Frequency-Independent Asymptotes of System Parameters of Urban Cellular Communications at Multipath Propagation of Radio Waves

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Abstract— **Frequency-independent relationships for estimating a following number of system parameters of cellular communications under the conditions of multipath propagation of radio waves in urban canyons and the presence of intrasystem interference are obtained: the required equivalent isotropic radiated power (EIRP) of subscriber stations, the maximum data transmission capacity of the uplink radio channel, the maximum distance of qualitative communication, and also the permissible level of intranetwork radio interference at given requirements for communication range and data transfer rate of uplink radio channel taking into account the accepted restrictions on EIRP of subscriber radio equipment. Together with the frequency-independent component of the electromagnetic background near the earth's surface, created by electromagnetic radiations of subscriber stations located outside the breakpoint vicinity of the observation point, these dependencies form a family of asymptotes that provide ample opportunities for system analysis and diagnostics of solutions and scenarios for the implementation of 4G/5G/6G systems and services in various conditions, taking into account the quality of frequency-spatial planning and the intra-system EMC design of radio networks of cellular (mobile) communications.**

Keywords—cellular communications, intrasystem EMC, electromagnetic radiation, electromagnetic background, system parameters, asymptotic dependences.

I. ABBREVIATIONS

BC – base station.
CC – cellular communications.
EMB – electromagnetic background..
EMC – electromagnetic compatibility.
EME – electromagnetic environment.
EMF – electromagnetic field.
EMLA – average electromagnetic loading on area.
EMR – electromagnetic radiation.
EIRP – equivalent isotropic radiated power.
OP – observation point.
RFC – radio (frequency) channel
RWP – radio waves propagation.
MS – mobile (subscriber's) station

II. INTRODUCTION

A considerable increase in the rates and volumes of data transmission over the radio channels of 4G/5G/6G cellular communications (CC), in spite of the known achievements in improving the spectral efficiency of these systems due to improved modulation / demodulation and encoding / decoding methods, as well as due to the use of MIMO technology, can be the reason for the significant complication of electromagnetic environment (EME), deterioration of electromagnetic ecology of human environment and electromagnetic safety of population.

This problem can be significantly weakened due to the development of CC full-fledged multilevel infrastructure, which provides a significant reduction in operating distances for high-speed data transmission. The latter is possible only in conditions of a significant reduction in sizes of sites in urban cellular radio networks by reducing the maximum operating distances to 200-300 m and less, and using of pico-sites with a communication range of up to 50 m at the lower hierarchical level of the network structure, which is consistent with [1-3].

However, this reduction is associated with very substantial costs, as a result of which even the development of 4G (LTE) network infrastructure, as a rule, lags behind the safe development of their subscriber's base and the increase in volume of network traffic. The last leads to a complication of EME in places with a high population density and a decrease in safety of CC use. Therefore, it is urgent to justify restrictions on the system parameters of 4G/5G networks, which make it possible to formulate requirements for the characteristics and pace of development the CC networks infrastructure to ensure their EMC, electromagnetic safety and ecology.

The important parameter of these networks is the maximum operating distance at various characteristics the of uplink radio frequency channel (RFC) under the restrictions on the equivalent isotropic radiated power (EIRP) of mobile subscriber's stations (MS). In [4], this problem was analyzed under the assumption that the maximum operating distance at the high data rate in the uplink RFC is commensurate with the radius of the region of free-space radio waves propagation (RWP) between MS and corresponding base station (BS).

However, a subsequent analysis of the problem detected the necessity of expanding the analysis to the area of multipath interferential RWP between MS and BS, typical for urban canyons of dense urban areas, formed by parallel rows of

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buildings with an observed decrease in the heights of elevation of BS antennas in order to reduce the levels of intranetwork interference due to the shielding effect of buildings, where the contribution from the RWP above their roofs is negligible.

The goal of this paper is to estimate the expected restrictions on characteristics of CC systems of new generations (4G, 5G, 6G, ...) under the existing restrictions on the MS EIRP, as well as in conditions where the boundaries of urban sites (micro-sites according to classification [1-3]) lie outside the free space RWP region between MS and BS.

III. BASIC MODELS AND RELATIONS

At the interferential (multipath) RWP in canyons of urban development, which are typical when the distances between BS and MS exceed the size R_{BP} of the free-space RWP area (or the so-called "breakpoint distance"), a "forked" estimation of RWP losses L_t for RWP between MS and BS is recommended in [1] under these conditions using the following expressions:

$$\left.\begin{aligned} L_t &= L_{to} = 16\pi^2 d^4 / \left(\lambda^2 G_{BS} R_{BP}^2\right); \\ L_t &= L_{to} = 1600\pi^2 d^4 / \left(\lambda^2 G_{BS} R_{BP}^2\right); \\ L_t &= L_{to} = 64\pi^2 d^4 / \left(\lambda^2 G_{BS} R_{BP}^2\right); \end{aligned}\right\} \tag{1}$$

$$d \geq R_{BP}, \quad R_{BP} = 4 H_{eBS} H_{eMS} / \lambda, \tag{2}$$

where d is the distance between MS and BS; λ is the wavelength, G_{BS} is the BS antenna gain, R_{BP} is the reference boundary of the range of distances between BS and MS (breakpoint distance), outside of which the RWP losses increases significantly due to multipath phenomena; H_{eBS} and H_{eMS} are respectively the equivalent heights of BS and MS antennas above the underlying (reflecting radio waves) surface (ground, building walls, etc.); L_{to} corresponds to the lower limit (optimistic estimate) of possible values of RWP losses for the MS, remote from the BS at a distance $d \geq R_{BP}$; L_{tp} corresponds to the upper limit (pessimistic estimate) of possible values of these losses, taken with a margin of 20 dB for fading; L_{tm} is the median value of RWP losses between BS and MS for the considered conditions.

The required minimal MS EIRP P_{MSR} (with antenna gain close to 1), at which the required data transmission rate is provided over the uplink RFC, which is characterized by the capacity close to the potential C_P [bit/s], and by the spectral efficiency S_{EP} [bit/s/Hz] of data transmission, is related to the attenuation L_t at RWP from MS to BS as follows [4]:

$$\left.\begin{aligned} &P_{MSR} = N_\Sigma C_P L_t \left(2^{S_{EP}} - 1\right) / S_{EP}; \\ &N_\Sigma = \left(K_{CC} + 1\right) P_{IN}, \quad K_{CC} = P_{INI} / P_{IN}, \quad P_{IN} = k T_0 K_N, \end{aligned}\right\} \tag{3}$$

where k is Boltzmann's constant ($1.38 \cdot 10^{-23}$ J/deg.), K_N is the radio receiver noise figure, T_0 is the ambient temperature ($T_0 =$ 290K); K_{CC} is the coefficient characterizing the ratio of the intra-network interference level P_{INI} and the receiver's own noise level P_{IN} ($K_{CC} \geq 3 \div 5$).

Expression (3) can be used to assess the system characteristics of modern (2G, 3G, 4G) and future (5G, 6G) CC generations, since the expected increase in spectral efficiency of 4G (LTE) and 5G (NR) RFC due to MIMO technology up to 10 times [3, etc.] allows us to conclude [4] that the use of this technologies can mostly roughly compensate for the imperfection of the modulation / demodulation and encoding / decoding processes. Therefore, the assessment of the expected limitations on the characteristics of CC in the conditions of interferential RWP at a first approximation can be carried out at the assumption that data transmission rats in RFCs of 4G/5G/6G CC systems will be close to the potential.

Substitution of one of the values (1) into expression (3) allows us

a) To relate the necessary P_{MSR} value required to ensure high-quality communication at a distance d, or estimate the maximum range d of high-quality communication at a given MS EIRP P_{MSR} (substituting L_{tp});

b) To evaluate the radio visibility distance d for the MS with EIRP P_{MSR} under favorable (optimistic) RWP conditions, from the observation point (OP) - phase center of the BS receiving antenna (substituting L_{to});

c) To implement the procedure for assessing the aggregate level of intranet interference as the sum of median values of the intensity of electromagnetic fields (EMF) from the BS of neighboring sites (substituting the expression for the median losses L_{tm}).

IV. ANALYSIS RESULTS

As a result of these substitutions, the following relationships were obtained for the upper limit L_{tp} of losses for RWP in urban canyons and for the upper limit P_{MSRp} of values of the required MS EIRP, at which, under these RWP conditions ($d \geq R_{BP}$), the required data rate is provided over the BS uplink RFC:

$$L_{tp} = \frac{100\pi^2 d^4}{G_{BS} H_{eBS}^2 H_{eMS}^2}, \quad d > R_{BP}; \tag{4}$$

$$P_{MSRp} = \frac{100\pi^2 d^4 C_P \left(K_{CC} + 1\right) k T_0 K_N \left(2^{S_{EP}} - 1\right)}{G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}, d > R_{BP}. \tag{5}$$

