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EMF Exposure Modelling in the Vicinity of the Radiocommunication Stations

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***Abstract*—Due to rapid development of wireless systems and future implementation of the 5G system, it is necessary to increase number of the stations and/or number of radio emissions in current and new mobile service frequency bands. For each of the new or modified radio installation in Poland the Electromagnetic Field (EMF) strength levels has to be evaluated and measured/validated in accordance with allowable limits. In the paper the model of estimation of total EMF levels coming from mobile base stations radio emissions to be used for estimation of the whole country territory EMF levels is proposed. Results of preliminary analysis were also shown on practical examples. The model presented in the paper can be used for initial finding of possible places where exist the risk of exceedance of the maximum exposure limits and for analysis of potential radio network development taking into account current regulatory limits. The model will be used in computerized system SI2PEM which is developing in Poland for EMF levels controlling and validation purposes.**

***Keywords*—EMF exposure limits, electric field strength distribution, 5G, EMF modelling, SI2PEM**

I. INTRODUCTION

Constant development of radiocommunication systems resulting, among others, in the growing demand for bandwidth and capacity of the mobile networks, currently mostly 2G, 3G and 4G LTE as well as in future also 5G networks, entails the need to expand mobile networks infrastructure by increasing the number of stations and the number of emissions in the radio networks, especially in an urban environment by the Mobile Network Operators (MNO's). The consequence of the expansion of the network and number of stations is the increase in the total electromagnetic field (EMF) strength generated by the newly created or modified installations, which bring an additional EMF to the existing one, thereby bringing the resultant field strength value closer to the values of the allowable limits that coming from applicable environmental protection standards, e.g. in Poland Ministry of Environment Regulation [1]. Modeling of electromagnetic field distributions in vicinity of the transmitting station is a complex issue, which has been constantly developed since the beginning of the discovery of the phenomenon of electromagnetic propagation. Mathematical models in idealized conditions based on solving complex mathematical formulas considering electromagnetic field phenomena (i.e. Maxwell's equations) have been known for over 100 years, but their practical implementation for carrying out detailed propagation and field analyzes in complex radiating environments has only been implemented for several decades thanks to the use of advance algorithms and advance computer methods with powerful computer systems that allow practical implementation of such complex and time-consuming calculations. While in ideal media (i.e., e.g. vacuum) and with known, ideal theoretical radiation sources (i.e., e.g. elemental dipole), a detailed analysis of the fields formed around them is possible, in real conditions of antenna structures and real media, as well as practical obstacles on the propagation way, it is necessary to make use of estimation solutions that give good approximations, which results from the complexity of the problem and limited access to detailed data that can be used for proper modeling. Results of such modelling should have good correlation with practical measurements which are performed in practical cases. Currently, two types of measurements are conducted in the field of testing the electromagnetic field in the environment in Poland: control measurements in accordance with [1], which are performed by accredited testing laboratories during the first start-up of a given installation or modification of its operating parameters, and continuing monitoring measurements conducted by: Chief Inspectorate of Environmental Protection, Inspection of Environmental Protection and Voivodship Inspectors of Environmental Protection at control points with the methodology in accordance with [2]. Carrying out measurements entails both time and cost constraints related to their executions in the real specific field conditions. An alternative to the measurements can be detailed computer simulations that will not only allows to verify the value of the generated field strength from existing or modified stations, but also permits to analyze the field strength at the radio network planning stage, before starting the installation and measurements. They can also be used as a preliminary step in determining the places where there may be a potential issue of exceedance of the permissible field strength for later measurement verification and determining the available network expansion potential in a given system service area. For such reasons in Poland the SI2PEM computerized system is developing, which will include on-line access to EMF simulation results in whole country territory as well as to the measurements results of all measuring laboratories through dedicated web site.

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II. SIMULATION MODEL AND ITS RESULTS

The presented model for simulation of the electric field strength distribution generated by the MNO's radiocommunication stations consists and require three basic elements: data to be used for the analysis, EMF field strength propagation modeling and visualization and mapping of the results in 2D or 3D space, taking into account clutter, buildings and ground terrain. The three elements of the simulation model are described in more details in the following sections.

