Estimation of Electromagnetic Background Intensity Created by Wireless Systems in Terms of the Prediction of Area Traffic Capacity

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Abstract— **A novel technique for estimating the level of electromagnetic background created by the wide spread wireless information services for population, is proposed. This technique is based on prediction of the total area traffic capacity processed by these systems, for estimating the average electromagnetic loading on considered area, which, in turn, is used for worst-case estimation of the electromagnetic background intensity near the ground surface. An essential dependence of the considered electromagnetic background intensity on the quality of intranetwork electromagnetic compatibility design is displayed.**

Keywords*— *wireless communications, area traffic capacity, electromagnetic background, intrasystem EMC, electromagnetic safety.

I. Abbreviations

ATC – area traffic capacity.
BC – base station.
CC – cellular communications.
CNIR – "carrier-to-(noise plus interference)" ratio.
EMB – electromagnetic background.
EMLA – electromagnetic loading on area.
EMR – electromagnetic radiation.
EIRE – equivalent isotropic radiated energy.
EIRP – equivalent isotropic radiated power.
FSP – frequency-spatial planning.
MPL – maximum permissible level.
OP – observation point.
QoS – quality of services.
RWP – radio waves propagation.
SS – subscriber's station

II. Introduction

In papers [1, 2], a technique for analyzing the level of electromagnetic background (EMB) created by cellular communications (CC) is proposed. The main idea of this technique is to use of an unambiguous analytical dependence of the average EMB intensity near the ground surface, on the average electromagnetic loading on area (EMLA) created by the base and subscriber CC radio equipment, while the EMB intensity near the ground surface is practically independent of antenna height of base stations (BS) if this height considerably exceeds the height of the observation point (OP) above the surface.

The main EMLA component which plays the main role in EMB creation, is the average EMLA formed by BS electromagnetic radiation (EMR); it corresponds to the average area density of the total BS equivalent isotropic radiated power (EIRP) [kW/km^2, W/m^2]; at its assessment, as a rule, the data concerned BS characteristics and location contained in licensing databases and technical specifications is used.

Such an approach can be considered as adequate when analyzing 2G (GSM) CC networks with limited capabilities for BS EIRP adjustment to CC network workload, but it turns out to be less useful when analyzing 3G/4G/5G networks, since a number of features of these networks (wide-range EIRP adjustment in forward and backward radio channels, implementation of radio network multi-level hierarchical structure, wide use of artificial intelligence, etc.) provide the possibility of a significant reduction in BS EIRP and in average EMLA in cases when

- traffic intensity (including its intensity during business hours) in CC radio network is less than its maximum permissible level,
- CC radio network is ever-developed, and sizes of sites are ever-reduced, which leads to a decrease in radio channels radiated power in comparison with maximum permissible levels specified in licensing databases;
- a constant increase in the volume and share of data traffic in comparison with voice traffic, and also increase in asymmetry of downlink and uplink data traffic, are registered; according to [3, etc.], the volume of mobile data traffic on forward (downlink) radio channels in CC networks can exceed the volume of voice traffic by 2 orders of magnitude and more.

All of the above mentioned causes are decrease in the objectivity of estimations of EMB intensity created by the modern and future CC radio networks, based on the use of BS EIRP registration data and information concerned the area density of cell phones and subscriber's activity.

The goal of this paper is to substantiate the possibility of the assessment of EMLA and intensity of EMB created by modern and future wireless systems of general information services, including 3G/4G/5G CC, directly on the base of

DOI: 10.1109/EMCEurope.2019.8871529

prediction of the average area traffic capacity (ATC) processed by these systems.

ATC is a very important and widely used integrated system parameter of wireless communications [3, 4], therefore, its use in implementing the approach [1, 2] to predict the intensity of EMB generated by these systems, can significantly expand the capabilities of intersystem EMC analysis for primary and secondary radio services, and also of the prediction of electromagnetic environment, of electromagnetic public safety and electromagnetic ecology of populous areas.