By inverting the expression (5), the following analytical dependences for the main system parameters of CC radio networks can also be obtained:

a) Expression for the boundary range d_{max} of a qualitative radio communication (due to the 20 dB correction for fading in (4)) at a given MS EIRP P_{MSR}:

$$d_{max} = \sqrt[4]{\frac{P_{MSR} G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}{100\pi^2 C_P \left(K_{CC} + 1\right) k T_0 K_N \left(2^{S_{EP}} - 1\right)}}, d_{max} > R_{BP}; \tag{6}$$

b) Dependence of the maximum RFC capacity C_{max} [bit/s] on the communication range d with a limited MS EIRP P_{MSR}:

$$C_{max} = \frac{P_{MSR} G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}{100\pi^2 d^4 \left(K_{CC} + 1\right) k T_0 K_N \left(2^{S_{EP}} - 1\right)}, \quad d > R_{BP}; \tag{7}$$

c) Dependence of the maximum permissible relative level of intranet interference K_{CCp} (characterizing the level of intra-network EMC) on the range d of radio communication with the

MS EIRP P_{MSR}, at which the specified RFC capacity C_P is provided:

$$K_{CCp} = \frac{P_{MSR} G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}{100\pi^2 d^4 C_P k T_0 K_N \left(2^{S_{EP}} - 1\right)} - 1, \quad d > R_{BP}. \qquad (8)$$

Due to the fact that an additional essential 20 dB correction for fading is introduced into model (4) for the interferential RWP, the obtained relations (5) - (8) provide a pessimistic assessment of the system parameters of the CC radio network with the use of high levels of useful MS signals, providing a sufficiently high quality of communication.

With regard to other types of assessments performed at the analysis of intersystem electromagnetic compatibility (EMC) of CC radio networks, the following expressions are of interest:

d) Expressions for the lower limit L_{to} of attenuation values at RWP in canyons of urban development and the lower limit P_{MSRo} of values of the required MS EIRP, at which in these RWP conditions the capacity C_P of the BS uplink RFC is provided:

$$L_{to} = \frac{\pi^2 d^4}{G_{BS} H_{eBS}^2 H_{eMS}^2}, \quad d > R_{BP}; \qquad (9)$$

$$P_{MSRo} = \frac{\pi^2 d^4 C_P \left(K_{CC} + 1\right) k T_0 K_N \left(2^{S_{EP}} - 1\right)}{G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}, \quad d > R_{BP}. \qquad (10)$$

e) Expressions for median values L_{tm} of attenuation for RWP in urban canyons and median values of P_{MSRm} of the required MS EIRP, at which, under these RWP conditions, the capacity C_P of the BS uplink RFC is provided:

$$L_{tm} = \frac{4\pi^2 d^4}{G_{BS} H_{eBS}^2 H_{eMS}^2}, \quad d > R_{BP}; \qquad (11)$$

$$P_{MSRm} = \frac{4\pi^2 d^4 C_P \left(K_{CC} + 1\right) k T_0 K_N \left(2^{S_{EP}} - 1\right)}{G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}, \quad d > R_{BP}. \qquad (12)$$

A very important circumstance is the independence of the expressions presented above from frequency (except the boundaries $d \geq R_{BP}$, $d_{max} \geq R_{BP}$ of their domains of definition), which makes it possible to determine a number of basic dependencies and restrictions that are valid for all frequency ranges of CC.

Figures 1-6 show families of curves (3), (5), (7), (8), calculated for typical values of CC RFC parameters: $S_{EP} = 5$, $K_N = 5$, $T_0 = 293\text{K}$, $G_{BS} = 50$, $H_{eMS} = 1.5$ m.

Figure 1 shows the typical calculated dependences $P_{MSR}(d)$ obtained using (3) and the pessimistic model [1] of RWP in urban canyons, including model (4) for the "far zone" - the region of interferential RWP ($d \geq R_{BP}$), and the free-space RWP model with fade margin of 20 dB for the "near zone" $d < R_{BP}$. These dependences were obtained for a number of frequency bands used and discussed for use by CC systems: for $\lambda = 0.67$ m (450 MHz, curve 1), $\lambda = 0.5$ m (600 MHz, curve 2), $\lambda = 0.33$ m (900 MHz, curve 3), $\lambda = 0.17$ m (1.8 GHz, curve 4) and $\lambda = 0.11$ m (2.7 GHz, curve 5); they are calculated for $C_P = 100$ Mbit/s, $K_{CC} = 10$ and $H_{eBS} = 10$ m. It is not difficult to verify the presence of a frequency-independent asymptote, which limits the possibility of reducing the required levels of MS electromagnetic radiation (EMR) at $d \geq R_{BP}$ by increasing the EMR wavelength. This asymptote is the dependence $P_{MSRp}(d)$ calculated using (5) for the same values of C_P, K_{CC}, S_{EP}, K_N, T_0, G_{BS}, H_{eBS}, H_{MS}, indicated by a dashed line. Frequency-dependent is only the position $d = R_{BP}$ of points of intersection of branches corresponding to the free-space and interferential RWP. Figure 2 shows the calculated dependences $P_{MSRp}(d)$ for a number of values of the equivalent height of BS antennas above the reflecting surface for similar conditions: for $H_{eBS} = 5$ m (curve 1), $H_{eBS} = 10$ m (curve 2, also presented in Fig. 1 as the dashed asymptote), $H_{eBS} = 20$ m (curve 3), $H_{eBS} = 40$ m (curve 4), $H_{eBS} = 80$ m (curve 5).

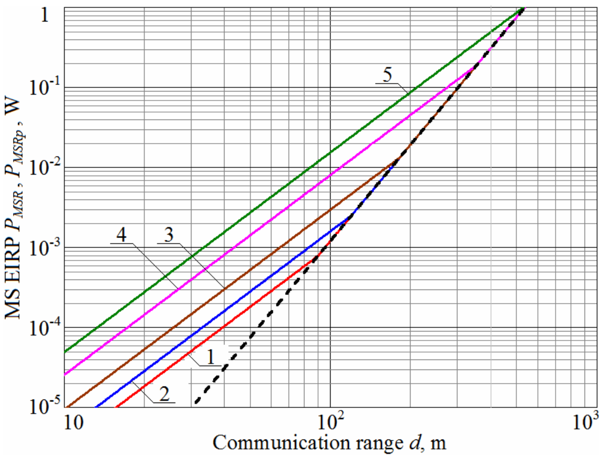

Fig. 1. Dependences $P_{MSR}(d)$ for free-space ($d < R_{BP}$) and interference RWP ($d \geq R_{BP}$) for few frequency ranges ($C_P = 100$ Mbit/s, $K_{CC} = 10$, $H_{eBS} = 10$ m).

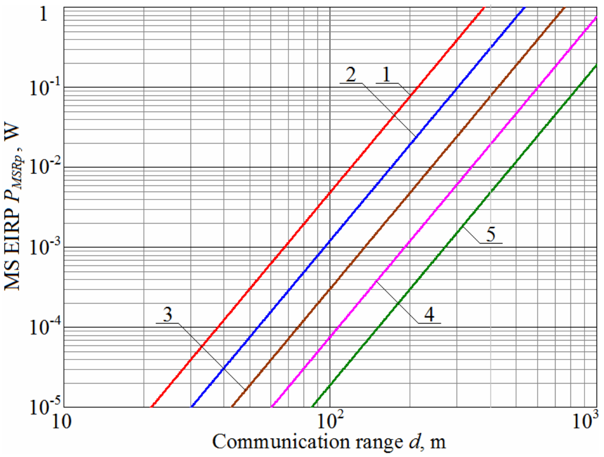

Fig. 2. Asymptotes $P_{MSRp}(d)$ for $d \geq R_{BP}$ (interference RWP) at different heights of BS antennas above the reflecting surface ($C_P = 100$ Mbit/s, $K_{CC} = 10$).

Figure 3 shows a family of calculated asymptotic dependences $P_{MSRp}(C_P)$ of the required MS EIRP (5) for the region $d \geq R_{BP}$ on the required RFC capacity for different levels of intranetwork interference: for $K_{CC} = 0$ (curve 1, an ideal intranetwork EMC), for $K_{CC} = 1$ (curve 2), for $K_{CC} = 10$ (curve 3), for $K_{CC} = 100$ (curve 4) and for $K_{CC} = 1000$ (curve 5); these plots are calculated for $d = R_{BP} = 400$ m, $\lambda = 0.15$ m (2 GHz) and $H_{eBS} = 10$ m. Figure 4 shows the family of asymptotic dependences $P_{MSRp}(K_{CC})$ of the required MS EIRP for communication ranges $d \geq R_{BP}$, obtained for the same conditions, on the relative level of intranetwork interference K_{CC} at different RFC capacity: for $C_P = 10^4$ (curve 1), $C_P = 10^5$ (curve 2), $C_P = 10^6$ (curve 3), $C_P = 10^7$ (curve 4), $C_P = 10^8$ (curve 5) and $C_P = 10^9$ (curve 6). Taking into account that MS EIRP levels which meet the specifications of modern and future CC systems [5-7], are limited to 20 - 23 dBm (0.1 - 0.2 W), the following conclusions can be drawn that clarify the conclusions [4]:

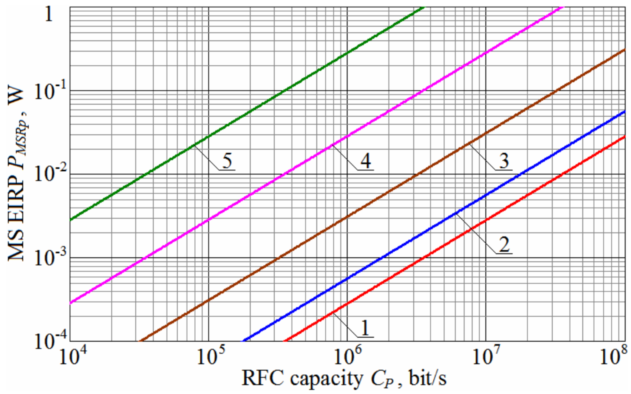

Fig. 3. Asymptotes $P_{MSRp}(C_P)$ at $d \geq R_{BP}$ for different relative levels of intranetwork interference ($d = R_{BP} = 400$ m, $\lambda = 0.15$ m).

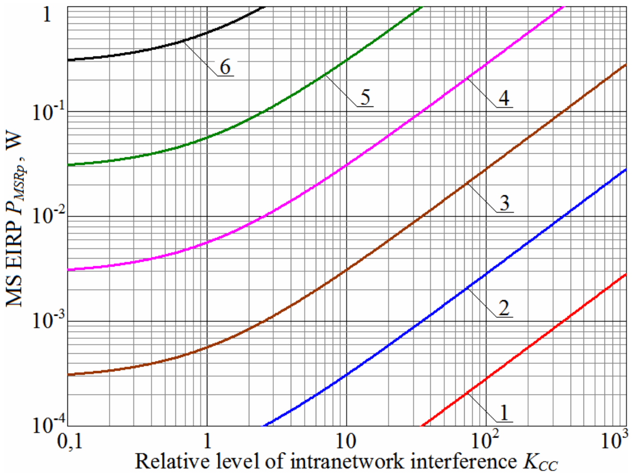

Fig. 4. Asymptotes $P_{MSRp}(K_{CC})$ at $d \geq R_{BP}$ for different RFC capacity ($d = R_{BP} = 400$ m, $\lambda = 0.15$ m).

a) At communication ranges of 200 - 400 m, approximately corresponding to the micro-cell's radii in urban development [1-3], voice communication's RFC which have a relatively low capacity of 10^4 - 10^5 bit/s, under appropriate conditions allow the presence of high relative levels of intra-network interference ($K_{CC} \approx 100$ ... 1000) without reaching the dangerous MS EIRP levels;

b) Under the same conditions, the safety of MS EMR via the uplink high-speed data transmission RFC at data rates of 10^8 - 10^9 bit/s requires a significant reduction in the relative level of intranetwork interference (no more than $K_{CCp} \approx 3$ ... 30) or a sharp increase in the quality of intranetwork EMC.

Figure 5 shows a family of calculated asymptotic dependences (7) of the maximum possible RFC capacity on the MS EIRP $C_{max}(P_{MSR})$ for the region $d \geq R_{BP}$ for different communication distances: for $d = 200$ m (line 1), $d = 400$ m (line 2), $d = 800$ m (line 3) and $d = 1600$ m (line 4); they are calculated for $d = R_{BP}$ and $K_{CC} = 10$. Figure 6 shows the family of "inverted" asymptotic dependences (8) of the maximum permissible relative level of intranetwork interference on the required RFC capacity $K_{CCp}(C_{max})$, obtained for the same conditions for the region $d \geq R_{BP}$, for different communication ranges: for $d = 200$ m (line 1), $d = 400$ m (line 2), $d = 800$ m (line 3) and $d = 1600$ m (line 4). Taking into account that the density of cellular BSs can be up to 10 micro-BS/km^2 or more in urban conditions, up to 1-3 BS/km^2 in suburban conditions and up to 0.1-0.2 BS/km^2 in rural areas [1-3], the following conclusions can be drawn from the analysis of the curves in Fig. 5.6:

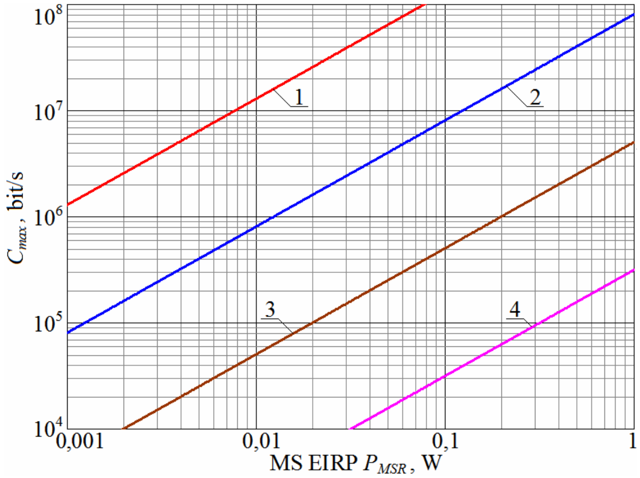

Fig. 5. Asymptotes $C_{max}(P_{MSR})$ at $d \geq R_{BP}$ for different communication ranges ($R_{BP} = 200$ m, $K_{CC} = 10$).

a) In urban conditions with a maximum communication range of no more than 200-400 m with the restrictions on MS EIRP adopted in [5-7], the high quality of intranetwork EMC ($K_{CC} \leq 10$) makes it possible to achieve data transfer rates in uplink RFCs declared in [8] for 4G/5G systems, and also for a significant part of declared 6G services [9] for individual users;

b) In suburban and rural areas, where the site radii increase up to 1-2 km, at MS EIRP levels adopted in [5-7] even the high quality of CC frequency-spatial planning and intranetwork EMC will not provide the data transfer rate from the MS to the BS higher than 10^5 - 10^6 bit/s; in these conditions, a significant increase in this data rates is possible only due to the implementation of the hierarchical structure of the CC radio network using pico-BS and hotspots in places of the most probable MS location - in specially organized local service areas in buildings, at infrastructure facilities, in vehicles, etc.;

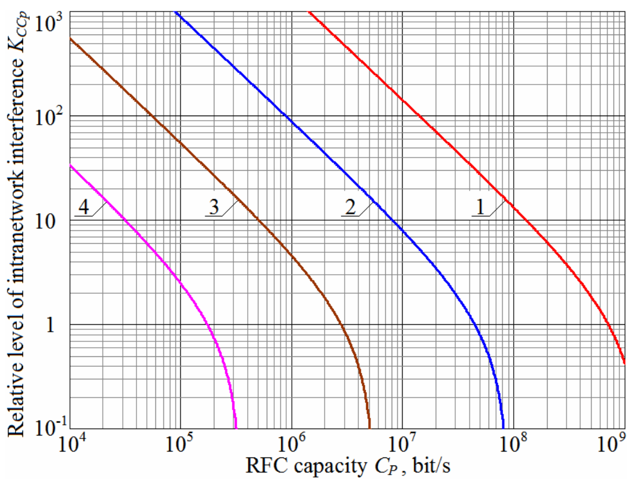

Fig. 6. Asymptotes $K_{CC}(C_P)$ at $d \geq R_{BP}$ for different communication ranges ($R_{BP} = 200$ m, $P_{MSR} = 0.1$ W).

c) The quality of the CC intrasystem EMC, determined by the quality of the frequency-spatial planning of CC radio networks and by the amount of radio frequency resource used by these CC systems, is of primary importance in terms of ensuring the required level of the most important system characteristics of modern and future CC, such as the expected high data transfer rates from the MS to the BS at the relatively large distances corresponding to the boundaries of BS service zones of CC radio networks in various conditions (urban, suburban, rural areas), in conditions of the accepted restrictions on the MS EIRP.

V. ELECTROMAGNETIC BACKGROUND CREATED BY THE SET OF MS LOCATED IN "FAR ZONE"

Earlier, author proposed a simple relation for frequency-independent asymptotic estimation of the average intensity of the electromagnetic background (EMB) $Z_{\Sigma MS2}$ [W/m^2] created at the OP near ground surface by EMFs of a set of radiating MS located outside the OP "breakpoint" vicinity and distributed over the area uniformly with the density ρ_{eMS} [MS/m^2] [10,11]:

$$Z_{\Sigma MS2} = \sum_{i=1}^{N} \left| Z_{MSi} \right| \approx \frac{B_{TMS}}{4}, \;\; B_{TMS} = \frac{\sum\limits_{i=1}^{M} P_{eMSi}}{S} = \rho_{eMS} P_{eMSav}, \quad (13)$$

where $Z_{\Sigma MS2}$ is defined as a scalar sum of power flux densities Z_{MSi} of EMFs presented in OP, which are radiated by the set of N MS distributed uniformly over the area S of the "far zone" - the zone of $d > R_{BP}$; B_{TMS} [W/m^2] is the average electromagnetic loading on area (EMLA) created by the set of EMRs of MSs in the "far zone"; P_{eMSi} - the EIRP of circular EMR of corresponding j-th MS; P_{eMSav} - the average EIRP of radiating MS of the "far zone".

