System Analysis of Electromagnetic Environment Created by Radiating 4G/5G User Equipment Inside Buildings

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Abstract—**The technique for estimating an electromagnetic background created by radiating user equipment of mobile communications in buildings is developed. It is based on system analysis of statistical regularities of electromagnetic environment in premises at different radiation power and indoor spatial density of sources, using the known empirical models of radio wave propagation in buildings. Results of analysis are the probability distribution density and mathematical expectation of power flux densities of electromagnetic fields generated by their sources from various parts of the building's interior space: from the near zone with radio wave propagation similar to free space conditions; and from the far zone, for which, along with attenuation of radio waves due to internal obstacles (walls, ceilings, etc.), a "quasi-waveguide" propagation of radio waves along corridors and industrial premises is also possible in certain directions. An essential regularities in the creation of statistical characteristics of the ensemble of these electromagnetic fields have also been discovered and described. Results obtained can be used at EMC analysis of systems using corresponding frequency bands on a primary and secondary basis and at estimation of electromagnetic safety of population at the full-scale implementation of 4G/5G wireless services.**

Keywords—mobile communications, 4G, 5G, building, indoor space, user equipment, radio waves propagation, electromagnetic, radiation, background, safety, EMC

I. INTRODUCTION

Fast evolution of systems and services of cellular (mobile) communications (CC) to the fourth (4G) and fifth (5G), and in near future to the sixth (6G) generation, is accompanied by an extremely intensive growth in spatial density of users equipment (UE), which electromagnetic radiation (EMR) provides the variety of wireless services. This density can reach 10^5 UE/km^2 in 4G networks (IMT-Advanced), 10^6 UE/km^2 in 5G networks (IMT-2020) and 10^7 UE/km^2 in prospective 6G networks [1, 2]. Due to a wide variety of functions and data transmission traffic volumes of various UE with approximately the same EMR power (21-24 dBm [3]), their average EMR power (as well as the relative duration of UE being in the radiation mode) during business-hours of CC networks, may differ by several orders of magnitude. Nevertheless, due to the very high declared 4G/5G/6G UE spatial density, the total intensity of the radiofrequency electromagnetic background (EMB RF) generated by them, even may exceed the accepted maximum permissible levels and pose a danger to the population.

An obvious fundamental feature of the spatial concentration of UE for the implementation of the set of 4G/5G/6G services is their volumetric (3D) distribution in multi-storey residential, office and industrial buildings. At the same time, both in the main recommendations [1, 3, etc.], and in known studies of processes of EMB RF formation by radiations of UE and base stations (BS) of CC [4-6, etc.], only 2D spatial location of EMR sources is considered. In particular, this can be explained both by the difficulties of objective analysis of radio wave propagation (RWP) processes inside buildings [7], and by the fact that the implementation of main scenarios of 5G is only at an early stage. Nevertheless, the problem of analyzing characteristics of the EMB RF created by the set of 4G/5G/6G UE radiations at the random UE distribution over the interior space of buildings is of increasing interest from the point of view of electromagnetic safety of population and electromagnetic ecology of habitat, as well as EMC of systems using CC frequency bands on a primary and secondary basis.

The goal of this paper is a system analysis of general regularities of the formation of statistical characteristics of electromagnetic environment (EME) in premises, which is created by a multitude of EMRs of spatially distributed UE with various degrees of saturation by them the internal space of buildings, and substantiation of the technique for assessing the intensity of EMB RF created by emitting UE in multi-storey buildings.

II. EMB RF SYSTEM ANALYSIS TECHNIQUE

In considered case, the analysis of EMB RF intensity is carried out according to the traditional technique [4-6], based on the use of well-known empirical models of RWP in building's inner space and the uniform random distribution of radiating UE in this space, as well as on the determination of the EMB RF intensity in the form of a scalar sum of values of power flux density (PFD) of electromagnetic fields (EMF) created by separate UE at the observation point (OP).