A. Data for the analysis

In connection with the phenomenon of aggregation of the EM fields from of all of the Base Terrestrial Stations (BTS's), it is necessary to take into account not only the given stations in the given analysed area but also the surrounding. The presented simulation model assumes the analysis of the generated and aggregated electromagnetic field strength by all radiocommunication stations from an area measuring around 2x2 km, while a detailed analysis taking into account the impact of all of the stations is performed for an area of 1x1 km. In Figure 1 it is shown in blue (2x2 km area), in which stations are qualified for analysis that can have a direct impact on the resultant field strength value in the target analysis area (violet color area – 1x1km). The whole country territory will be split into the 1 x 1 km basic areas and calculation will be performed for each of the area and results will be then aggregated. In order to model of the electromagnetic field strength distributions as closely as possible around all the base stations, detailed radiation characteristics of antenna systems (divided into individual sectors) are used. Calculations of the EM field strength distribution can be performed with any resolution, however for practical reasons (calculation time and size of the results obtained) the optimal resolution is a resolution of 0.5-1 m for the vertical and horizontal axis (in the 1x1km analysis area). The minimum height of the analyzed layer (vertical axis) is determined on the basis of the minimum height in a given area obtained from the GUGIK NMT resource (Numerical Terrain Models) – a map resource representing the height of the terrain itself [in m asl] without altitude data of land cover (e.g. forests, buildings etc.), while the maximum height (vertical axis) to

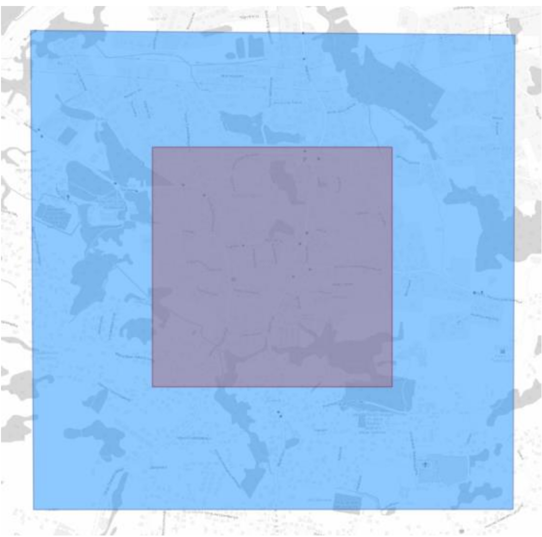

Fig. 1. An example of the selection area of the stations (blue) and the area for determining the EMF (violet)

which calculations should be made (the highest building or the highest situated area) is obtained from the GUGIK NMPT resource (Numerical Land Cover Models) – the resource map representing the total height of the area along with the height of coverage. The GUGIK is polish Head Office of Geodesy and Cartography and is responsible for preparing and maintenance of the NMT and NMPT maps with highest available in country resolutions coming from laser scanning method (LIDAR).

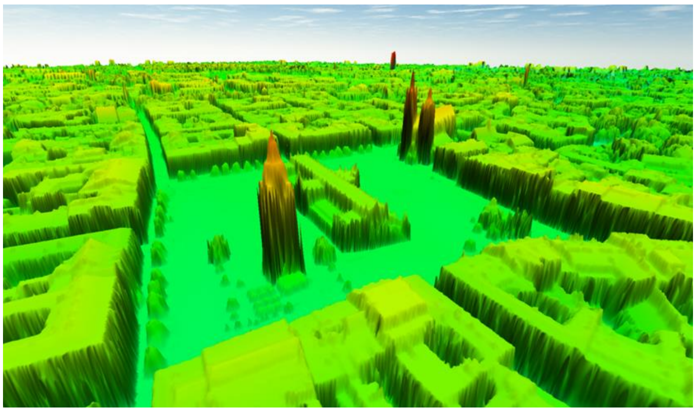

Fig. 2. Visualization of sample NMPT map resources for part of the Kraków city centre area (land cover)

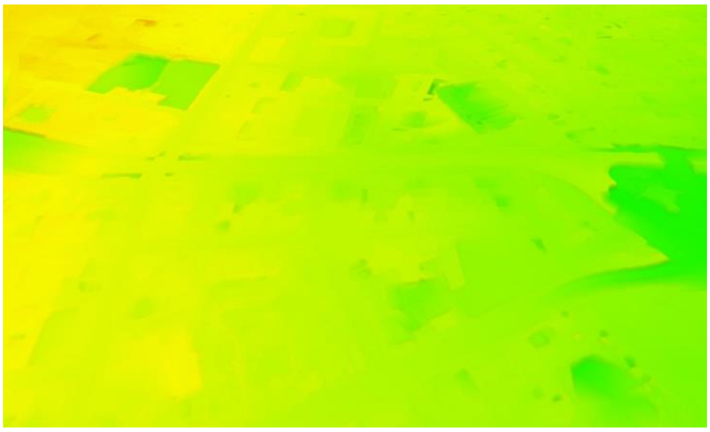

Fig. 3. Visualization of sample NMT map resources for part of the Kraków city centre area (pure land without clutter cover)

B. EMF modelling

In theory, mathematical modelling with detailed analysis of EMF in the vicinity of the stations is possible and there are detailed methods allowing such process (e.g. The method of moments (MoM) [7] or Finite-difference time-domain (FDTD) [8, 9]). However, for the methods, detailed structure and electric parameters of radiated elements are needed for proper modelling. In real cases, in practice, there are complex antenna systems and structures (combined and closed panel antennas), usually without known detailed parameters and its detailed structure. Antenna manufacturers then provide only the physical dimensions of the antenna system and basic parameters for modeling distributions of fields in the far zone, i.e. emission bands, antenna radiation characteristics and antenna gain for a given bands. For this reason, in practice, for commercial off the shelf (COTS) antennas only approximate modeling is possible to model EMF in vicinity of the stations, based only on known, published parameters provided by antenna manufacturers.

In the EMF modeling for the SI2PEM system, the basic point model of the radiation source presented in ITU-T K.70 Recommendation (01/2018 [3] and PN-EN 62232 [4] was used to determine the distribution of the electromagnetic field strength in the vicinity of the station's antenna systems. This model assumes that for the far radiation zone the transmitting antenna is represented by a point source located at the point corresponding to the electrical center of the antenna and the defined radiation characteristics of the transmitting antenna are known. At the first stage, a classical free space loss (FSL) propagation model was used. FSL for the far zone, in next stages of the project will be supplemented also with additional elements (i.e. radiowave diffraction attenuation analysis) in order to improve its results quality. In the far field area for a plane wave, the power density is given by the formula:

$$\boldsymbol{S} = \frac{\boldsymbol{P_{EIRP}}}{\boldsymbol{4\pi R^2}} \cdot \boldsymbol{F}(\boldsymbol{\theta}, \phi) \qquad (1)$$

where:

S - power density equivalent to a plane wave in a given direction [W/m^2],
$\boldsymbol{P_{EIRP}}$ – equivalent isotropic radiated power [W],
R - distance from the radiation source [m],
$\boldsymbol{F(\theta,\phi)}$ - normalized gain of the transmitting antenna, determined numerically, for a given elevation angle θ, in the range -90 ° ÷ 90 ° and azimuth angle ϕ, in the range 0 °- 360 °

As a far field of radiation source, points located at a distance greater than the value of d_r determined by the relationship [4] are assumed:

$$\boldsymbol{d_r} = \mathbf{max}\,(\mathbf{3}\lambda, \boldsymbol{2D^2}/\lambda) \qquad (2)$$

where:

λ	wavelength [m]
D	maximum linear dimension of the transmitting antenna [m]