III. Basic Models and Relations

In accordance with the fundamental Shannon-Hartley theorem [5], the potential channel capacity C_P [bit/s], meaning the theoretical upper bound of the data rate through the analog communication channel with additive white Gaussian noise of power N, with the average signal power S, is such as

$$C_P = \Delta F \cdot log_2(1+SNR), \quad SNR = S/N \,, \tag{1}$$

where ΔF is the channel bandwidth, [Hz]; S is the total signal power in the band ΔF, [W]; N is the total noise power in the band ΔF, [W]; SNR is the signal-to-noise ratio in the communication channel.

For radio channels of modern digital cellular communications can be accepted the following [6]:

1. The spectral power density of the radio channel thermal noise can be considered to be constant $N_0 \approx N/\Delta F_R$ [W/Hz]; in accordance [7]:

$$N_0 = kT_0K_N \,, \tag{2}$$

where k is the Boltzmann's constant, $1.38\cdot10^{-23}$ [W/K]; K_N is the radio receiver noise factor, T_0 is an ambient temperature (T_0=290K).

2. The frequency spectrum of radio signal of S_R power is close to rectangular, its width corresponds to the width of the radio channel bandwidth ΔF_R, and its spectral power density can be considered to be constant $S_0 \approx S_R/\Delta F_R$ [W/Hz].

3. The spectral power density N_{INT} [W/Hz] of the intranetwork interference created in CC radio channels by the signals of another BS which use the same operating frequencies, also can be considered to be constant.

4. The difference between the channel noise bandwidth ΔF_N of and the channel signal bandwidth ΔF_R can be neglected: $\Delta F_N \approx \Delta F_R$.

5. As a result, the expression for the potential radio channel capacity can be reduced to the following form

$$C_{PR} \approx \Delta F_R \cdot log_2(1+CNIR), \quad CNIR = S_0/(N_0+N_{INT}), \tag{3.1}$$

$$S_{EP} = C_{PR}/\Delta F_R \approx log_2(1+CNIR), \tag{3.2}$$

where S_{EP} [bit/s/Hz] is the potential spectral efficiency of data transfer over the radio channel, $CNIR$ is the channel "carrier-to-(noise plus intrasystem interference)" ratio.

6. The actual radio channel data rate C_{RR} is m times smaller than the potential channel capacity C_{PR}; as much as the real spectral efficiency S_{ER} of this channel is less than the potential one:

$$C_{PR} = mC_{RR}, \quad S_{ER} = S_{EP}/m \,. \tag{4}$$

7. The factor m in (4) reflects both the ratio of potential and real radio channel spectral efficiency, and the contribution of MIMO technology in its improvement. In cellular radio channels without the use of MIMO technology $m \approx 2...10$ [8]. Thus, the expected increase in LTE radio channel's spectral efficiency due to MIMO technology by 2-8 times [9, 10] actually allows only to compensate for the imperfectness of modulation/demodulation and coding-decoding processes. Therefore, further analysis will be performed for $m = 1$ under the assumption that the data rate in cellular radio channels is close to the potential in definition (1): $C_{RR} \approx C_{PR}$.

8. The minimum power P_{DSIN} of the useful signal in radio channel (the real radio reception sensitivity) which provides the channel capacity C_{PR} in presence of internal thermal noise of power N and of intranetwork interference of power P_{INT}=$N\cdot K_{CC}$ (ignoring the differences in the influence of these total noise components on the radio channel capacity) is determined by the ratio [6]:

$$P_{DSIN} = N_\Sigma \Delta F_R CNIR_{min}, \quad CNIR_{min} = \left(2^{mS_{ER}}-1\right), \tag{5.1}$$

$$N_\Sigma = (K_{CC}+1)kT_0K_N \,, \tag{5.2}$$

where the factor $K_{CC} \approx N_{INT}/N_0$ characterizes the excess of the internal thermal noise level by the intranetwork interference level; its value is determined by the quality of the frequency-spatial planning (FSP) of the CC radio network. It can take values in a wide range from 0 (intranetwork interference is absent) to 100...1000 and even more at low FSP quality (at poor intrasystem EMC); at CC cluster spatial topology the overestimated levels of a useful signal caused by overestimated BS EIRP also can be a reason of the overestimated levels of intranetwork interference.

IV. Average EMLA Created by EMR of BS

At the real radio reception sensitivity P_{DSIN} the minimum required signal energy for receiving information at a rate of C_{ER} [bit/s] during period t [s] is equal to $E_{DSIN}(t) = P_{DSIN}\cdot t$, and the energy level per bit of the received data at data rate $C_\Sigma(t)$= =$t\cdot C_{ER}$=$t\cdot S_{ER}\Delta F_R$, should not be lower than the following value:

$$E_{br} = \frac{E_{DSIN}(t)}{C_\Sigma(t)} = \frac{\Delta F_R N_\Sigma \left(2^{mS_{ER}}-1\right)}{S_{ER}\Delta F_R} = \frac{(K_{CC}+1)kT_0K_N\left(2^{mS_{ER}}-1\right)}{S_{ER}}. \tag{6}$$

In order for the signal at the receiver input to have power (6), and the CC handover to be provided, the following is necessary:

1. Radio signals should be emitted by BS transmitters with energy compensating for the basic losses of L_b in the radio waves propagation (RWP) from the BS transmitting antenna to the receiving antenna of subscriber's station (SS) [11]. With regard to the "worst-case" estimation we will take

into account the RWP losses $L_b = L_{bf}$ in free space (since in a densely populated urban area the radius of CC micro-sites is usually less than the radius of the free RWP zone ("breakpoint distance" in [12]), defined taking into account the BS EMR reflection from the ground surface), and the average losses on the attenuation in buildings and fading in street canyons.

The average losses in buildings L_m is near to 12 ... 18 dB [13-15] and depends on the frequency range, as well as floor number, building material, etc. The losses at RWP in street canyons L_c are caused by multipath phenomenon due to the reflection from buildings and earth's surface, and also the diffraction; they depend on the housing density and height, floor level, BS antenna height, etc., and can reach 10-20 dB. But taking into account the required communication quality, it is accepted at the level of 20 dB (this value is taken as a fading correction factor at RWP model (1)-(5) in [12], which is recommended for the analysis of RWP losses in city building).

2. The useful signal energy at the SS receiver's input must additionally exceed the minimum required level by a certain amount of K_H, which provide the necessary margin on the level of the received signal for the handover implementation. So, in general, the BS equivalent isotropic radiated energy (EIRE) per bit of the transmitted data should be provided at the level of $E_{bt} = E_{br} L_{bf} L_m L_c K_H$.

The free-space RWP model is defined as follows [16]:

$$L_{bf} = \left(\frac{4\pi R}{\lambda}\right)^2 \text{ [units]}; \tag{7}$$

this implies:

$$E_{bt}(R) = L_{bf} L_m L_C K_H E_{br} = K_1 R^2, \tag{8.1}$$

$$K_1 = \frac{16\pi^2 k T_0 K_N L_m L_C K_H \left(2^{mS_{ER}} - 1\right)\left(K_{CC} + 1\right)}{\lambda^2 S_{ER}}. \tag{8.2}$$

The probability distribution density (p.d.d.) of distances R between transmitter (BS antenna) and receivers (SS) at SS random uniform distribution on area, is of the form [17]:

$$w(R) = \frac{2R}{R_{max}^2 - H^2}, \tag{9}$$

$$H = H_{BS} - h \approx H_{BS} << R_{max}; \quad H \le R \le R_{max},$$

where H_{BS} is BS antenna height ($H_{BS} \ge$ 10m), h is SS height above the surface ($h \approx$ 1-2m taking into account probable SS locations at different attitudes of human body); R_{max} is a radius of service area, on the border of which the level (5.1) of useful signal on SS receiver's input requires the maximum BS EIRE per bit for data transmitting.

As the distances between the receiver and the transmitter in CC are random, the corresponding RWP losses and E_{bt} values are also random (because in CC radio channels of 3G and further generations the deep BS EIRP adaptation is used which provide a minimum necessary useful signal level on inputs of SS receivers). Using (8.1), (9), we will define the p.d.d. of BS EIRE per bit of the transmitted data:

$$w(E_{bt}) = w(R(E_{bt}))\left|\frac{dR(E_{bt})}{dE_{bt}}\right| = \frac{1}{E_{btmax} - E_{btmin}} \approx \frac{1}{E_{btmax}}; \tag{10}$$

$$m_1(E_{bt}) \approx \frac{8\pi^2 k T_0 K_N K_H L_m L_C \left(2^{mS_{ER}} - 1\right)\left(K_{CC} + 1\right) R_{max}^2}{\lambda^2 S_{ER}}; \tag{11}$$

thus, the p.d.d. of BS EIRE per bit of the transmitted data is uniform; its assembly average is equal to the half from the maximum value appropriate to SS location on a site border.