A. Models of RWP Conditions

Taking into account the extremely complex nature of RWP conditions in buildings, the following well-known empirical models of these conditions were used:

1) Generalized empirical model [7, 8] of attenuation of radio waves in buildings:

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$$L_t(R) = L_C\left(\frac{R}{R_0}\right)^{\nu}, \quad L_C = const\,, \tag{1}$$

where ν determines the rate of increase in radio waves attenuation with an increase in the OP distance and, in an averaged form, reflects the influence of internal obstacles (walls, floors, equipment, etc.) on the RWR process; R_0 - "reference" distance, determined taking into account the peculiarities of the OP location inside or outside the building. For "quasi-waveguide" RWP along corridors and walls of premises within the line of sight $\nu \approx 1.6 \ldots 1.8$, for the main part of UHF range and the lower part of SHF range $\nu \approx 4 \ldots 6$ for RWP inside office and residential buildings , $\nu \approx 2 \ldots 3$ for RWP in industrial buildings, $\nu \approx 3 \ldots 5$ for outdoor OP near the earth's surface in conditions of shading by urban buildings [8]. The R_0 value is determined empirically for each case, taking into account the relative position of OP and the internal room surfaces or shading building elements.

2) An empirical "Ericsson indoor path loss model" [9], which is a development of model (1) for multi-storey buildings and radiation frequencies close to 900 MHz (which roughly corresponds to UE EMR frequencies in mMTC 5G networks [3] and in LTE frequency bands No. 5, 6, 8, 12-14, 17-20, 26-28, 44, 68 [10]), and characterized by different values of ν at different distances between OP and UE:

$$Z = \left\{ \begin{array}{ll} \dfrac{P_e}{4\pi R^2}, & R_0 \le R \le R_1; \\ \dfrac{R_1 P_e}{4\pi R^3}, & R_1 \le R \le 2R_1; \\ \dfrac{2R_1^4 P_e}{\pi R^6}, & 2R_1 \le R \le 4R_1; \\ \dfrac{2^{13} R_1^{10} P_e}{\pi R^{12}}, & 4R_1 \le R \le R_M; \end{array} \right\} \tag{2}$$

where Z [W/m^2] is a EMF PFD, created in OP by UE with the equivalent isotropic radiated power (EIRP) P_e located at a distance R from the OP; $R_0 = 1$ m, $R_1 = 10$ m, $R_M >> 4R_1$.

B. Model of UE and OP spatial allocation

We consider a random distribution of a set of UE with an average density ρ_e [UE/m^3] in the inner space of a multi-storey building. In the room in which the OP is located, there is also a certain amount of UE; for which conditions of RWP to the OP can be considered as free-space RWP (upper expression in (2)). For EMRs of UE outside this room, but located inside the building, models (1), (2) with parameter $\nu \neq 2$ must be used. Model shown in Fig. 1 is a primary model of mutual spatial allocation of the OP and of the multitude of UE.

In this model, R_m is the "reference" distance limiting the space of free RWP between OP and UE, R_M is the radius of UE radio visibility from OP; for more distant UEs, levels of their EMFs in the OP is less than the threshold level corresponding, for example, to the threshold sensitivity of radio reception. For EMFs of UE located in an annular space bounded by the inner and outer radii R_m and R_M , conditions of RWP in OP are complicated due to the presence of numerous obstacles in the form of walls, floors, etc.; for these conditions, as a rule, $\nu > 2$.

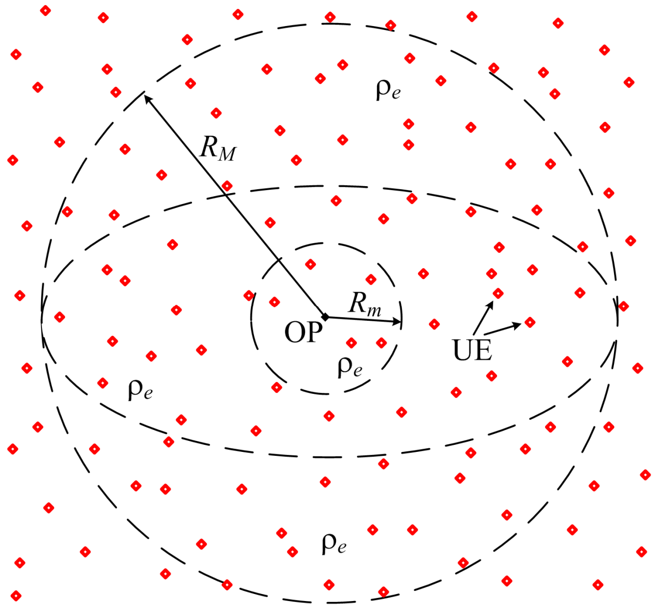

Fig.1. 3D-model of the spatial location of the observation point (OP) and the set of point radiating objects "UE".