As opposed to the contribution to the total EMB intensity of the EMFs set of "far zone" MS ($d > R_{BP}$), the contribution of EMFs of the MS located in the OP breakpoint vicinity ("near zone") depends both on the MS EMR wavelength and on MS & OP heights ($H_{MS} \approx H_{OP} \approx h$) above the surface. For the same average EMLA created by radiating MS from both the "far zone" and from the OP breakpoint vicinity, the contribution of the "near zone" MS in the total EMB intensity in OP is dominant and is determined by the following relation [10,11]:

$$Z_{\Sigma MS1} = \left(B_{TMS}/2 \right) ln\left(8\pi h^2/\lambda^2 \right), \text{ W/m}^2. \quad (14)$$

If, at the first approximation, the average MS EMR power corresponding to the average communication range d_{av} for the "far zone" MS, is equal to its median value (12), then the contribution of EMFs of these MS to the total EMB intensity in OP can be estimated using the following relation:

$$Z_{\Sigma MS2} = \frac{\pi^2 d_{av}^4 \left(K_{CC} + 1 \right) k T_0 K_N \left(2^{S_{EP}} - 1 \right) S_{TRM}}{G_{BS} H_{eBS}^2 H_{eMS}^2 S_{EP}}, \; S_{TRM} = C_P \rho_{eMS}. \quad (15)$$

In this expression, the value $S_{TRM} = \rho_{eMS} C_P$ [bit/s/m^2] is a pessimistic estimation of the average area uplink traffic capacity generated by a set of spatially distributed MSs (under the assumption that RFCs data rates are equal to its capacity).

Figure 7 shows the dependences $Z_{\Sigma MS2}(S_{TRM})$ for different quality of CC intranetwork EMC design and support for the following typical values of CC parameters: $S_{EP} = 5$, $K_N = 5$, $T_0 = 293$K, $G_{BS} = 50$, $h = 1.5$ m, $d_{av} = 400$ m, $H_{eBS} = 10$ m. Line 1 corresponds to $K_{CC} = 0$ (ideal intranetwork EMC, no intranetwork interference), line 2 corresponds to $K_{CC} = 1$, line 3 corresponds to $K_{CC} = 10$, lines 4 and 5 correspond to the high relative levels of on-network interference ($K_{CC} = 100$ and $K_{CC} = 1000$, respectively); horizontal line 6 corresponds to the level of 0.1 W/m^2, which is accepted in many countries as the EMB maximum permissible level (MPL) for population taking into account the danger of non-thermal effects of exposure of radio frequency EM fields on the human body.

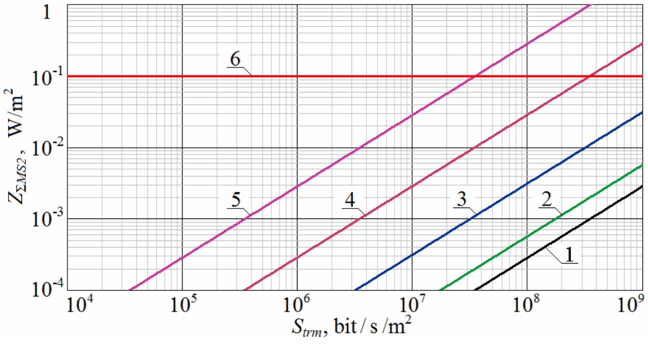

Fig. 7. Frequency-independent asymptotes $Z_{\Sigma MS2}(S_{TRM})$ at $d \geq R_{BP}$ for different relative levels of intranetwork interference.

Figure 8 shows the dependences of the ratio $Z_{\Sigma MS2}/Z_{\Sigma MS1}(\lambda)$ of EMB components in the OP, created by the MS EMRs from the regions $d \geq R_{BP}$ and $d < R_{BP}$, respectively, on the MS EMR wavelength at different h. Curves 1, 2 and 3, which corresponds to the values $h = 0.5$ m, $h = 1$ m and $h = 2$ m, respectively, are of the main practical interest; curve 4 corresponds to the height $h = 4$ m, which is significantly higher than the height of the human body.