In the case of modeling the distribution of electromagnetic fields in the near (radiated) zone, the relationships [4] were used:

a) for omnidirectional antennas (3)

$$\hat{S}\,(r) = \frac{P_{av}}{\pi \cdot r \cdot L \cdot cos^2(\gamma) \cdot \sqrt{1+\left(2\frac{r}{r_0}\right)^2}}, \quad r_0 = \frac{1}{2} D_A L\, cos^2(\gamma)$$

b) for sector antennas (4)

$$\hat{S}\,(r,\phi) = \frac{2\,P_{av}\,2^{-\left(2\frac{\phi}{\Phi_{3dB}}\right)^2}}{\Phi_{3dB} \cdot r \cdot L \cdot cos^2(\gamma) \cdot \sqrt{1+\left(2\frac{r}{r_0}\right)^2}}, \quad r_0 = \frac{\Phi_{3dB}}{12} D_A L\, cos^2(\gamma)$$

where:
Ø - is the azimuth angle for sector antennas
r – is the distance from the center of the antenna
P_{av} - is power available at the antenna input (W);
L - antenna physical dimension (m);
D_A - Antenna maximum gain (without units);
Φ_{3dB} - Antenna beamwidth (3 dB) (radian);
γ - The angle of the electric tilt of the antenna (radian).

Using the above equations and taking into account the real radiation characteristics of the transmitting antennas together with their physical orientations i.e. azimuths, elevation angles, ranges of electrical and mechanical tilts and physical dimensions of the antennas, the field strength value is calculated at a point from a single source (from each cellular base station/sector/channel), and then the aggregated value of the electric field strength E_w (derived from N single sources) is determined according to the relationship:

$$E_w = \sqrt{\sum_{i=1}^{N} E_i^2} \qquad (5)$$

Each source means single band/sector/antenna emission, so in practice for “a single BTS station” many sources are describing the total BTS station emissions (different bands, sectors and antennas at a single BTS mast).

Simulation results of the electromagnetic field strengths are generated to three types of result data:

a) A matrix grid of points that enables the reading and visualization of field strength values with a resolution of 0.5-1 m for the analyzed area (1x1 km) and at any height in the range of the minimum and maximum values for the analyzed area.

b) Spatial distribution of field strength for a given limit value of electromagnetic field strength. It allows visualization of the distribution of the electromagnetic field strength for a given limit value (e.g. 7 V / m, 27.5V/m, 61 V/m etc.)

c) Spatial distribution of field strength for a given limit value of electromagnetic field strength and for a range of altitude e.g. 0.3-2 m a.s.l. (space available to the public).

d) Flat 2D distribution of areas where a given limit value of electromagnetic field strength is exceeded in space available to the public. e.g. maximum from the range 0.3-2 m a.s.l.

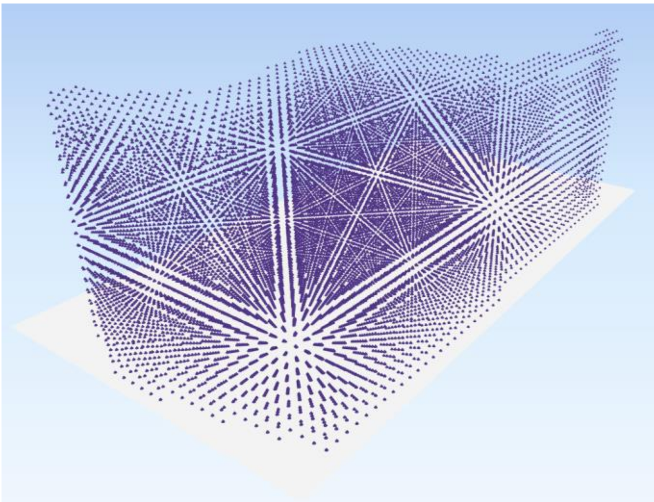

Fig. 4. Spatial matrix grid of points representing the aggregated field strength with a resolution of 0.5-1m vertically and 0.5-1m horizontally

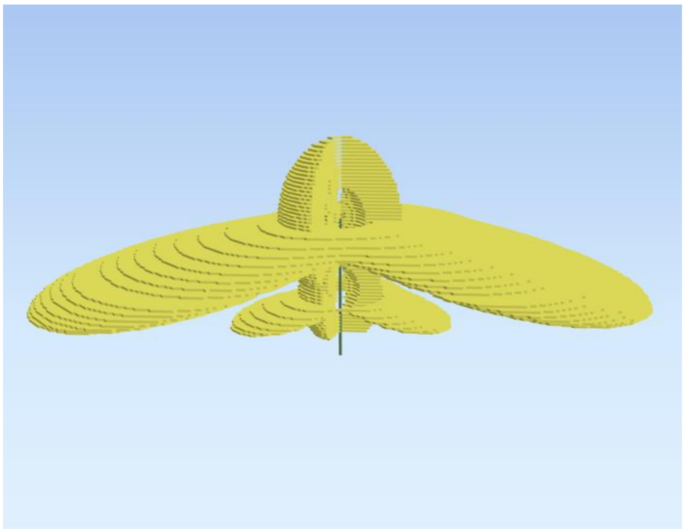

Fig. 5. Visualization of the 3D spatial distribution of the electromagnetic field strength for a given limit value (e.g. 7 V/m).

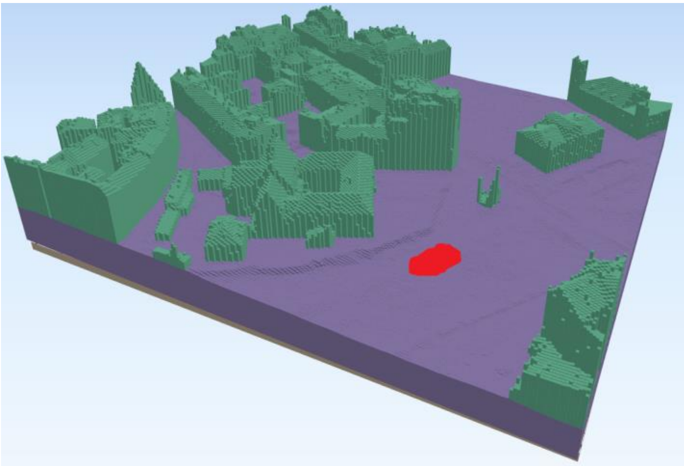

Fig. 6. Spatial distribution of field strength exceeded for a given limit value (7 V/m) of electromagnetic field strength and for a height range of 0.3-2 m a.s.l. (red area)

C. Results mapping in a real environment

The obtained results of electromagnetic field strength distributions for the purposes of verification of potential exceedances of the permissible electromagnetic field strength should be mapped also in the real environment, which is represented by the detailed digital terrestrial maps (in case of Poland GUGiK NMT and NMTP resources) in the case of spatial visualization and in plane morphological map resources (BDOT10k in Poland) in the case of visualizing the distribution of field strength for two-dimensional flat visualization. An examples of spatial and two-dimensional visualization are presented in Figures 5 - 10.

The use of detailed high-resolution map resources (such as GUGiK) and calculated high-resolution spatial aggregated electric field strength distribution allows for the assessment of the possibility of exceeding the permissible electric field strength both: in the space available to the society resulting from EMF limits standards at ground level (in places 0.3-2 m available to the public), as well as in places accessible for people at higher heights such as roofs, terraces or walls of buildings.

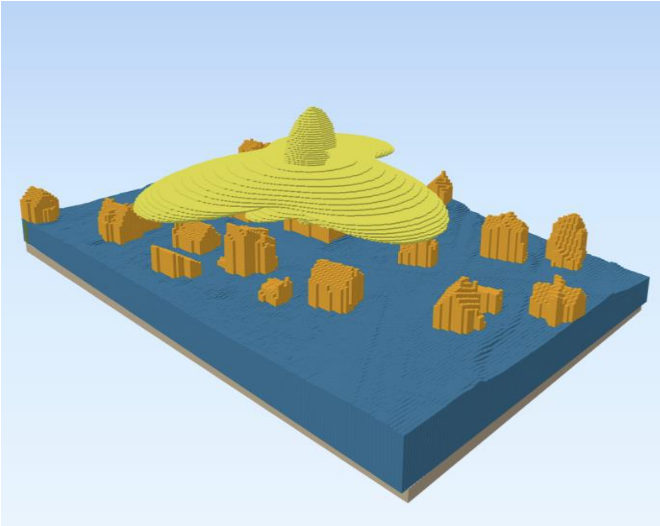

Fig. 7. Visualization of the 3D spatial distribution of electromagnetic field strength for a given limit value, taking into account surrounding terrain and buildings.