III. Analysis Results

For the adopted models of UE spatial distribution and conditions of RWP between UE and OP, as well as on the assumption that all UEs have omni-directional EMR with an average EIRP P_e, the following characteristics have been determined:

1) Probability distribution density (p.d.d.) $w_{NZ}(R)$ of the distance R from the OP to the UEs, located uniformly randomly with an average density ρ_e in the "near zone" - a spherical region of radius R_m :

$$w_{NZ}(R) = \frac{3R^2}{R_m^3}, \quad 0 \le R \le R_m\,. \tag{3}$$

2) P.d.d. $w_{FZ}(R)$ of the distance R from the OP to the UEs, located uniformly randomly with an average density ρ_e in the "far zone" - a spherical region of radius R_M except for the inner "near zone" space of radius R_m:

$$w_{FZ}(R) = \frac{3R^2}{R_M^3 - R_m^3}, \quad R_m \le R \le R_M\,. \tag{4}$$

3) P.d.d. $w_a(Z)$ and math. expectation value $m_{1a}(Z)$ of PFD values Z of EMFs created in OP by UEs of the near zone:

$$w_a(Z) = \frac{3Z_m^{\frac{3}{2}}}{2Z^{\frac{5}{2}}}, \quad m_{1a}(Z) = 3Z_m\,, \tag{5}$$

$$Z \ge Z_m = \frac{P_e}{4\pi R_m^2}\,.$$

Hyperbolic distribution (5) of degree -5/2, obtained for 3D-model of a random uniform spatial distribution of point EMR sources, has a first initial moment, as opposed to a similar hyperbolic distribution of degree -2, obtained for a 2D-model of their spatial distribution [4,5]. This avoids a number of limitations and make it possible to define the average EMB RF level as the product of the magnitude of average PFD created by a separate UE at the OP, and the average number of UEs in the considered spatial domain.

4) The average level $Z_{\Sigma 1UE}$ [W/m^2] of the EMB RF component in OP formed by radiations of the near zone UE, is determined as a scalar sum of the average values of PFD of these EMRs in the OP:

$$Z_{\Sigma 1UE} = m_{1a}(Z) N_{VS} = \frac{\rho_e P_e^{\frac{3}{2}}}{2\sqrt{\pi Z_m}}, \tag{6}$$

$$N_{VS} = V_S \rho_e = \frac{\rho_e}{6\sqrt{\pi}} \cdot \left(\frac{P_e}{Z_m}\right)^{\frac{3}{2}},$$

where N_{VS} is the average number of radiating UEs in a spherical region of radius R_m and volume V_S.

5) For UEs located in the far zone, the RWP model (1) takes the following form:

$$Z = \frac{R_m^{\nu-2} P_e}{4\pi R^{\nu}}, \quad R_m \le R \le R_M . \tag{7}$$

6) P.d.d. $w_a(Z)$ and math. expectation value $m_{1b}(Z)$ of PFD values Z of EMFs created in OP by set of UE of the far zone:

$$w_b(Z) = \frac{3}{\nu Z^{(3+\nu)/\nu}\left(Z_0^{-3/\nu} - Z_m^{-3/\nu}\right)}, \tag{8}$$

$$Z_0 = \frac{R_m^{\nu-2} P_e}{4\pi R_M^{\nu}} \le Z \le Z_m ;$$

$$m_{1b}(Z) = \begin{cases} \dfrac{3 Z_m^{\frac{3}{\nu}} Z_0^{\frac{3}{\nu}} \left(Z_m^{\frac{\nu-3}{\nu}} - Z_0^{\frac{\nu-3}{\nu}}\right)}{(\nu-3)\left(Z_m^{\frac{3}{\nu}} - Z_0^{\frac{3}{\nu}}\right)}, & \nu \ne 3 \\ \dfrac{Z_m Z_0}{Z_m - Z_0} \ln \dfrac{Z_m}{Z_0}, & \nu = 3 \\ \approx \dfrac{3}{(\nu-3)} Z_0^{\frac{3}{\nu}} Z_m^{\frac{\nu-3}{\nu}}, & \nu \ne 3, Z_m >> Z_0 \\ \approx Z_0 \ln \dfrac{Z_m}{Z_0}, & \nu = 3, \quad Z_m >> Z_0 \end{cases}; \tag{9}$$

