# Influence of Base Stations Radiation Patterns on the Level of the Outdoor Electromagnetic Background Created by Mobile (Cellular) Communications 

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#### Abstract

Base stations (BS) radiation is the main source of electromagnetic background generated by mobile (cellular) communications. The known technique for estimating an average intensity of background generated by BS radiation takes into account the directivity of BS antennas in a simplified form, assuming that the width of the main lobe of the radiation pattern is equal to the width of BS servicing sector and not taking into account the radiation directivity in vertical plane. Noted simplifications determine too pessimistic nature of these estimations. The paper contains results of the refined analysis of this problem using a two-level models of antenna radiation patterns, which give the actual values of the width of antennas main lobe in horizontal and vertical planes, the relative levels of side lobes and the ratio of radiation power of the main and side lobes. The analysis was performed both for stationary sector antennas of cellular communication systems and for adaptive phased antenna arrays of $4 \mathrm{G} / 5 \mathrm{G}$ systems capable of providing service using narrow beams. Obtained results reduce by $5-15 \mathrm{~dB}$ the degree of pessimism provided by known techniques in the estimation of the average levels of electromagnetic background created by BS radiations near the Earth's surface.


Keywords-mobile communications, base station, electromagnetic radiation, antenna, pattern, main lobe, side lobes, electromagnetic background

## I. Introduction

Electromagnetic pollution of the environment caused by the intensive use of wireless information services, their penetration into all spheres of human activity, is becoming one of the most acute technogenic problem of our time. Of course, the rapid evolution of generations of mobile (cellular) communications (MC) $4 \mathrm{G} \rightarrow 5 \mathrm{G} \rightarrow 6 \mathrm{G}$ determines one of the main directions of human progress. MC $4 \mathrm{G} / 5 \mathrm{G} / 6 \mathrm{G}$ are deeply integrating with all spheres of human existence, but at the same time they use technologies that are potentially dangerous to public health. Under certain conditions, this can cause a significant deterioration of an electromagnetic ecology of the habitat, and an unacceptable increase in forced and voluntary risks to public health.

In [1-3], a technique for estimating the averaged total intensity of the radio frequency electromagnetic background (EMB) created by electromagnetic (EM) radiations of base station (BS) was proposed and verified using the published results of experimental studies of the electromagnetic environment (EME) in dozens of countries on five continents. This technique is based on the analysis of system characteristics of MC networks: average area density of
wireless traffic ("Area Traffic Capacity" (ATC)) and average electromagnetic loading on area (EMLA), created by the totality of BS EM radiation in various MC frequency bands; spectral efficiency of downlink data transmission, etc. This technique allows us to take into account the influence of the spatial selectivity of BS radiation on the averaged intensity of EMB.

This analysis becomes particularly relevant in connection with the use of active phased antenna arrays (AAA) as BS antennas in MC 4G/5G. "2D MIMO" antenna arrays ensure the formation of a "fan" multipath radiation pattern with a width of each beam of $12^{\circ}-36^{\circ}$ in the BS service sector, and AAA "Massive MIMO" using the beamforming mode, provides the formation of individual relatively narrow beams for each of the serviced subscriber stations (SS) [4].

The goal of this paper is to clarify the influence of the directivity of BS EM radiation in the horizontal and vertical planes on the EMB intensity created by MC radio networks.

## II. Analysis Methodology

## A. Basic expressions for estimation the EMB intensity generated by $B S$

EMB is created at randomly selected observation point (OP), placed near the earth surface at a height $H_{O P}$, by a set of BSs, located in the region of radio visibility from OP. Pessimistic (worst-case assessment) of the averaged total intensity of EMB $Z_{B S \Sigma}\left[\mathrm{~W} / \mathrm{m}^{2}\right]$ is determined in OP by the following expression [1-3]:

$$
\begin{equation*}
Z_{B S n} \approx \frac{B_{n}}{2} \ln \left(\frac{4 H_{O P} \sqrt{e}}{\lambda}\right), H_{O P} \geq \frac{\lambda}{4} ; Z_{B S \Sigma}=\sum_{n=1}^{N}\left|Z_{B S n}\right|, \tag{1}
\end{equation*}
$$

where the value of $Z_{B S \Sigma}$ is defined as the scalar sum of the values of levels $Z_{B S n}, n \in[1, N]$ of averaged EMB intensities of each of $N$ frequency bands of MC;
$B_{n}\left[\mathrm{in} \mathrm{W} / \mathrm{m}^{2}\right]$ is the average EMLA created by BS radiations of the $n$-th frequency band in the considered area;
$\lambda$ is the wavelength of the $n$-th frequency band used;
OP height $H_{O P} \approx 1 \ldots 2$ approximately corresponds to the human height, and heights of BS antennas $H_{B S} \gg H_{O P}$.

The averaged EMLA over an area of $A\left[\mathrm{~m}^{2}\right]$, generated by a set of $K$ base stations distributed uniformly, is the sum of values of the total radiated power covering this area
(covering total radiated power CTRP [3]) $P_{e k}$ of each BS per unit of area:

$$
\begin{equation*}
B=\frac{1}{A} \sum_{k=1}^{K} P_{e k}, \quad P_{e k} \approx \frac{1}{2 \pi} \int_{0}^{\pi \pi} \int_{0}^{\pi} P_{k}(\theta, \varphi) \sin (\theta) d \theta d \varphi, \tag{2}
\end{equation*}
$$

where $P_{e k}$ is a part of the total radiated power (TRP [5]) $P_{T x k}$ of the $k$-th BS radiated in the solid angle $\Omega \leq 2 \pi$ covering the underlying surface $A$, minus losses in the antenna-feeder path;
$P_{k}(\theta, \varphi)=P_{T x} k \cdot g_{k}(\theta, \varphi)$ is the power of the $k$-th BS antenna radiation in the direction $(\theta, \varphi)$,
$g_{k}(\theta, \varphi)$ is the normalized pattern defined for the power flux density of the antenna (for $k$-th BS), characterizing its spatial selectivity by azimuth $\varphi$ and angle of sight $\theta$ (see Fig. 1).

The approximate equality in (2) reflects the fact that the range of viewing angles of a spherical Earth's surface from the phase center of the BS antenna, located above Earth, is somewhat less than $\pi$. In (2), when calculating $P_{e k}$, integration is performed only along the lower hemisphere (Fig. 1) in a solid angle, tightened by the Earth's surface, with the vertex $O$ placed in the phase center of the BS antenna, since EM power radiated into the upper hemisphere does not participate in formation of EME and EMB at the Earth's surface. This is the difference between the $P_{e k}(C T R P$ parameter) and the TRP parameter introduced in [5]. Since the power, emitted by modern antennas in the main lobe and outside it, have similar values [6], the values of the CTRP parameter are less than the values of the $T R P$ parameter by $1 . . .3 \mathrm{~dB}$.


Fig. 1. The BS antenna pattern in spherical coordinates $\{\theta, \varphi\}: \varphi_{M L}, \theta_{M L}$ is the direction of the main lobe (ML) axis; OB - the projection of the ML axis onto the XY plane

Uniform random distribution of SS has an average density by area $\rho$ [in $\mathrm{SS} / \mathrm{m}^{2}$ ]. SSs are serviced with a data rate of $V[\mathrm{bit} / \mathrm{s}]$. The average area traffic density of information services through downlink BS channels is $\left.S_{t r}=\rho V\left[\mathrm{bit} / \mathrm{s} / \mathrm{m}^{2}\right)\right]$ and the average EMLA $B\left[\mathrm{~W} / \mathrm{m}^{2}\right]$ created by the BS will be [2,3]:

$$
\begin{gather*}
B\left(R_{\max }, \mathrm{S}_{\mathrm{tr}}, \lambda\right)=\frac{8 \pi^{2} k T_{0} K_{N} \mathrm{D}_{\Sigma}\left(2^{m W_{E R}}-1\right) \mathrm{R}_{\max }^{2} \mathrm{~S}_{\mathrm{tr}} U}{\lambda^{2} W_{E R}},  \tag{3}\\
D_{\Sigma}=\left(\mathrm{K}_{\mathrm{CC}}+1\right) L_{\mathrm{m}} L_{\mathrm{C}} \mathrm{~K}_{\mathrm{H}},
\end{gather*}
$$