At terrestrial random uniform distribution of radiating SS with average density ρ [SS/m^2], if each SS is receiving the data with the rate V [bit/s], average downlink ATC created by BS will be equal to $S_{tr} = \rho\ V$ [bit/s/m^2], and the average EMLA B [W/m^2] created by the terrestrially distributed set of BS, will be

$$B = m_1(E_{bt}) S_{tr} =$$

$$= \frac{8\pi^2 k T_0 K_N K_H L_m L_C \left(2^{mS_{ER}} - 1\right)\left(K_{CC} + 1\right) R_{max}^2 S_{tr} Q}{\lambda^2 S_{ER}}, \tag{12}$$

where $Q=P_{AR}/P_{AI}<1$ is the system parameter of the EMR BS directivity; in this ratio P_{AR} and P_{AI} are values of BS radiating power which reaches an observation area near ground surface by the real BS antenna with horizontal and vertical selectivity, and by the ideal isotropic antenna with the same antenna gain, correspondingly [18]. Expression (12) is obtained at the conditions that signals presented on SS receivers inputs are of minimum necessary level which corresponds to the necessary *CNIR* value, and that the CC radio network structure is regular with N_S sectors on each BS; $Q \approx 1/N_S$.

V. Average Inteensity of EMB Created by BS

Substitution the (12) in formula offered in [1, 2] for a pessimistic (worst-case) estimation of the average total EMB intensity created in OP near ground surface by all set of BS randomly distributed over the considered area (including a vicinity of free-space RWP between OP and BS, and a remote area of interference RWP between them), we will receive a following expression for an estimation the intensity of EMB, created in OP by the set of BS of CC radio network operating in a comparatively narrow frequency band with wavelength λ:

$$Z_{BS} \approx \frac{B(R_{max}, S_{tr}, K_{CC}, S_{EP}, \lambda)}{2} ln\left(\frac{4H_{OP}\sqrt{e}}{\lambda}\right) \text{ [W/m}^2\text{]}, \tag{13}$$

where $H_{OP} > \lambda/4$ is OP height above the surface, $H_{OP} \approx h$.

Expressions (8.1)/(8.2), (11), (12), (13) depends on a wavelength λ. In view of the relative narrowness of frequency bands allocated for BS EMR (the ratio of a width of the selected band to the value of its left boundary makes 2.7% for GSM-900, 4.2% for GSM-1800, 2.8% for UMTS and less than 5% for each of bands allocated for LTE [19]), these estimations for each band can be made at the corresponding fixed wavelength. As at each frequency band the specific CC standard can be implemented, and also the separate values of K_{CC}, S_{EP}, S_{tr}, R_{max} can be appropriated, the total EMB intensity $Z_{\Sigma BS}$ created by all J separate subsets of BS, operating in all frequency bands allocated for CC, can be defined evidently:

$$Z_{\Sigma BS} = \sum_{j=1}^{J} \frac{B\left(R_{max j}, S_{tr j}, K_{CC j}, S_{EP j}, \lambda_j\right)}{2} ln\left(\frac{4H_{OP}\sqrt{e}}{\lambda_j}\right), \quad (14)$$

where $Z_{\Sigma BS}$ [W/m^2] is defined as a scalar sum of all separate EMR power flux densities created in OP by separate BS of all J separate frequency bands and behavioral hierarchy of CC structure, located in areas of BS radio visibility from OP.

VI. Estimations of EMB Inteensity Created by BS

Estimations of an average ATC created by CC BS at various conditions are given below in the Table 1.