7) The average level $Z_{\Sigma 2UE} = m_{1b}(Z) \cdot N_{VSR}$ of the EMB RF component in OP formed by radiations of the far zone UE, is also determined as a scalar sum of the average values of PFDs of these EMRs in the OP:

$$Z_{\Sigma 2UE} = \begin{cases} \dfrac{\rho_e P_e^{\frac{3}{2}} Z_m^{\frac{6-3\nu}{2\nu}} \left(Z_m^{\frac{\nu-3}{\nu}} - Z_0^{\frac{\nu-3}{\nu}}\right)}{2(\nu-3)\sqrt{\pi}}, & \nu \ne 3 \\ \ln \dfrac{Z_m}{Z_0} \cdot \dfrac{\rho_e P_e^{\frac{3}{2}}}{6\sqrt{\pi Z_m}}, & \nu = 3 \end{cases}, \tag{10}$$

$$N_{VSR} = V_{SR} \rho_e = \frac{4}{3}\pi\left(R_M^3 - R_m^3\right) = \frac{\rho_e P_e^{\frac{3}{2}} Z_m^{-\frac{3}{2}}}{6\sqrt{\pi}} \left(\left(\frac{Z_m}{Z_0}\right)^{\frac{3}{\nu}} - 1\right),$$

where N_{VSR} is the average number of radiating UEs in the far zone of the V_{SR} volume.

8) The total average EMB RF intensity $Z_{\Sigma UE}$ created in OP by radiations of the set of UE from the entire spherical region of their radio visibility from the OP is determined in an obvious way: $Z_{\Sigma UE} = Z_{\Sigma 1UE} + Z_{\Sigma 2UE}$. Of interest is the ratio $Z_{\Sigma 1UE} / Z_{\Sigma 2UE}$, which characterizes the relative contribution of radiations of UE from the far zone to the total EMB RF level in the OP:

$$\frac{Z_{\Sigma 1UE}}{Z_{\Sigma 2UE}} = \begin{cases} \dfrac{\nu-3}{\left(\dfrac{Z_m}{Z_0}\right)^{\frac{3-\nu}{\nu}} - 1}, & \nu \ne 3 \\ \approx \nu - 3, & Z_m >> Z_0, \quad \nu > 3 \\ \approx (3-\nu)\left(\dfrac{Z_0}{Z_m}\right)^{\frac{3-\nu}{\nu}}, & Z_m >> Z_0, \nu < 3 \\ \dfrac{3}{\ln\left(\dfrac{Z_m}{Z_0}\right)}, & \nu = 3 \end{cases}, \tag{11}$$

The calculated dependences (11) on the Z_m/Z_0 ratio for various ν are shown in Fig. 2. These dependences illustrate the presence of asymptotes determined by the second and third rows of (11) at $Z_m >> Z_0$, and also allow one to estimate approximately the relative contribution to the EMB RF intensity in OP of the set of near zone UE EMRs, which is predominant only at $\nu>4$, and at $\nu<4$, as a rule, is significantly inferior to the contribution of far zone UE EMRs.

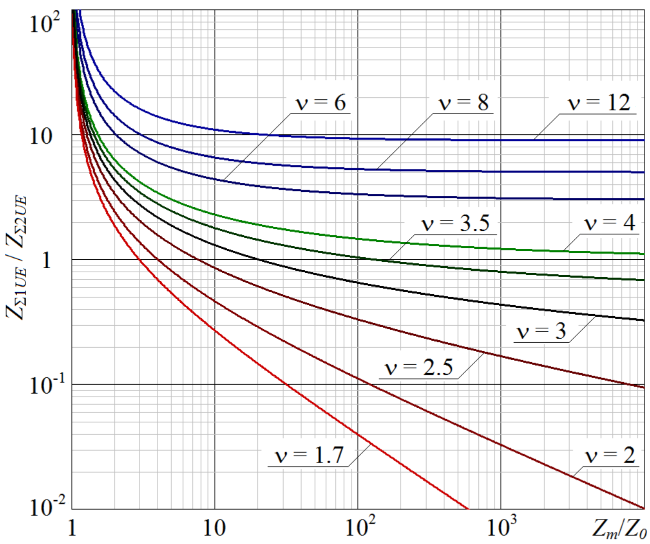

Fig.2. Dependences of $Z_{\Sigma 1UE} / Z_{\Sigma 2UE}$ on the ratio Z_m/Z_0 for different RWP conditions inside building (different ν).

