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: