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Electromagnetic Environment Estimation for an Inclined Roof with LTE Antenna

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Abstract. In many countries the expansion of digital share in the overall economy has led to a density increase of BTS antenna of cellular network in major cities. The electromagnetic background strengthening in residential areas of the cities is the negative consequence of the process. In turn, the intensity increase of antenna-emitted electromagnetic fields impacts the health of population, such as the elderly, children, and sick, who are permanently located near BTS antenna disposition. In the paper the research results are given for the influence of roof architectural constructions (its slope) and aggregate BTS antenna location on rooftop sanitary protection zones where the population is strictly prohibited. It is shown that the rooftop can be considered safe for people for an indefinite time if antenna is installed at the upper part of the roof, as close to the upper edge as possible and if transmitter operates with a halved power.

1. Introduction

High data rates of broadband cellular communication systems of LTE-Advanced and WirelessMAN-Advanced (WiMAX) standards, reaching up to 100 Mbps for high-mobility users in trains or cars and 1000 Mbps for low mobility users (pedestrians and fixed users) [1, 2], allowed to significantly expand Internet scope of use. According to [3], in 2017 the mobile service covers 84% of the European Union population and provides online purchases (66% of users), online banking (59% of users), electronic invoices (18% of European enterprises), and filling out online forms without paper copies (34% of Internet users). The significant level of Internet technologies penetration into business, which exceeded 60% in some developed countries, was the reason to set out the digital economy as a new level of the economy development in 2009. Digital technologies are the main driving force of this economy, they provides the country's GDP growth by 0.4..1.4% for every 10% increase in broadband Internet networks users [6]. Consequently, it is projected [6] that the digital economy share in global GDP will reach 30-40% by 2030 with the continued growth in the number of Internet users. The economic efficiency of the digital economy has made it a priority in many states of the world [7, 8].

One of the end-to-end digital technologies underlying the digital economy development is wireless broadband Internet access technologies that provide high data rates, including for mobile users [7]. Their implementation is directly related to the use of new communication technologies that provide high data rates (LTE-Advanced, 5G), as well as the direct expansion of existing and modernized cellular networks [8]. In turn, a significant increase in the number of radio-emitting objects (BTS antenna) will subsequently strengthen the electromagnetic background at their locations [9-11]. Despite the fact that the BTS antenna radiation is non-ionizing and has a relatively low power level, it is long-term and continuous [9, 12]. On the other hand, it is impossible not to use electromagnetic fields in wireless communication, for they determine the way information is transmitted. Within this context, the questions arise on the degree of BTS antenna radiation adverse effect on people health, especially the elderly, children, and sick, which are permanently located close to antenna disposition in residential blocks, as well as on the protection methods.

2. The standards of the maximum permissible level of antenna radiation

Population protection from electromagnetic field exposure is regulated in the legal field by state standards for electromagnetic safety [13-16]. However, the risk of radiation exposure affecting human health is assessed differently in Western and Russian standards. For example, in Western standards [10, 11, 13, 14, 17] the maximum permissible level of such radiation is set at 100 mW/cm2, which is three orders of magnitude higher than the level assigned in Russia [10, 11, 15, 16]. Such a large discontinuity in values is due, as it is shown in [11], to the Western standards opted-out the long-term (from 1 hour to 10 years) non-thermal impact of low-intensity electromagnetic fields, that characterize non-ionizing fields of BTS antenna, on human body. According to M S Markov [18], it happened due to the necessity of large investments for long-term medical research, as well as lobbying for the interests of large industrial concerns. The expansion of Western radioelectronics market in Russia has ended with an adoption of the Eurasian Economic Community standard close to the Western one in 2013 [19]. At present time, however, this standard is valid only in the Republic of Belarus; for in Russia it was recommended to exclude it from the State standards list on October 13, 2017 [20].