9) In practice, the multitude of UE in the OP vicinity may not be located throughout the entire volume of the near zone, but near its inner surface. If all N_{VS} radiating UEs of this region are located evenly along its inner surface at a distance

R_m from the OP, then the average level $Z_{\Sigma SUE} = N_{VS}Z_m$ of the EMB RF created by them in OP is determined by the relation

$$Z_{\Sigma SUE} = \frac{\rho_e P_e^{\frac{3}{2}}}{6\sqrt{\pi Z_m}} = \frac{Z_{\Sigma 1UE}}{3} = EML_{SE} = \frac{N_{VS}P_e}{4\pi R_m^2}, \qquad (12)$$

where EML_{SE} is the equivalent average electromagnetic loading on the surface of the inner spherical boundary of the near zone, which is equal to the ratio of the total average power of the UE radiation of this zone per unit area of this boundary.

10) If radiating UE are distributed randomly uniformly with an average density ρ_e not over the entire spherical region with parameters R_m, R_M, but only in a certain solid angle Ω (Fig. 3) formed by the corresponding subtend surfaces $A_{\Omega 1}$ and $A_{\Omega 2}$ of an arbitrary configuration, then relations (5), (6), (8), (9) and (11) remain valid, and the average intensities (6), (10) of EMB RF components in the OP should be multiplied by the ratio $\Omega/4\pi$.

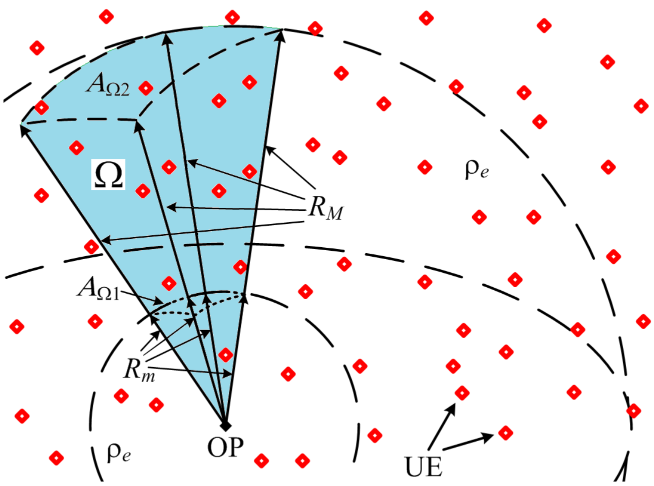

Fig.3. Model of the spatial location of OP and the set of UEs in the solid angle Ω, formed by the subtend areas $A_{\Omega 1}$ at the border of the near zone and $A_{\Omega 2}$ at the border of the far zone.

This allows us to propose a general technique for determining the EMB RF intensity in OP located inside a building of complex shape, based on the approximation of separate sections of the inner surface S_{NZ} of the premises in which the OP is located (the inner surface of the near zone), and of the outer surface of the building S_{FZ} in which the considered premises is located (the outer surface of the far zone). This approximation is carried out by the corresponding parts of the inner and outer spherical surfaces, subtending the corresponding solid angles Ω_j, $j\in[1, J]$ (Fig. 4). In general case, the total average intensity $Z_{\Sigma UE}$ [W/m^2] of the EMB RF created in OP by radiations of the set of UEs located in building can be determined as follows:

$$Z_{\Sigma UE} = \sum_{j=1}^{J} Z_{\Sigma 1UEj} + \sum_{j=1}^{J} \Sigma_{2UEj}\ , \qquad (14)$$

$$Z_{\Sigma 1UEj} = \frac{\rho_{e1j}P_{e1j}A_{sj}}{4\pi R_{mj}}\ ;$$

$$Z_{\Sigma 2UEj} = \frac{\rho_{e2j}P_{e2j}\left(R_{mj}R_{Mj}^{\nu_j-3} - R_{mj}^{\nu_j-2}\right)A_{Sj}}{4\pi(\nu_j-3)R_{Mj}^{\nu_j-1}}, \quad \nu_j \neq 3;$$

$$Z_{\Sigma 2UEj} = \frac{A_{Sj}\rho_{e2j}P_{e2j}R_{mj}}{4\pi R_{Mj}^2} ln\frac{R_{Mj}}{R_{mj}}, \quad \nu_j = 3,$$