Analysis of dependencies in Fig. 7 and 8 indicates the following:

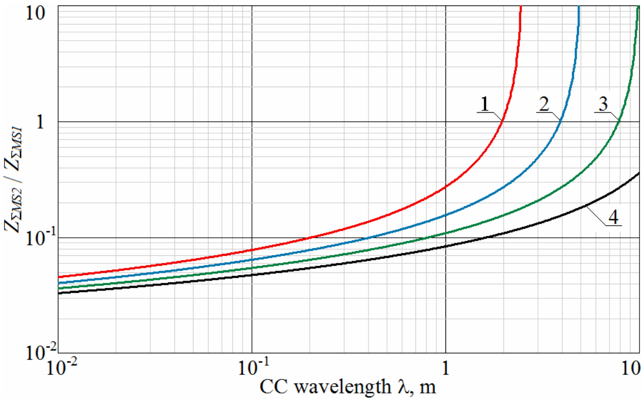

Fig. 8. Dependences of ratio $Z_{\Sigma MS2} / Z_{\Sigma MS1}(\lambda)$ of EMB components created by sets of radiating MS from areas of free-space and multipath RWP, for different $h \approx H_{MS} \approx H_{OP}$.

a) At the high quality of intranetwork EMC ($K_{CC} < 10$ dB), the contribution of MS EMRs from the "far zone" is relatively small, it is significantly lower than 0.1 W/m^2. At the same time, the low quality of the frequency-spatial planning of CC radio networks and of the intranetwork EMC design and support at the expected levels of average area uplink traffic capacity in 4G/5G/6G networks (see data [8-10], taking into account the expected downlink and uplink traffic asymmetry) can be the reason that even at a local low MS area density in OP vicinity, the EMB level created by EMFs of the "far zone" with a high area density of radiating MS can exceed the accepted maximum permissible level;

b) Contribution of MS EMRs from the "far zone" to the total EMB intensity in OP decreases with an increase in the MS and OP elevation above the surface. It can be explained by the increase in the radius of the breakpoint vicinity and the relative number of "near zone" MSs, which EMRs make the main contribution to the EMB intensity created in the OP. With the adopted model of the MS spatial distribution above the surface, with an increase in *h*, the size of the MS radio visibility region from the OP increases relatively slightly, since it is determined mainly by the MS EIRP, by the earth curvature and by the power threshold of radio visibility of the MS EMF in the OP (this threshold can be equal to the threshold of sensitivity of the MS radio receiver with respect to the useful signal).

VI. CONCLUSION

In this paper, frequency-independent asymptotic relations (5) - (8) are given for a number of system parameters of CC (L_{tp}, P_{MSRp}, d_{max}, C_{max}, K_{CCp}) in conditions of multipath (interferential) RWP between BS and MS in urban canyons. These RWP conditions can be accepted as typical for communication with the MS located near the boundaries of the sites at a relatively large distances $d \geq R_{BP}$ from the BS.

The existence of these asymptotes can be explained by the mutual compensation of the frequency dependence of (1) and (2) when expression (2) is substituted into relation (1).

Obtained with the use of the pessimistic branch L_{tp} of the model (1) for RWP in urban canyons, the use of which, due to the presence in (4) the 20 dB correction for fading, corresponds to the conditions of high communication quality, these asymptotic relations turn out to be adequate for all cellular frequency bands for which the model (1), (2) can be used.

The obtained relations (5) - (8) allow us to estimate the limits of possible values of the system parameters L_{tp}, P_{MSRp}, d_{max}, C_{max}, K_{CCp} of modern and future CC systems, and also provide the possibility of substantiating the requirements for the quality of support the CC intranetwork EMC based on the existing restrictions on the MS EIRP and the required data rates in the uplink RFC of CC radio networks.

Jointly with the frequency-independent component (13) of the total EMB intensity near the earth's surface, created by MS EMRs located outside the OP breakpoint vicinity, these relations create a family of asymptotes that provide opportunities for system analysis of solutions and scenarios for the implementation of 4G/5G/6G systems and services in various conditions, taking into account the quality of the CC intranetwork EMC.

Expressions and curves given above make it possible to estimate the required levels of MS EIRP, possible RFC data rates and expected EMB levels created by CC, at various implementation scenarios for 4G/5G/6G systems and services, including typical scenarios recommended by [2,3,12,13].

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