The results of independent statistical studies published by the scientists from different countries, for example, [11, 21-25] may be the key argument in the dispute over the standards. These results have confirmed the correlation between the BTS network expansion and the incidence rates in their locations. Thus, in [24] it was shown that the correlation coefficient between the investigated incidence rates of oral cavity and pharynx oncology and the number of cellular communication BTS was equal to 0.696 ± 0.227 for the study period, which indicates a noticeable positive dependence [26]. In [21], a reliable relationship has been found between the BTS network expansion and such diseases as ear diseases, acute myocardial infarction, child congenital anomalies of the circulatory system, and a number of others. In statistical studies reports [31] not only this relationship has been confirmed, but the recommendations on sanitary protection zones allocation near cellular communication antennas have been provided for residential areas. Russian standards [14, 15] limit the sanitary protection zones (SPZ) measured at height of 2 m above ground or above top floor of building if antenna is located at the rooftop. These limits correspond to maximum permissible level of 10 μW/cm^2. Moreover, the requirement of socially-oriented electromagnetic monitoring is introduced to explain the current state of the electromagnetic situation in residential areas to the public intelligibly [10, 27].

3. Result presentation requirements for socially-oriented monitoring

The visualization of the electromagnetic field distribution with sanitary protection zone boundaries separation at 10 μW/cm^2 is one of the most simple and usable by non-specialists ways of representing the electromagnetic environment near the BTS antenna within the socially-oriented monitoring framework.

The easiest was to obtain information for real-time electromagnetic situation representation is the computational prediction method [27]. It is based on strict electrodynamic models, as well as "preventive principle", a worst-case design, which is recommended by the World Health Organization [28]. It this case it is impossible to use any standard solutions because antenna locations differ from each other. In [16, 27], a method is given for calculating the electromagnetic situation near antennas of various designs. However, for the presentation generality, the calculation is carried out at individual points and not in the investigated planes, as it is recommended. In [29, 30], the results of the electromagnetic environment estimation near GSM and LTE BTS antennas are presented. The main recommendations on the location of aggregate BTS antenna atop of high-rise building roof are formulated in the same papers. The electromagnetic field distribution in the horizontal plane 2 m above the roof surface was considered as the field of study. Thus, the hypothesis on the possibility of non-professionals admittance to the roof with a radiating antenna was tested. This is a relevant problem for many architects are currently carrying out projects of residential buildings with rest areas located on roofs [31]. The location recommendations for BTS antenna set on the roof of a building, which were formulated in [29, 30], are now being successfully implemented. In particular, to exclude the necessity of sanitary protection zones creation within the roof, antenna set is located at the roof edge along the perimeter; the radiation maxima is oriented away from the roof for each antenna. Thus, the sanitary protection zone is created near the building in the antenna vertical plane.

Despite the results of the studies listed above and published in [29, 30], the question about the roof geometry influence on the electromagnetic background close to cellular BTS antenna installed on it remains unknown.

4. Results and Discussion

4.1. Climate dependence of roof geometry

Roof geometry is defined by climate and architectural solutions [32]. Thus, flat roofs are common in arid regions, pitched roofs are characteristic for regions with a large amount of precipitation. In urban areas, the most common are the single-, double- and four-slope roof shape. So, the single- and double-pitched roof shapes are the most simple and cost-effective with the minimum requirements for their construction. The four-slope roof (hipped one and its types - tent and gambrel) withstands large wind loading and is suitable for large houses. The pitch angle of the roof is determined by the amount of precipitation. In areas with frequent rain, the minimum roof pitch is recommended to be around $45° – 60°$ [33]. For areas with strong winds and abundant solar periods, low-inclined roofs with low wind profile are used; in addition, they reduce the heated surface as much as possible. The pitch angle for such structures varies in the interval of $9° – 20°$. As it is shown in [33], the general value of pitch angle lies within the interval of $20° – 45°$. The angle reference is shown on Figure 1. Snow load on the roof structure is reduced at such pitch angles, for the snow cover slides from the roof by gravity. Figure 2 shows the option of placing a set of BTS antennas on an inclined roof.

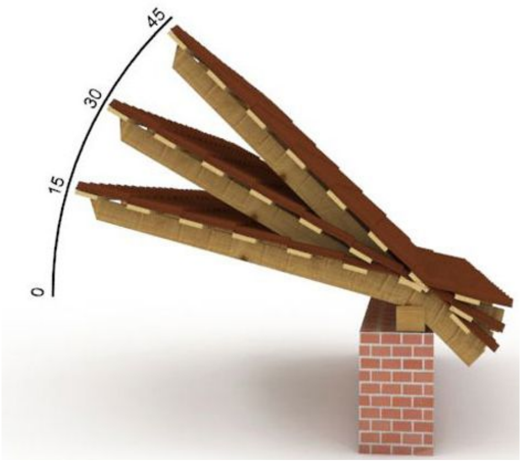

Figure 1. Angle reference for roof inclination.