where $k=1.38 \times 10^{-23} \mathrm{~J} / \mathrm{C}$ is the Boltzmann constant;
$K_{N}$ is the SS's receiver noise factor,
$T_{0}$ is the ambient temperature ( $T_{0}=290 \mathrm{~K}$ );
$W_{E R}[\mathrm{bit} / \mathrm{s} / \mathrm{Hz}]$ is the downlink BS radio channel spectral efficiency, which differs from the potential spectral efficiency, determined in accordance with the known Shannon-Hartley theorem, in $m$ times;
$K_{C C}=N_{I N T} / N_{0}$ is the factor characterizing the excess of the thermal noise level $N_{0}$ of SS receivers by the level $N_{I N T}$ of intra-network interference; created in the radio channel;
$S_{t r}\left[\mathrm{bit} / \mathrm{s} / \mathrm{m}^{2}\right]$ is the average ATC generated by a set of BS in the considered area (integral system characteristic of 4G/5G/6G MC [7, 8]);
$R_{\max }$ is the radius of the BS service area, at the border of which the SS service with the necessary signal-to-(noise + interference) ratio (SNIR) requires the maximum equivalent isotropic radiated energy of BS per bit of transmitted information;
$D_{\Sigma}$ is the cumulative reserve in the BS radiation power associated with the necessity to overcome intra-system interference, compensation for losses $L_{m}$ on attenuation of radio waves in buildings, losses $L_{C}$ of radio waves propagation in the "canyons" of urban due to multipath effect and diffraction, $K_{H}$ is the necessary reserve in the level of the received SS signal for the handover implementation.

The system directivity parameter $U$ in (3), characterizing an integral form of the spatial selectivity of BS antenna radiation for the downlink data, is introduced by formula:

$$
\begin{equation*}
U=\frac{P_{A R}}{P_{A I}} \tag{4}
\end{equation*}
$$

where $P_{A R}$ is the total power of the BS radiation exposing the area $A$ of Earth's surface in the radio visibility of BS for the case when the ML of BS antenna with pattern $g(\theta, \varphi)$ is directed to the serviced SS;
$P_{A I}$ is the total power of an ideal omnidirectional (isotropic) BS antenna, irradiating the same area of Earth's surface.

It is supposed that both powers ( $P_{A R}$ and $P_{A I}$ ) provide a signal of the same level at the input of the SS receiver located at a point corresponding to the direction $\left(\theta_{M L}, \varphi_{M L}\right)$ of the ML axis, and this level is not lower than the required $\operatorname{SINR}$ value at the border of the BS service area. So, $P_{A R}\left(\theta_{M L}, \varphi_{M L}\right)=P_{A I}$ in direction of ML, and $U=P_{A R} / P_{A I}<1$ in other directions.

Thus, if BS antenna normalized pattern $g_{N}(\theta, \varphi)$ is known, then parameter $U$ for the BS radiation is determined by integration in limits of the solid angle covering the surface $A$ :

$$
\left.\begin{array}{c}
U=\frac{1}{2 \pi} \int_{0}^{\pi \pi} \int_{0}^{\pi} g_{N}(\theta, \varphi) \sin (\theta) d \theta d \varphi  \tag{5}\\
g_{N}(\theta, \varphi)=\frac{g(\theta, \varphi)}{g\left(\theta_{M L}, \varphi_{M L}\right)} \leq 1
\end{array}\right\}
$$

If the structure of the MC radio network is regular with $N_{S}$ azimuth sectors in each BS, then a rough worst case estimation of the average EMB intensity $Z_{B S \Sigma}$ created by a set of BS exposing the considered area, the directivity parameter $U_{\varphi}$ in horizontal plane is $U_{\varphi} \approx 1 / N_{S}[2,3]$. However, this estimation does not take into account the spatial selectivity of

BS radiation exactly, in particular, the selectivity $U_{\theta}$ in vertical plane. Essential overestimation is eliminated by introduction of system directivity parameter (4). To ensure a sufficient adequacy of estimation of EMB created by radiation of BS antennas, it is reasonable to determine system directivity parameter $U$ corresponding to the real characteristics of BS antennas with known antenna patterns.