TABLE I. AVERAGE ATC IN DIFFERENT CONDITIONS

Features of services and service area of CC of different generations	***V*, bit/s**	**ρ, SS/m^2**	**S_{tr}, bit/s/m^2**
GSM voice traffic, high area density of radiating SS	$3.3\cdot10^4$	$10^{-4}...3\cdot10^{-3}$	$10^1...10^2$ (very low)
GSM voice traffic, very high area density of radiating SS	$3.3\cdot10^4$	$3\cdot10^{-2}$	10^3 (low)
Total mobile traffic (voice & data), high area density of 2G/3G/4G consumers of CC services	$4\cdot10^6$	$2.5\cdot10^{-3}$	10^4 (middle)
Predicted volume of services in 4G CC, very high SS area density [20]	10^7	10^{-2}	10^5 (high)
Predicted volume of services in 5G CC, high SS area density [20]	10^7	10^{-1}	10^6 (very high)
Expected volume of services in 5G CC, extremely high SS area density [20]	$10^7...10^8$	$10^{-1}...1$	10^7 (extr. high)

For validation the practical applicability of presented technique the comparative assessment of EMB intensity (created by typical set of GSM-1800) with the use of approach [1, 2] and with the use of (8.1),(11)-(13), is performed below.

The following typical parameters of GSM network are considered: 1.8 GHz frequency range (λ≈0.16 m); area density of radiating SS is $\rho=5\cdot10^{-4}$ SS/m^2 (M_{SS}=500 SS/km^2 at the SS density 5000...6000 SS/km^2 and specific voice traffic intensity 0.08...0.1 Erl. [21, 22]), data transfer rate of one GSM voice traffic channel is $V=2^{15}$ bit/s [23], one GSM radio channel provide 8 voice traffic channels; SS antenna gains are close to 1 (0 dB), all BS of the considered regular GSM network are of three-sector structure (Q≈1/3) with 4 radio channels in each sector (30 traffic channels & 2 control channels) with total EIRP 800W (59 dBm) at radio channel EIRP 53 dBm (200W).

A. Estimates Based on BS Registration Data and SS Average Area Density (on Direct EMLA Assessment)

At BS three-sector structure with 4 radio channels in each sector (30 traffic channels + 2 control channels) the total BS capacity is 90 traffic channels. Nevertheless to ensure high QoS (call blocking probability p≤1%) in the BS sector service area should be on average no more than 20 serviced SS [24] (redundancy of electromagnetic radiation is 1.6 times), or M_{SSS}=60 serviced (operating) SS within the separate BS site. Hence,

- BS area density is M_{SS}/M_{SSS}≈8.3 BS/km^2 = $8.3\cdot10^{-6}$ BS/m^2 , so the area of the circular zone, covering a hexagonal BS site, is ≈0.12 km^2 and its radius is R_{max}≈200m;
- At 800W of the total BS EIRP, the average EMLA generated by all BS is B_A≈0.0067 W/m^2 (6.7 kW/km^2);
- Such EMLA, according to (13), at the height of H_{OP}=2m above the ground surface creates the EMB with average intensity

$$Z_{BS(A)} \approx \frac{0.0067}{2} ln\left(\frac{4\cdot 2\sqrt{e}}{0.16}\right) \approx 0.015 \text{ W/m}^2.$$

To perform the comparative assessment of EMB intensity, it is necessary to take into consideration the following:

1. Threshold sensitivity of GSM-1800 SS is -105 dBm ($3.16\cdot10^{-14}$ W) [23]. This is agree with estimations by (5.1),(5.2): if K_N=5, ΔF=200 kHz, T_o=290K, then $P_{DSIN}=kT_oK_N\Delta F=4\cdot10^{-15}$ W or -144 dBW = -114 dBm; at $CNIR_{min} = 2^{Sep}-1 = 8$ (or 9 dB) the sensitivity of radio reception will be $P_0 = P_{DSIN} + CNIR_{min}$ = -105 dBm.

2. In accordance with (7), the free space RWP losses at a distance of 200 m are about 84 dB. But, as at the derivation of expressions (10), (11) in terms of the p.d.d. (9) of distances, we obtain the form of the L_{bf} p.d.d. and expectation:

$$w\left(L_{bf}\right) = w\left(R\left(L_{bf}\right)\right)\left|\frac{dR\left(L_{bf}\right)}{dL_{bf}}\right| = \frac{1}{L_{bf\,max} - L_{bf\,min}} \approx \frac{1}{L_{bf\,max}}; \quad (15)$$

$$m_1\left(L_{bf}\right) \approx \frac{L_{bf\,max}}{2} = \frac{8\pi^2 R_{max}^2}{\lambda^2}; \quad (16)$$

at R_{max}=200 m, λ = 0.16 m we obtain $m_1(L_{bf})=1.234\cdot10^8$ or $m_1(L_{bf})$=80.9 dB≈81 dB.