where P_{e1j}, ρ_{e1j} и P_{e2j}, ρ_{e2j} are the average EIRP and the average spatial density of UE, respectively, in the solid angle Ωj in the space of the near zone, bounded by the subtend surface A_{sj}, and in the space of the far zone between the subtending surfaces A_{sj} and A_{Sj}, respectively. $Z_{\Sigma 1UEj}$, $Z_{\Sigma 2UEj}$ are components of the average EMB RF level, created by UEs of near and far zones, respectively, of the Ωj solid angle. The values of each of the elementary solid angles Ω_j can be chosen arbitrarily, taking into account the configuration of the near zone and the building itself, the degree of uniformity of the UE spatial distribution and the dependence of the RWP parameter ν on the orientation of Ωj, $j\in[1,J]$.

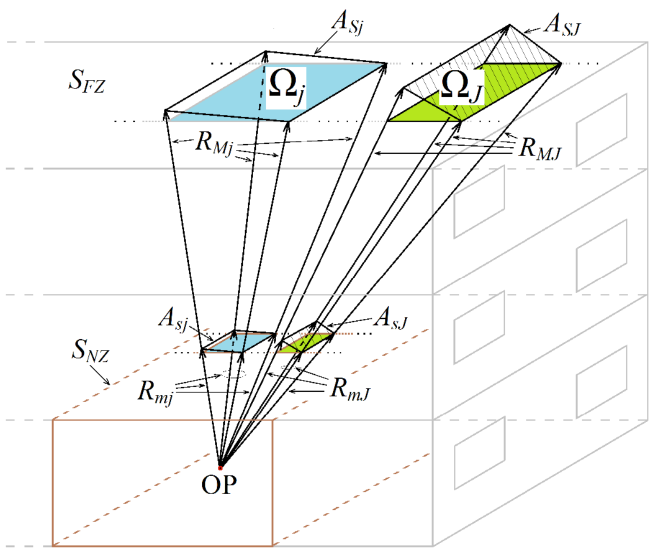

Fig.4. Element-wise analysis of the building internal space in separate solid angles Ω_j, $j\in[1, J]$, the subtend areas of which A_{Sj}, A_{sj} approximate the corresponding parts of external surfaces of the building and the internal surfaces of the premises.

11) Taking into account that model (1) is used not only for indoor RWP conditions, but also for outdoor RWP conditions in urban area [8], this technique can also be used to estimate the EMB RF intensity in OP located outdoors in a dense urban territory.

In addition, when analyzing the EMB RF intensity created by UE radiations in dense multi-storey urban development, it should be taken into account that, due to the large dynamic range of UE EMF levels in OP, the internal spaces of separate solid angles Ω_j, $j\in[1,J]$, whose contributions to the formation of the total EMB RF intensity are summarized in (14), can sequentially cover parts of the internal spaces of several neighboring buildings and the external space between them, as shown in Fig.5. These buildings may differ in architecture, physical properties of the interior space and, as a result, in the internal RWP conditions (the value of parameter ν). Thus, the contribution of UE radiations located in the inner space of a separate solid angle Ω_j to the average EMB RF intensity in OP should be determined as the sum of contributions of UE radiations from separate parts of this space, characterized by volumes V_1, V_2, V_3, ..., by UE spatial densities ρ_1, ρ_2, ρ_3, ... (and in general, their average EIRP), as well as the parameters ν_1, ν_2, ν_3, ... of RWP conditions. As a result, the component of the total average intensity $Z_{\Sigma j}$ of EMB RF created in OP by radiations of a set of UE of a separate solid angle Ω_j can be determined as follows:

$$Z_{\Sigma\Omega j} = \sum_{k=1}^{K} N_{VSk}\, m_{1k}(Z), \quad N_{VSk} = \frac{\rho_k \Omega_j}{3}\left(R_k^3 - R_{k-1}^3\right), \tag{15}$$

where R_k, R_{k-1} are distances from the OP to the k -th and k-1 -th boundaries B_k, B_{k-1} of the corresponding part of the space with the volume V_k in the solid angle Ω_j (Fig. 5); the average PFD values $m_{1k}(Z)$, created in the OP by UE radiations from a part V_k of the space, can be determined using (5), (9).