## B. Model of Directivity of BS antenna radiation

The analysis of the influence of the BS radiation selectivity in planes of azimuth $\varphi$ and angle of sight $\theta$ on the value of the parameter $U$ in (3) was performed by integrating (5) of BS antenna pattern models along spherical coordinates (with the horizontal position of the zenith axis) in the solid angle $\Omega_{S} \approx 2 \pi$, constricted by the Earth's surface bounded by the horizon line. Point $O$ is an vertex of this solid angle, the ML of BS antenna is directed to the Earth's surface by angle $\theta_{M L}$. BS radiation in the upper hemisphere is not considered, since it does not participate in the creation of EMLA (3) on the Earth's surface. Therefore, integration in (5) should be carried out at intervals $\{\varphi \in[-\pi / 2, \pi / 2], \theta \in[0, \pi]\}$ or $\{\varphi \in[-\pi, \pi], \theta \in[0, \pi / 2]\}$.

The analysis was performed for the BS antenna pattern, represented by a known two-level model, the parameters of which are the values of $\Delta \varphi_{M L}, \Delta \theta_{M L}$ of the ML width in azimuth and angle of sight, respectively (Fig. 2), the relative level $G_{S L}$ of the side lobes, as well as the ratio $C_{p}=P_{M L} / P_{S L}$ of the BS radiation power in ML and side lobes [6]. This model includes the following relations:


Fig. 2. The ML limited by angles $\Delta \varphi_{M L}$ and $\Delta \theta_{M L}$ of a two-level model of antenna pattern as a part of a sphere with apex at the phase center $O$

- for normalized antenna pattern:
- for the gain $G_{M L}$ in the ML of the antenna pattern:

$$
\begin{equation*}
G_{M L}=\frac{2 \pi C_{P}}{\left(C_{P}+1\right) \sin \left(\Delta \theta_{M L} / 2\right)} ; \tag{7}
\end{equation*}
$$

- for the ratio of the radiated power in the main and in the side lobes:

$$
\begin{equation*}
C_{P}=\frac{G_{M L} \Delta \varphi_{M L} \sin \left(\Delta \theta_{M L} / 2\right)}{2 \pi-G_{M L} \Delta \varphi_{M L} \sin \left(\Delta \theta_{M L} / 2\right)} . \tag{7}
\end{equation*}
$$

## III. Results of the Analysis and Discussion

The analysis of the influence of the spatial selectivity of BS radiation on the EMB level created by them at the Earth's surface was performed for a typical sector topology of the MC radio network, which is characterized by the following:
a) At a three-sector topology of a $2 \mathrm{G} / 3 \mathrm{G} / 4 \mathrm{G}$ cellular radio network, ML of BS antennas with a (half-power) azimuthal width of $60^{\circ}-70^{\circ}$ and zenithal width $12^{\circ}-24^{\circ}$ in the frequency bands of the lower third of the UHF range (CDMA-450, GSM 800/900) and $5^{\circ}-12^{\circ}$ in its upper half (GSM-1800, UMTS, LTE), with an ML axis inclination angle of $\theta_{\mathrm{ML}} \geq 10^{\circ}$, are usually used.
b) At the AAA use in sectors of $4 \mathrm{G} / 5 \mathrm{G}$ MC radio networks in the most usable frequency range FR1 (0.417.125 GHz ) with fixed multipath pattern structure in the service sector (AAA "2D MIMO") and with adaptive dynamic formation of lobes for each serviced SS (AAA "Massive MIMO" in beamforming mode) width of the separate beams is $12^{\circ}-110^{\circ}$ in the horizontal plane and $6^{\circ}-$ $24^{\circ}$ in a vertical plane with ML axis inclination angle $\geq 10^{\circ}$ [4, 9, 10].

According to [6], for directional antennas, the $C_{P}$ ratio of EM radiation powers in the main and side lobes can take values in the range [1, 10]. For BS antennas with limited azimuth selectivity, which provides SS service in the azimuth sector in combination with the possibility of electronic ML adjustment along both coordinates, this parameter, as a rule, takes values in the interval [1,3]. Its estimates obtained using (5)-(7) for a number of known BS antennas of UHF are shown in Table 1.

TABLE I. Estimates of the $C_{P}$ Ratio for Some Known BS ANTENNAS

| Antenna type | Frequency band, MHz | $G_{M L}, \mathrm{~dB}$ | $\Delta \varphi_{M L}{ }^{\circ}$ | $\Delta \theta_{M L}{ }^{\circ}$ | $C_{P}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Kathrein 742151 | 824-880 | 14.0 | 70 | 16.0 | 2.12 |
|  | 880-960 | 14.5 | 65 | 15.0 | 1.98 |
|  | 1710-1880 | 16.5 | 60 | 8.0 | 1.08 |
| $\begin{aligned} & \text { Huavei } \\ & \text { A2645 1800v06 } \end{aligned}$ | 1710-2690 | 18.0 | 65 | 5.9 | 1.42 |
| Commscope HBX-6513DS-VTM | 1710-1880 | 14.7 | 68 | 15.0 | 2.67 |
|  | 1850-1990 | 14.8 | 66 | 14.1 | 2.12 |
|  | 1920-2180 | 15.2 | 64 | 13.5 | 2.25 |
| Commscope RRV4-65B-R6N39 | 694-806 | 14.2 | 72 | 10.8 | 0.98 |
|  | 790-894 | 14.5 | 61 | 9.9 | 0.70 |
|  | 890-960 | 15.0 | 58 | 9.4 | 0.72 |
|  | 1695-1920 | 15.9 | 65 | 9.2 | 1.29 |
|  | 1920-2200 | 16.4 | 70 | 8.2 | 1.54 |
|  | 2300-2490 | 16.9 | 69 | 7.4 | 1.54 |
|  | 2490-2690 | 17.0 | 58 | 6.6 | 0.87 |

Estimates of the ratio (7) of EMR power for the main and side lobes of the BS antennas patterns, presented in Table.1, as well as those obtained for multi-element AAA with low levels of side lobes ( $-30 \ldots-40 \mathrm{~dB}$ or less - AAA with DolphChebyshev patterns, with Taylor patterns awing the nearly constant low-level side lobes, with Bayliss patterns, etc. [11]), may be seemed as significantly underestimated, but here it should be taken into account that the main contribution to the power of such antennas radiation in side lobes is made by the ML side parts with relative levels less than -3 dB . In model (5)-(7), the ML corresponds to the halfpower beamwidth (HPBW) region of antenna pattern, and the part of the pattern named as the first null beamwidth (FNBW) and located outside the HPBW (Fig. 3), is assigned to the side lobe region. So, the part of FNBW outside HPBW actually make a significant contribution to the power value of EM radiation from the side lobes of BS antennas.


Fig. 3. Part of FNBW (tinted) that makes a significant contribution to the level of BS radiation power outside the HPBW (ML of BS radiation pattern in model (6))

The results of the quantitative analysis of the influence of the BS radiation spatial selectivity on the parameter $U$ value, which determines the level of the average EMLA (3) created by radiation of the BSs totality at the Earth's surface, are shown in graphic form in Fig. 4-7.

In Fig.4, the solid curves correspond to the calculated dependence $U\left(\theta_{M L}\right)$ obtained using (5) for $\mathrm{CP}=1.5$, for the ML width in azimuth $\Delta \varphi_{M L}=60^{\circ}$ and various values of its width $\Delta \theta_{M L}$ in the angle of sight. The dotted horizontal lines correspond to the values $1 / G_{M L}$ obtained using (7) for the same values of $\Delta \varphi_{M L}, \Delta \theta_{M L}$. The pairs of dependencies No. 1, No. 2, No. 3 and No. 4 correspond to the values of the ML width in vertical plane $24^{\circ}, 18^{\circ}, 12^{\circ}$ and $6^{\circ}$, respectively. The lower limit of the analyzed viewing angles is limited by the value of $\theta_{\text {min }}=10^{\circ}$, which is associated with ensuring a reduction in the levels of intra-system interference in MC radio networks. Similar dependences obtained for $C_{P}=5$ are shown in Fig. 5.

In connection with the use in $4 \mathrm{G} / 5 \mathrm{G}$ MC networks the AAA ensuring the formation of a set of beams of smaller width in the service sector in both the horizontal and vertical planes, it is of interest to assess the possible reduction due to this of the average EMLA created by the set of BS in the serviced area. Figure 6 shows pairs of calculated dependences characterizing the influence of spatial selectivity of the EM radiation of AAA on the average

EMLA. They are similar to the curves in Fig. 4 and Fig. 5 and correspond to the ML width $\Delta \varphi_{M L}=24^{\circ}, \Delta \theta_{M L}=12^{\circ}$ at $C_{P}=1$ (dependences 1) and $C_{P}=2$ (dependences 2), and also to the ML width $\Delta \varphi_{M L}=\Delta \theta_{M L}=12^{\circ}$ at $C_{P}=1$ (dependences 3 ) and $C_{P}=2$ (dependences 4).