3. So, at P_0 = -105 dBm, the minimum required EIRP of one BS frequency channel is -24 dBm (4 mW). At the 53 dBm (200 W) of GSM-1800 radio channel EIRP, its excess over the minimum required level is $K_T = K_H L_m L_C(K_{CC}+1)$ = 77 dB (his provides the reserve for fading, for attenuation in buildings, for handover, for intranetwork interference, etc.).

B. Estimates based on the ATC Prediction

At data rate from BS to SS $V=2^{15}$ bit/s and $\rho=5\cdot10^{-4}$ SS/m^2, the average downlink ATC will be $S_{tr} = \rho\, V \approx 16.4$ bit/s/m^2.

When calculating (6) for K_{CC}=0 (intrasystem interference is absent), S_{EP}=3.17 (at $2^{mS_{ER}}-1 = CNIR = 8$ (or 9 dB), S_{ER}=1.31, m=2.42 [6]), we get the threshold value of energy per 1 bit of information received by SS:

$$E_b == \frac{\left(K_{CC}+1\right)kT_0K_N\left(2^{mS_{ER}}-1\right)}{S_{ER}} \approx 1.22\cdot10^{-19}\,J\,.$$

Verification: at GSM radio channel data rate $C=2^{18}$ bit/s, the real radio reception sensitivity is $P_{DSIN}=C\cdot E_b$=$3.2\cdot10^{-14}$ W, or -104.9 dBm which is the same as in [23].

Estimate the EMLA and the EMB intensity using (12)&(13) at S_{tr}≈16.4 bit/s/m^2, Q≈1/3 and E_b≈$1.22\cdot10^{-19}$J, and also for the same reserve $K_T = 5\cdot10^7$ for fading, for attenuation in buildings, for handover, for intranetwork interference, we get B_B ≈ 0,0041 W/m^2 and

$$Z_{BS(B)} \approx \frac{0.0041}{2} ln\left(\frac{4 \cdot 2\sqrt{e}}{0.16}\right) \approx 0.009 \text{ W/m}^2.$$

Thus, the estimates based on the prediction of ATC are fully agreed with estimates based on BS registration data and SS average area density, since the ratio $B_A/B_B \approx 1.63$ and $Z_{BS(A)}/Z_{BS(A)} \approx 1.67$ matches well with the value of the redundancy of electromagnetic radiation (1.6 times) adopted in the first case (subsection *A)* to ensure high QoS.

VII. EMB CREATED BY CC AND INTRASYSTEM EMC

In typical examples described above, at 53 dBm of EIRP of GSM BS radio channel we detected an EIRP reserve $K_T = K_H L_m L_C(K_{CC}+1) = 77$ dB. The unavoidable part $K_H L_m L_C$ of this reserve for fading, attenuation in buildings and handover in total may take values 30-40 dB and not exceed 50 dB. So at GSM BS radio channel EIRP 47-57 dBm mainly used in macro-BS at urban areas, the reserve $(K_{CC}+1)$ in CC intrasystem EMC imperfectness (in intrasystem interference) is not less than 20-30 dB.

In expressions (5.2)-(14) the factor K_{CC} is a ratio of levels of intranetwork interference and internal thermal noise presented in CC radio channel. It indicate the quality of design of intrasystem EMC of CC radio network: at poor intrasystem EMC K_{CC}>>10.

The results of the analysis of the total intensity (13) of EMB generated by CC BS in some typical conditions at the different quality of intrasystem EMC, are given below. These results are obtained for area density of SS in the active mode $\rho \approx 10^3 ... 3 \cdot 10^4$ SS/km^2 ($10^{-3} ... 3 \cdot 10^{-2}$ SS/m^2) and for the 2 GHz frequency range (λ=0.15 m).