Figure 2. An example of BTS antenna placement on the inclined roof.

4.2. Electric parameters of cellular communication BTS antenna

When conducting an electromagnetic environment study near the BTS antennas of LTE systems installed on inclined roofs, the same parameters as for a flat roof shape in [29] can be used. In the simulation, the total power was assumed to be 46 dBm or 40 W; it corresponds to the recommendations from [9], which limits the BTS total power in urban conditions to 43-47 dBm. As in [29], it was considered that the BTS LTE consisted of 9 identical ASTRA antennas, which have a main-lobe width of 36 degrees in the horizontal plane and 18 degrees in the vertical plane. Antenna gain was assumed to be 13 dB. Two frequency bands were used: 790-960 / 1700-2700 MHz.

4.3. Electromagnetic exposure estimation by forecast calculation

Using the software developed by the authors, the electromagnetic situation was evaluated near LTE antennas installed on the inclined rooftop. The roof corners were given by coordinates $A(0,0,0)$, $B(-7,4,0)$, $C(-13.5,-4,0)$, $D(-2.5,-8.5,0)$ as it had been done in [29] for GSM antenna. The building height was not taken into account, since the studies were carried out in the horizontal plane only. For simulation antenna phase center was placed in two points with coordinates $\Phi(-5.5,1,3.8)$ and $\Phi(-9.5,-3.0,3.8)$. In the first case, antenna was located in the lower part of the inclined roof; in the second case - at the top part. For the study pitch angles were assumed to be equal to 0, 15, 30 and 45 degrees, which corresponds to the optimal roof inclinations for the central Russia.

Energy flux density distribution was calculated in a horizontal plane 2 meters above the roof surface; two values of transmitter power were considered, 40 W and 20 W. These power levels correspond to the power of BTS transmitters under operating and reduced power conditions [29].

Table 1 lists the maximum values of the energy flux density calculated for the both antenna locations described above, near the lower and top edges of the roof.

Table 1. Maximum values of the energy flux density depending on antenna location and roof inclination

Total transmitter power, W	Antenna location	Maximum value of energy flux density, μW/cm^2			
		Roof pitch angle, degree			
		0	15	30	45
40	1	19.54	626.16	2643	9507.00
	2	16.15	28.38	22.63	22.54
20	1	9.77	313.08	1321.00	4754.00
	2	8.08	14.09	11.32	11.27

Table data analysis shows that if BTS antenna is located at the top of the inclined roof (option 2) the energy flux density level on the roof is safe for any pitch angle from the considered range. This effect is also related to the antenna pattern shape in the vertical plane. In the lower part of the roof, the calculated points are located at high altitudes, where the energy flux density value is much lower. If the antenna is located the lower part of the inclined roof (option 1), the electromagnetic environment on the roof is dangerous for people. In this case, the electromagnetic field distribution 2 m above the roof surface at the various pitch angles for transmitter power of 40 W is shown in Figure 3.

Data analysis for both table and Figure 3 shows that if BTS antenna is located in the lower part of the inclined roof (option 1), the rooftop electromagnetic environment is dangerous for people. At the same time, the energy flux density level exceeds the permissible level of 10 μW / cm2 [15] by several orders of magnitude. Safe zones are located directly under the antennas (safe zone radius is about 3 m). As it was noted earlier, for example, in [29, 30], these zones appear due to the narrow-beam shape of the antenna directivity pattern in the vertical plane.

Thus, if it is necessary to place cellular antennas on inclined roofs, they are to be located as close to the top edge as it is possible to ensure people safety.

5. Conclusion

The expansion of cellular communication networks within the framework of digital economy development programs and the associated increase in the BTS density in residential areas of large cities lead to a significant strengthening of the electromagnetic background. Because it is impossible to eliminate the harmful factor, which is the electromagnetic field emitted by the antenna, the problem of electromagnetic monitoring in residential areas arises including socially-oriented electromagnetic monitoring as its subtype. This subtype allows real-time result representation for the electromagnetic environment estimation at the locations of cellular BTS antennas and thus excludes the social tension. The electrodynamic models for the electromagnetic environment estimation have to consider the aspects of roof geometry, such as pitch angle; pitch angle magnitude depends on climate and architectural solutions.