Fig. 4. Dependences of BS radiation selectivity parameter $U$ for $C_{P}=1.5$ on the tilt angle $\theta_{M L}$ of the ML of sector antenna pattern $\left(\Delta \varphi_{M L}=60^{\circ}\right)$ for different $\Delta \theta_{M L}$


Fig. 5. Dependences of BS radiation selectivity parameter $U$ for $C_{P}=5$ on the tilt angle $\theta_{M L}$ of the ML of sector antenna pattern $\left(\Delta \varphi_{M L}=60^{\circ}\right)$ for different $\Delta \theta_{M L}$

Despite the significant difference in the values of $\Delta \varphi_{M L}$, $\Delta \theta_{M L}$, and $C_{P}$, corresponding to different dependences in Fig. 4,5 , and 6 , when the antenna ML is tilted approximately $30^{\circ}$ down with respect to the horizon, the value of the spatial selectivity parameter $U$ of the BS radiation turns out to the value inverse to the gain of the antenna ML: $U \approx 1 / G_{M L}$. At smaller angles of ML inclination, the use of this value of the parameter $U$ in (3) provides some pessimism in estimating the average intensity of the EMB generated by the totality of BS , due to the fact that for the angles of ML inclination of $10-20$, the value of $1 / G_{M L}$ exceeds the value $U$, obtained using (5), by $1-3 \mathrm{~dB}$.

The reverse situation is observed when ML tilt angles are more than $30^{\circ}$, however, such tilt angles for sector antennas
are rarely used, and their consideration may be of interest only for the "Massive MIMO" AAA with adaptive dynamic beam formation for each SS in the beamforming mode. At the uniform random SS distribution over the Earth's surface, the probability distribution density of the angle of sight determining the SS position relative to the phase center of the BS antenna has a significantly asymmetric form [12], and probability of the serviced SS location in the area of sight angles $\theta_{M L}>30^{\circ}$ is small.


Fig. 6. Dependences of EM radiation selectivity parameter of BS active antenna array for ML width $\Delta \varphi_{M L}=24^{\circ}, \Delta \theta_{M L}=12^{\circ}$ (curves 1,2) and $\Delta \varphi_{M L}=\Delta \theta_{M L}=12^{\circ}$ (curves 3,4) on the tilt angle $\theta_{M L}$ for different $C_{P}$

In Fig. 7, the calculated relation of probability $V_{I N T}$ of hitting of randomly selected SS in the "internal" interval of angles $30^{\circ}+\Delta \theta_{M L} / 2 \leq \theta_{M L}{ }^{\circ} \leq 90^{\circ}$ and the probability $V_{\text {OUT }}$ of its appearance in the "external" interval of angles $\theta_{\text {min }} \leq \theta_{M L}{ }^{\circ} \leq 30^{\circ}+\Delta \theta_{M L} / 2$, in dependence on the value $\Delta \theta_{M L}$ of ML width in the vertical plane, are given for a uniform random distribution of SS over the Earth's surface. Dependences are obtained for different values of the lower border $\theta_{\text {min }}$ of viewing angles of the boundaries of the BS service area: curve 1 for $\theta_{\min }=10^{\circ}$, curve 2 for $\theta_{\min }=7.5^{\circ}$ and curve 3 for $\theta_{\text {min }}=5^{\circ}$. They allow us to conclude that due to the fact that for BS antennas with real values of $\Delta \theta_{M L}$, these probabilities differ by an order of magnitude or more, differences in the estimates of the values of the parameters $U$ and $1 / G_{M L}$ can be neglected for the entire area of possible viewing angles of the directions to the serviced SS.

The presented results allow us to make the following conclusions:

1) The BS radiation spatial selectivity can significantly affect the intensity of the EMB created by MC radio networks in the residential area. The parameter $U$ in integral form reflects the degree of this influence. Depending on the values of basic parameters $\Delta \varphi_{M L}, \Delta \theta_{M L}, \theta_{M L}$ and $C_{P}$ of BS antennas, factor $U$ can take values in the range of $10 \ldots . .25 \mathrm{~dB}$, which is $5 \ldots 20 \mathrm{~dB}$ greater than the value of $1 / N_{S} \approx 5 \mathrm{~dB}$, which was used in $[2,3]$ for the pessimistic assessments of the EMB intensity created by radiation of the BS totality.
2) Parameter $U$ significantly depends on the angle of ML inclination of BS antennas. In practice, angles of ML inclination are selected from the interval $\theta_{\text {min }} \leq \theta_{M L}{ }^{\circ} \leq 30^{\circ}$,
$\theta_{\text {min }} \in\left[1^{\circ}, 5^{\circ}\right]$, which provides an increase in the relative area of ML cross-section at the Earth's surface. Taking into account the spatial selectivity of BS antennas in the vertical plane provides a more adequate assessment of the average EMLA (3) and the average intensity of EMB created by a set of MC BS in the serviced area.


Fig. 7. Dependences on $\Delta \theta_{M L}$ of the ratio of probability of SS hitting the range of viewing angles $30^{\circ}+\Delta \theta_{M L} / 2 \leq \theta_{M L}{ }^{\circ} \leq 90^{\circ}$ and probability of it appearance into the interval $\theta_{\text {min }} \leq \theta_{M L}{ }^{\circ} \leq 30^{\circ}+\Delta \theta_{M L} / 2$
3) Majority of BS sector antennas of the UHF range have gain coefficients from $10 \ldots 15 \mathrm{~dB}$ at $\Delta \varphi=60^{\circ} \ldots 90^{\circ}$ and $\Delta \theta_{M L}=12^{\circ} \ldots 24^{\circ}$, to $16 \ldots 20 \mathrm{~dB}$ at $\Delta \varphi=60^{\circ} \ldots 70^{\circ}$ and $\Delta \theta_{M L}=5^{\circ} \ldots 12^{\circ}$; the gain coefficients in relatively narrow ML of BS AAA of $4 \mathrm{G} / 5 \mathrm{G}$ systems reach $24 \ldots 25 \mathrm{~dB}[4,9,10$, etc.]. And, as follows from Fig. 4-6, for the ML angles of inclination used in practice, the value of the system directivity parameter in (3) can be taken to be the inverse of the BS antenna gain: $U \approx 1 / G_{M L}$.

## IV. CONCLUSION

The results of the analysis of BS radiation spatial selectivity on the average level of EMB, created by the totality of BS, confirmed the hypothesis that the value of the integral parameter $U$ of the BS radiation spatial selectivity in the analysis of the EMLA (3) created by the MC radio networks, corresponds to the value inverse of the gain in the ML of the BS antenna pattern. This makes it possible to refine significantly the technique for worst-case estimating the average levels of EMB created by BS radiations of 4G/5G MC.

A decrease in $\theta_{M L}$ leads to a decrease in values of system directivity parameter $U$ in (3). It leads to a decrease in the average EMLA level and to corresponding decrease in the intensity of the created EMB. But, at the same time, it causes an increase in co-channel interference in nearby sites using the same operating frequencies (deterioration of intrasystem EMC). This interference results in increase of the parameter $K_{C C}$ in (3). Therefore, it is of interest the determination of optimal values of $\theta_{M L}$, which the lowest EMB levels are provided.

Since the average EMLA (3) actually determines the physical limitations on the development of cognitive radio systems designed to operate in the MC frequency bands on a
secondary basis, as well as hygienic restrictions on the development of infrastructure and services of $4 \mathrm{G} / 5 \mathrm{G} \mathrm{MC}$, it is of interest to refine the results obtained using more detailed models of patterns of BS antennas (including models based on 3D pattern measurements and electrodynamic modeling) and to perform the verification of the methodology (1), (3) of prediction of the average EMB intensity for $U \approx 1 / G_{M L}$, based on experimental studies of EMB levels, created by MC in various conditions.

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## AbBreviations

AAA - active phased antenna array.
ATC - area traffic capacity.
BS - base station.
EM - electromagnetic.
EMB - electromagnetic background.
EME - electromagnetic environment.
EMLA - electromagnetic loading on area.
HPBW - half-power beamwidth.
FNBW - first null beamwidth
MC - mobile communications.
ML - main lobe.
OP - observation point.
SS - subscriber station

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