Fig.1 shows the calculated dependences of the EMB intensity on the radius of BS service area $Z_{BS}(R_{max})$, obtained for three-sector CC network structure ($Q \approx 1/3$), for average downlink ATC $S_{tr}=10^4$ bit/s (middle ATC in Table 1), and for other typical parameters $S_{EP}=5$, $K_N=5$, T_0=290K and $L_m L_C K_H$=50 dB. Calculated dependences of the EMB intensity on the ATC $Z_{BS}(S_{tr})$, obtained for $Q \approx 1/3$ and for the radius of BS service area R_{max}=300m and R_{max}=100m, are given in Fig. 2 & 3 correspondingly. Curves on Fig.1, 2, 3 corresponds to K_{CC}=0 (black line 1), K_{CC}=1 (brown line 2), K_{CC}=10 (green line 3), K_{CC}=100 (blue line 4) and K_{CC}=1000 (pink line 5); horizontal red line 6 Z_{BS}=0.1 W/m^2 corresponds to the maximum permissible level (MPL) of EMB accepted in some countries.

A comparison of these dependencies for different K_{CC} allows to make a conclusion about the extremely significant impact of the FSP quality and ensuring of intrasystem EMC of CC networks on their safety for the population. In particular,

- at $S_{tr}=10^4$ bit/s/m^2, $Q \approx 1/3$ and $K_{CC} \geq 10^2$ (high levels of intranetwork interference), as well as at overrated *CNIR* values, the CC safety is provided only when using micro-sites with BS area density of about 15-20 BS/km^2 and more; in considered typical conditions the achievement of the high intrasystem EMC quality ($K_{CC} \leq 10$) allows to decrease the BS area density to 4-10 BS/km^2;

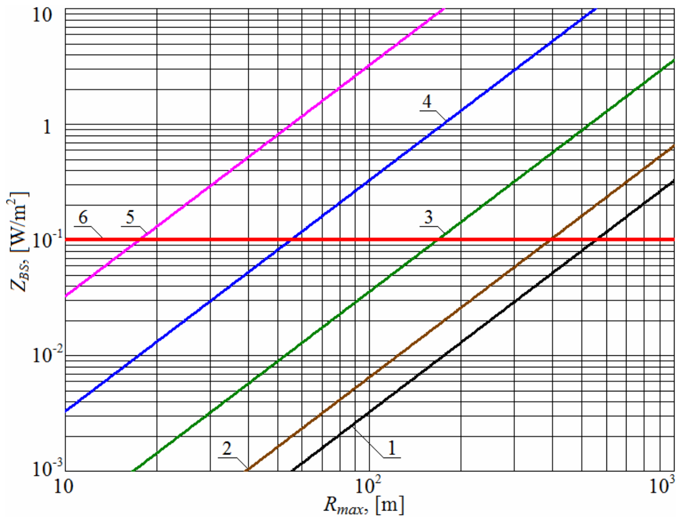

Fig.1. Dependences $Z_{BS}(R_{max})$ for $S_{tr}=10^4$ bit/s/m^2, obtained for different K_{CC} values at $Q \approx 1/3$, $S_{EP}=5$, $K_N=5$, T_0=290K, $K_H L_m L_C$ =50 dB, λ=0.15m (2 GHz)

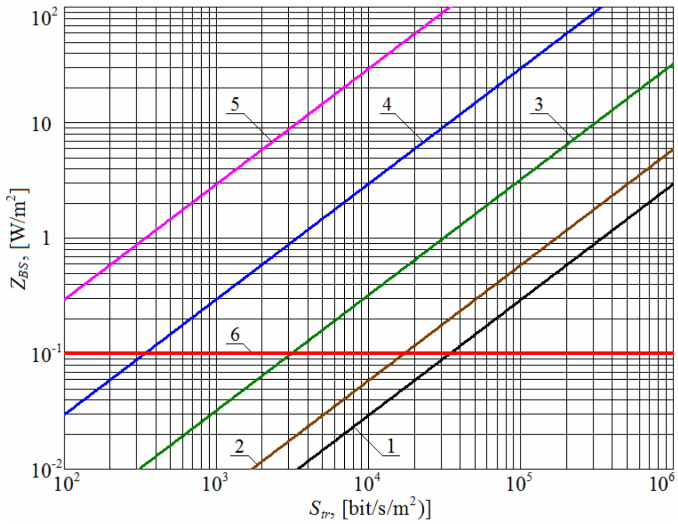

Fig.2. Dependences $Z_{BS}(S_{tr})$, obtained for R_{max} = 300 m at different K_{CC} values and $Q \approx 1/3$, $S_{EP}=5$, $K_N=5$, T_0=290K, $K_H L_m L_C$ =50 dB, λ=0.15m (2 GHz)

