necessary to take into account peak traffic parameters and requirements to the call blocking probability (%) for modes of data transmission.

VI. CONCLUDING COMMENTS

Thus, the described approach provides for a possibility to evaluate the maximum permissible RFR volume, dedicated to the cellular communication operator, that will provide necessary from the ecology point of view trends in the radio network development. The evaluations, as presented above, are of preliminary nature, illustrating the approach used to determine ecology-related limitations for the RFR for the network under diversified conditions. Specifying this approach and the results obtained are possible based on specifying radio waves propagation models for diverse conditions (in particular, specifying the radio waves fading characteristics in urban area and vegetation of various types), as well as specifying energy criterion to evaluate in certain frequency ranges (currently data on SS EMR tolerance limits in various frequency bands, cited in different sources, in particular, in [2,3,7], are mutually contradictory.

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 $\mathbf{S_0}$ [W/m^2] of EMF power flux density of the population irradiation in certain frequency ranges or values of Specific Absorbtion Rate (SAR) [W/kg] regulated by the international (ICNIRF) or national standards or recommendations. In particular, the maximum permissible value $\mathbf{P_{SS\ PM}}$ of the EMR SS power is proportional to the standardized irradiation reference level value: $\mathbf{P_{SS\ PM} = const \cdot S_0}$. The one place relation between the value $\mathbf{P_{SS\ PM}}$ 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 [2,3,7]. Nevertheless, these activities has to be finished as only by defining limitations for the radiated SS power it will be possible to determine correctly all necessary limitations for system characteristics of cellular networks, in particular limitations for the dedicated RFR.

In general the systematic view, suggested in the paper, that describes the cellular network ecologic characteristics enables to determine in terms of quantity their relation to the capacity and quality of the RFR allocated to the network, and to the parameters of the intrasystem (intranetwork) EMC, as well as to formulate a number of the following possible trends to improve the cellular network ecologic compatibility.

1. Limiting the RFR allocated to an operator; under these conditions to support a dense traffic the operator has to develop the network infrastructure in the frame of the limited RFR, that is to split sites, thus increasing the frequency repetition factor.
2. Limiting the minimal tolerable BS space density (max. site size) at least in the urban area, introducing limitations on the minimal admissible number of sites at the initial stages of the network development.
3. To prefer where possible, relatively low-frequency ranges (400-450, 800-900 MHz), especially in rural and in suburban areas; it is reasonable to utilize the resource within the ranges of 1800-2200 MHz only under conditions where the BS density is high, and large SS EMR is not required (micro- and picocells).
4. When planning the RFR for prospective mobile communication networks (3G, 3G+, 4G) it is reasonable for these networks from the ecologic point in addition to the bands in the frequency ranges of 800/900 MHz and 2 GHz to consider the feasibility and expediency to release the bandwidth, previously employed by mobile communication service (300-350, 400-450 MHz, etc.) to process speech traffic in rural and suburban, recreational areas, etc.
5. Further evolution of methods and algorithms to support the intranetwork EMC, intended to reduce the aggregate interference level within the network, in particular in the non-regular structured network.
6. Comparative system ecology analysis of cellular communication technologies (FDMA, TDMA, CDMA) with the purpose of determining the ecologically safest solutions at each hierarchical level of prospective radio telecommunication networks (3G, 3G+, 4G).

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