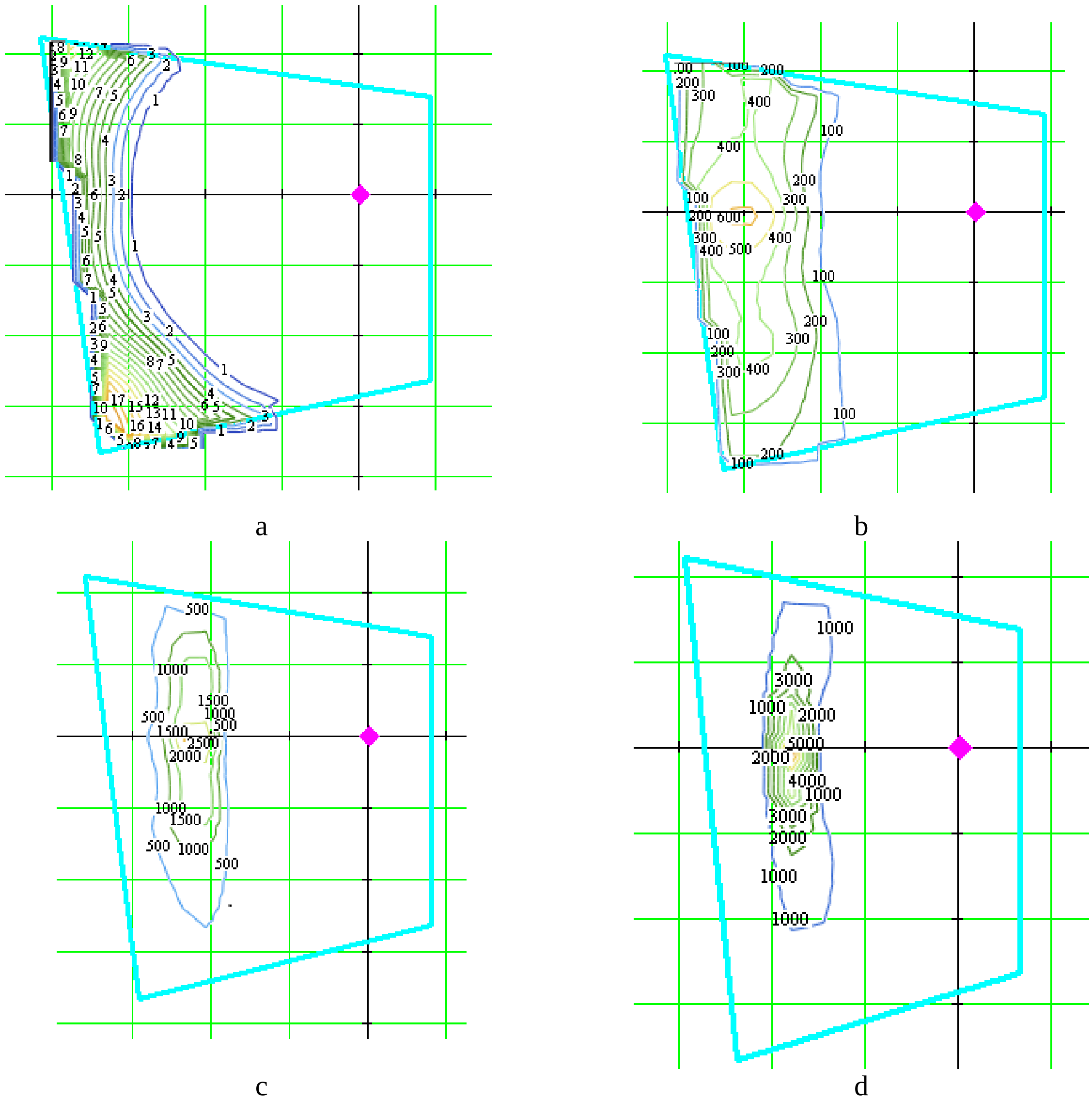

Figure 3. Energy flux density distribution near cellular communication antenna for some roof pitch angles: a – $\alpha = 0°$; b – $\alpha = 15°$; c - $\alpha = 30°$: d - $\alpha = 45°$

The electromagnetic environment analysis for the inclined roof with BTS LTE antenna at some values of roof pitch angle showed that the roof could be considered safe for people for an indefinite time, if the antenna was located as close to the top edge of the roof as possible and the transmitter operated with half the power. Under normal operating conditions, the sanitary protection zones are located on the inclined roof even if the set of antennas is placed close to the top edge.

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