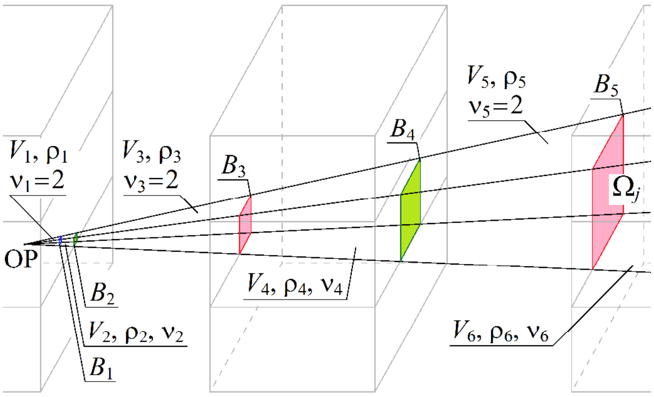

Fig.5. Estimation of the contribution to the EMB RF of radiated UEs, located in the solid angle Ω_j in the internal space of several adjacent buildings and the external space between them. B_1 - boundary between the near and far zones, B_2, ... , B_5 - boundaries between solid angle elements with different RWP conditions and different characteristics of the UE ensembles.

12) For the empirical model (2) of RWP conditions [9], which refines model (1) for multi-storey buildings and EMR frequencies close to 900 MHz, and for 3D model of UEs and OP spatial distribution inside building, similar to the given in Fig.1, the following expressions are obtained for the total average EMB RF intensity created in OP by the set of radiating UE, distributed randomly uniformly with a density of ρ_e over the internal space of the building:

a) for a part of space limited by distances $1\text{m} \le R \le 10\text{m}$ from OP to UEs, for which RWP conditions in free space (ν=2) and statistical models (3), (5) with parameter R_m=R_1 are valid, the average level $Z_{\Sigma1}$ of the EMB RF component created in OP by radiated UEs of this region is determined by the relation similar to (6):

$$Z_{\Sigma1} = \frac{\rho_e P_e^{\frac{3}{2}}}{2\sqrt{\pi Z_{1m}}}, \quad Z_{1m} = \frac{P_e}{4\pi R_1^2}; \tag{16}$$

b) for a part of space limited by distances $10\text{m} \le R \le 20\text{m}$ from OP to UEs, for which RWP conditions with parameter ν=3 and statistical models (4), (8) with parameters R_m=R_1 R_M=R_2 are valid, the average level $Z_{\Sigma2}$ of the EMB RF component created in OP by radiated UEs of this region is determined by the relation similar to the second line of (10):

$$Z_{\Sigma2} = \frac{\rho_e P_e^{\frac{3}{2}} \ln 8}{6\sqrt{\pi Z_{1m}}} \approx 0.69 Z_{\Sigma1}; \tag{17}$$

c) for a part of space limited by distances $20\text{m} \le R \le 40\text{m}$ from OP to UEs, for which RWP conditions with parameter ν=6 and statistical models (4), (8) with parameters R_m=R_2, R_M=R_3 are valid, the average level $Z_{\Sigma3}$ of the EMB RF component created in OP by radiated UEs of this region is determined by the relation similar to the first line of (10):

$$Z_{\Sigma3} = \frac{7\rho_e P_e^{\frac{3}{2}}}{96\sqrt{\pi Z_{1m}}} \approx 0.15 Z_{\Sigma1}; \tag{18}$$

d) for a part of space limited by distances $R > 40$m from OP to UEs, for which RWP conditions with parameter ν=12, and statistical models (4), (8) with parameter R_m=R_3 and parameter R_M corresponding to the distance of the UE radio visibility boundary from OP for the level Z_0, are valid, the average level $Z_{\Sigma4}$ of the EMB RF component created in OP by radiated UEs of this region is determined by the relation similar to the first line of (10):

$$Z_{\Sigma4} = \frac{\rho_e P_e^{\frac{3}{2}}}{192\sqrt{\pi Z_{1m}}} \approx \frac{Z_{\Sigma1}}{96}, \quad R_M = 2\left(\frac{2R_1^{10} P_e}{\pi Z_0}\right)^{\frac{1}{12}}, \tag{19}$$