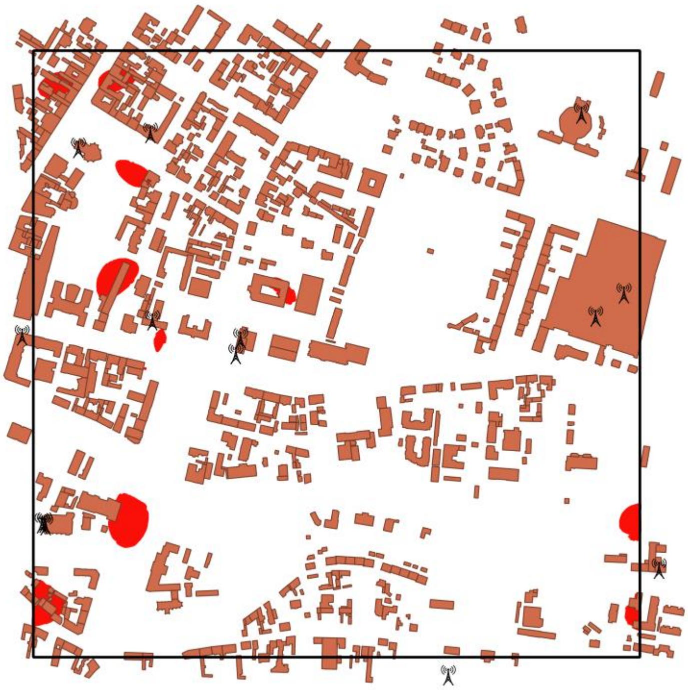

Fig. 8. Visualization of an example flat 2D electromagnetic field strength distribution for the selected exceeded limit value of (7 V/m) for a height in the range of 0.3-2 m a.s.l. at a map including a plane buildings (BDOT10K). Places with estimated values > 7 V/m are marked in red.

In the presented examples the first step results calculated for the estimation of the aggregated field strength were show. In the analysis it was assumed that all of the BTS's were working in the full load occupation conditions where maximum radiated power of all stations is taken into account. This gives maximum possible EMF level conditions results which is rather theoretical maximum then practical and measurable ones. In practise all of the analysed stations are working according with current, less occupation then maximum, so in order to be much more closer to the practical measurements results the tuning process of the calculation model will be needed. For such cases practical traffic data and power load for occupation of each BTS's sector in practical usage will be taken into account, based on real

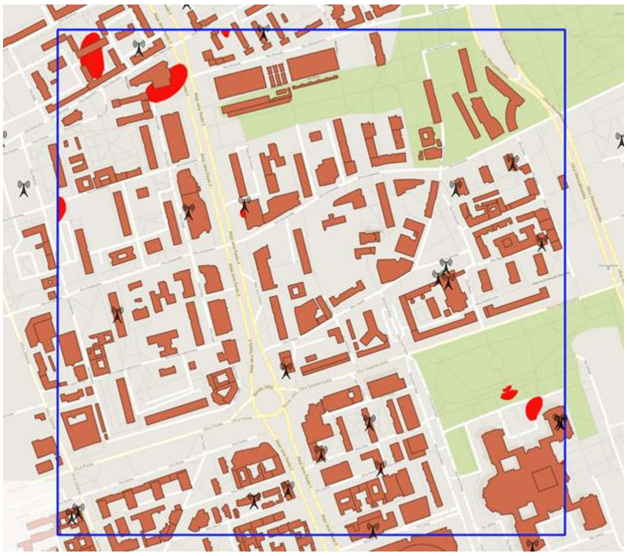

Fig. 9. Visualization of an example of electromagnetic field strength distribution for the selected exceeded limit value of (7 V/m) for a height in the range of 0.3-2 m a.s.l. at a city centre map. Places with estimated values > 7 V/m are marked in red (city centre above and village area below).

