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]:

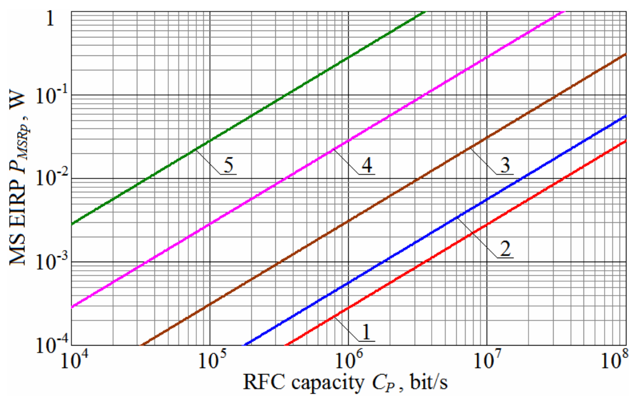

Fig. 3. Asymptotes $P_{MSRp}(C_P)$ at $d \geq R_{BP}$ for different relative levels of intranetwork interference ($d = R_{BP} = 400$ m, $\lambda = 0.15$ m).

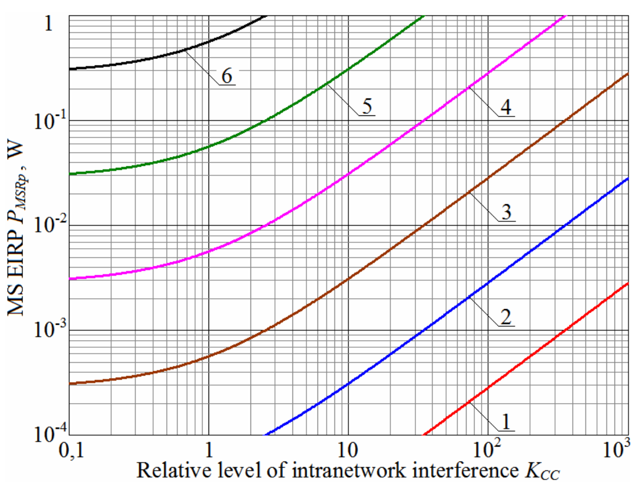

Fig. 4. Asymptotes $P_{MSRp}(K_{CC})$ at $d \geq R_{BP}$ for different RFC capacity ($d =$ $= R_{BP} = 400$ m, $\lambda = 0.15$ m).

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:

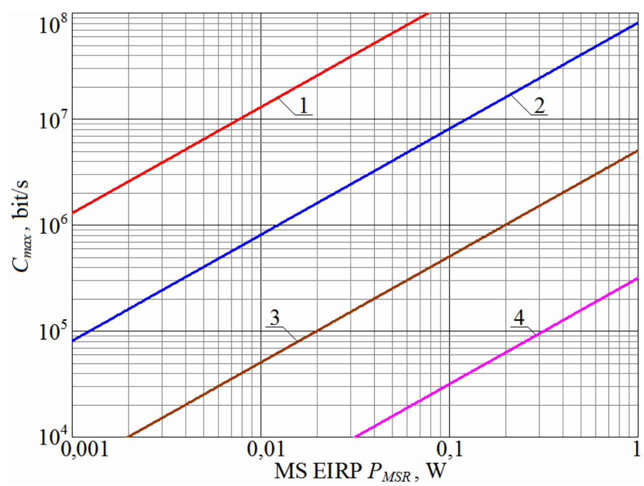

Fig. 5. Asymptotes $C_{max}(P_{MSR})$ at $d \geq R_{BP}$ for different communication ranges ($R_{BP} = 200$ m, $K_{CC} = 10$).

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.;

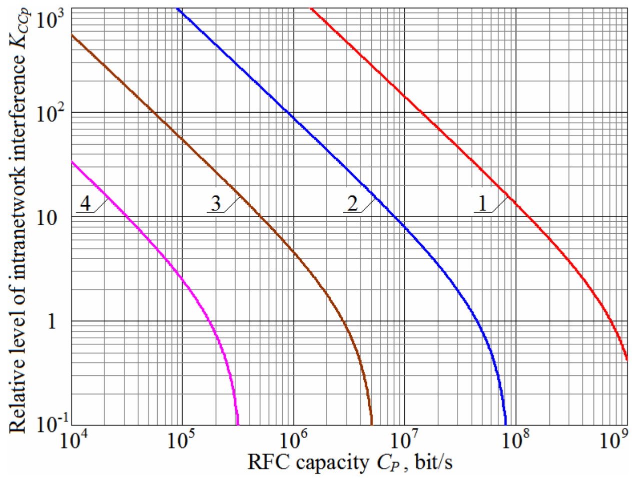

Fig. 6. Asymptotes $K_{CC}(C_P)$ at $d \geq R_{BP}$ for different communication ranges ($R_{BP} = 200$ m, $P_{MSR} = 0.1$ W).

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]:

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

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]:

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

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:

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

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.

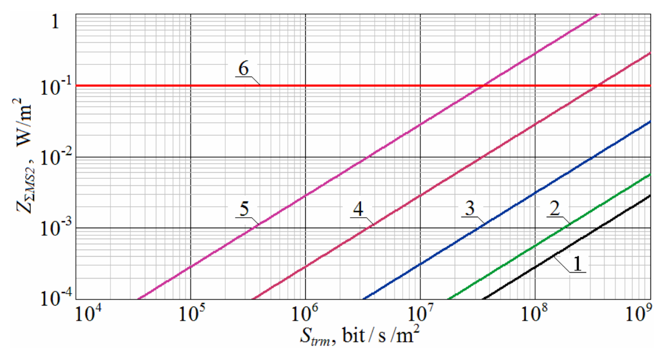

Fig. 7. Frequency-independent asymptotes $Z_{\Sigma MS2}(S_{TRM})$ at $d \geq R_{BP}$ for different relative levels of intranetwork interference.

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:

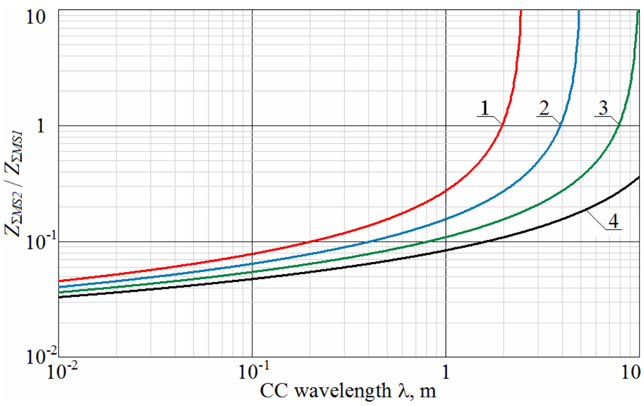

Fig. 8. Dependences of ratio $Z_{\Sigma MS2} / Z_{\Sigma MS1}(\lambda)$ of EMB components created by sets of radiating MS from areas of free-space and multipath RWP, for different $h \approx H_{MS} \approx H_{OP}$.

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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