Thus, if RWP conditions inside the building correspond to the empirical model (2), then the main contribution to the EMB RF intensity created by the entire set of radiated UEs, distributed randomly uniformly over the internal space of a multi-storey building, is made by UEs of the near zone with free space RWP, and the contribution of UEs outside this zone does not exceed 3 dB:

$$Z_{\Sigma UE} = Z_{\Sigma1} + Z_{\Sigma2} + Z_{\Sigma3} + Z_{\Sigma4} \approx 1.85 Z_{\Sigma1}. \tag{20}$$

IV. Conclusion

1) For well-known empirical models of RWP conditions in buildings and a uniform volumetric random distribution of radiating UE of CC over the internal space of a multi-storey building, a number of important relationships have been obtained that characterize the processes of EME formation in buildings by these EMR sources:

relations (5), (8), (9) for statistical characteristics of the ensemble of EMF PFD values created in OP by UE radiations from different parts of the building's internal space: from the near zone (the room in which the OP is located), with the free-space conditions of RWP between UEs and OP (ν=2); and from the far zone (building space outside the near zone), for which, along with an additional attenuation of radio waves (ν> 2), due to the internal obstacles (walls, ceilings, etc.), a "quasi-waveguide" RWP from UEs to OP is also possible in some directions (ν<2) along corridors and lengthy premises;

relations (6), (10), (15)-(19), which make it possible to estimate the average levels of separate EMB RF components, defined in a form of scalar sums of average values of corresponding PFD ensembles, created in OP by UE radiations as from the near zone, and from the far zone as a whole or its separate parts, characterized by different RWP conditions (different ν);

relations (11) for the ratio of intensities of EMB RF components of the near and far zones. The estimates obtained indicate that for $\nu>3$ this ratio asymptotically approaches the value of $\nu-3$. At $\nu>4$, the contribution of EMB RF component of the near zone turns out to be predominant, but at $\nu < 4$ it is significantly inferior to the contribution of UE radiations of the far zone, and at $\nu<3$, the EMB RF intensity in the indoor OP is practically determined by the totality of radiations of the far zone UE;

2) A general technique is proposed for estimating the EMB RF intensity in an OP located in a complex-shaped building, based on the approximation of separate sections of the inner surface of premises in which the OP is located and the outer surface of the building, in the inner space of which radiating UEs are randomly distributed. This approximation is carried out by corresponding similar sections of internal and external spherical surfaces, subtending the corresponding solid angles, in the separate elements of the space of which different spatial UE densities and EIRP, as well as various RWP conditions are possible. In general case, the total average intensity of the EMB RF created in OP by radiations of the set of UE located in the building is determined by the ratio (14).

Since model (1) is used to describe the RWP conditions not only inside buildings, but also outside them in urban space, this technique can also be used for averaged system estimations of EMB RF intensity in OP, located both inside and outside premises, with random 3D placement of point EMR sources with different spatial density and different EIRP in dense multi-storey urban development both inside and outside premises.

An important circumstance that made it possible to determine the average EMB RF level in the form of sums (14), (15) of the average values of its components is the existence of the first initial moment (6) of the hyperbolic probability distribution (5) of PFD levels created in OP by UE radiations from the near zone at 3D spatial random UE distribution (a similar probability distribution of degree -2 for 2D spatial random UE distribution has no initial moments). This determines a use of the methodical technique based on the representation of the space surrounding OP as a set of individual solid angles, which in total make up the full solid angle 4π.

3) Expressions (6), (10), (14), (15)-(20) can be used to analyze the total intensity of EMB RF created in multi-storey buildings by a variety of EMR sources - various 4G/5G UEs operating in the "quasi-continuous" FDD mode, as well as stationary pico-BS of CC (wireless broadband access points, etc.), which makes it possible to perform generalized system assessments of the electromagnetic safety of population in these buildings, as well as the EMC of these EMR sources in relation to systems operating in the CC frequency bands on a secondary basis.

P.d.d. (5), (8) of the random PFD values of EMFs created in OP by UEs, for which RWP conditions (2), (7) are valid, are obtained from (3), (4) according to the known rule for determining the p.d.d. for a random variable, functionally transformed using (2), (7).

For EMB RF formed in 5G networks by a set of pulse radiations of mMTC UE in the form of a Poisson flow of random electromagnetic pulses [3], expressions (5), (8) allow us to determine the p.d.d. of levels of separate pulses, and ratios (6), (10), (14), (15)-(19) allow to estimate their total average power in various conditions.

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