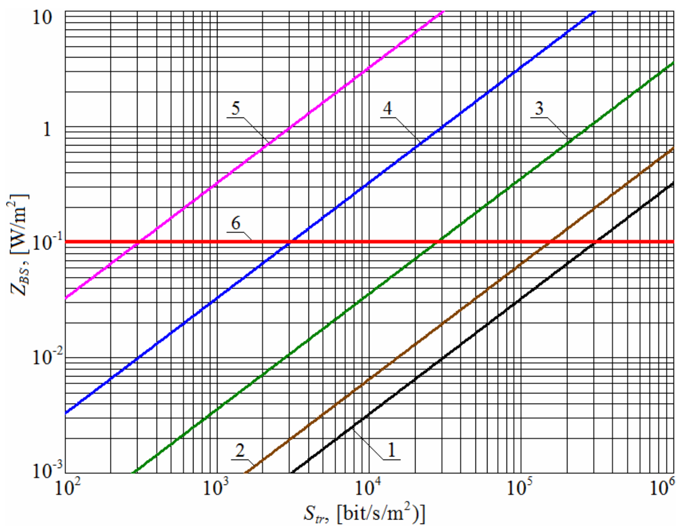

Fig.3. Dependences $Z_{BS}(S_{tr})$, obtained for R_{max} = 100 m at different K_{CC} values and $Q \approx 1/3$, $S_{EP}=5$, $K_N=5$, T_0=290K, $K_H L_m L_C$ =50 dB, λ=0.15m (2 GHz)

- at a small ATC, ensuring the population electromagnetic safety is not a problem, but with the expected high increase of ATC (to 10^6 bit/s/m^2 for 5G [20]), its ensuring will require a significant reduction in intranet interference levels due to a significant expansion of the radio frequency spectrum allocated for the 4G/5G of CC [19], and due to the improvement of technologies for the intrasystem EMC development.

These conclusions are confirmed by the analysis of the calculated dependences of the average EMB intensity created by BS, on the potential spectral efficiency of corresponding radio channels for different ATC levels. A direct increase in the spectral efficiency of CC radio channels, achieved by increasing the *CNIR* and corresponding BS EIRP growth, also results in an increase in the level of intranet interference and, as a consequence, an increase in EMB levels. However, the use of MIMO technology and adaptive BS antennas (decrease in Q values) in the future can change the situation.

At decreasing wavelength λ, the requirements for reducing the relative level of intranet interference and for the quality of intrasystem EMC are becoming tougher (see (11)-(13)), however, implementation of this requirements should not cause fundamental difficulties due to the increased directivity and adaptability of the BS EMR of 4G/5G CC (at decrease in the value of the system parameter Q of EMR directivity) and the degree of EMR shielding by buildings, vegetation, etc, and due to an expected expansion of the CC radio frequency resource.

VIII. Conclusion

Expressions (12) - (14) given above provide the possibility of using the technique [1, 2] for estimating the EMB intensity created by the set of BS in the CC service area, based on the forecast of the average ATC created by the wireless public information services during the busy hours, and on information about the sizes of CC sites on the considered area.

And since the EMB estimates based on direct EMLA assessment, are in good agreement with the results of physical measurements [25], one should also expect a good agreement between the results of experimental EMB analysis and the proposed technique of EMB estimates on the basis of ATC prediction.

Expressions (12) - (14) make it possible to quantify the effectiveness of different ways of reducing the BS EIRP redundancy $K_T = K_H L_m L_C (K_{CC}+1)$ which provides the reserve for fading, for attenuation in buildings, for handover, for intranetwork EMC, etc., including estimation of the necessary degree of reduction in the level of intrasystem interference to ensure the acceptable level of EMB intensity.

As a result, the development of technique of calculation of EMB intensity created by wireless systems, based on the prediction of ATC, essentially simplify the procedures of analysis of intersystem EMC and of the prediction of electromagnetic environment, of electromagnetic public safety and of electromagnetic ecology of populous areas.

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