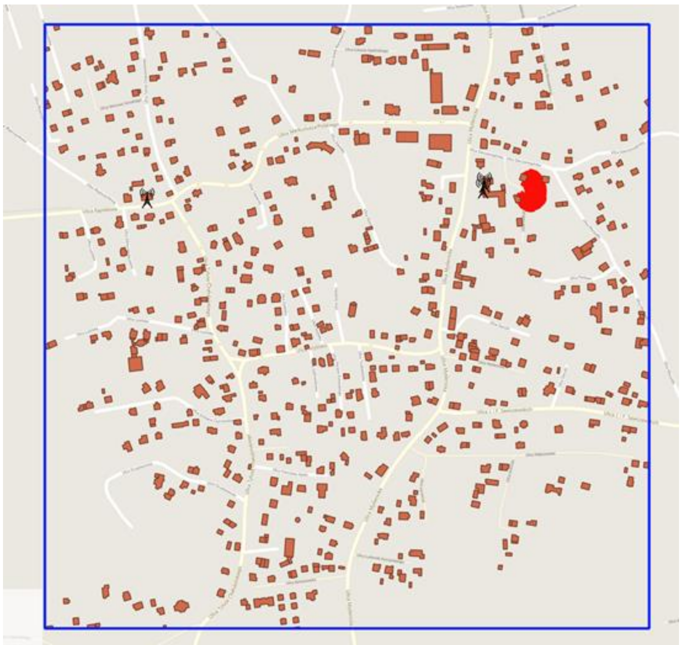

Fig. 10. Visualization of an example of electromagnetic field strength distribution for the selected exceeded limit value of (7 V/m) for a height in the range of 0.3-2 m a.s.l. at a village region map. Places with estimated values > 7 V/m are marked in red (city centre above and village area below).

MNO's data allowing that simulation results which will be very close to the measurements data ones. Finally all the simulation results will be calculated for the whole Poland country territory with resolution 1x1m and will be presented free for public through Internet access to the SI2PEM computerized system web site developed for such purposes. Also in the SI2PEM system the measurements data results will be also presented, so people and networks operators will be able to compare simulated and measured results in they interesting areas. For the operators special additional software tool will be implemented, allowing them for testing addition or modification of the BTS station and then checking results for the electromagnetic environment change. This will be used for the determining potential issues with areas where EMF levels may exceed allowable limits.

CONCLUSIONS

The presented simulation model together with the method of visualization of its results can be used to modelling and presenting of the electromagnetic field strength distributions for the current radio frequency bands as well as for a new frequency bands related to the planned implementation of the 5G systems in future, taking also into account the conditions arising from the restrictions of network development associated with limits of permissible electric field strengths [1]. Preliminary analyzes of the EMF estimation were performed using real data from network operators (MNO's) for example areas. The preliminary model, after appropriate calibration according to the practical measurements results – taking into account the average load and volume of traffic at stations, as well as taking into account detailed wave propagation analyzes mechanism including additional phenomena (such as e.g. diffraction and/or radiowave reflection), can be used as a tool for typing areas, in which the electric field may be exceeded in practice, and thus indicate the measuring places at the points most exposed to the occurrence of increased field strength. For such reasons the use of the model can be useful not only for the environmental analysis of existing BTS's installations, but also by the network operators at an early stage of planning the network development as a method of verifying the value of the electromagnetic field strength (e.g. for national EMF protection levels as well as those used in other countries) in the event of congestion and extension of existing BTS's infrastructure. By providing access to detailed data on networks and installations of other operators, it is possible to simulate the resultant field strength value taking into account all existing emissions. In the next stage, it will be possible to consider even giving up costly and time-consuming measurements campaigns, for examples in cases where the simulation results show that in places accessible to the public the accident level of EMF does not exceed the set value (e.g. 70% of the applicable standard) under estimation of developed network sites. Such actions may facilitate and accelerate building of the 5G radio network in the whole country. The developed SI2PEM computerized system can be proposed for such purposes. The system is planned to be finished and available to the public in the next year, so its practical results can be checked and evaluated by all the network operators as well as all the society.

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