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SIMULATION OF ELECTROMAGNETIC FIELD PROPAGATION GENERATED BY RADIO WAVES FROM ANTENNAS FOR MOBILE CELLULAR COMMUNICATIONS

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Abstract. The methods frequently employed for predicting the intensity of an electromagnetic field in urban localities are based on empirically established factors. In order to predict the intensity of the electromagnetic field in an adjacent transmitter zone and on building facade flats, the method of simulating of direct visibility rays seems to be a suitable tool. With reference to the introduced method, the article describes the offered algorithm applied for performing experimental calculations. Also, the method of monitoring has been based on the calculated values of the intensity of the electromagnetic field.

Keywords: 3 D ray intersection point, electromagnetic field propagation, mobile cellular communications, non-ionizing radiation.

1. Introduction

In process of designing the limits of sanitary area coverage of mobile cellular communications base station antenna, the task of prediction of electromagnetic field propagation is being solved. Initial data for solving the this task are diagrams and tables of directivity diagrams in vertical and horizontal planes, data of antenna mounting position. This data is provided by the manufacturer of mobile cellular communications antenna. The obtained information faces difficulties in considering the main physical objects like relief, buildings, etc. limiting electromagnetic field propagation. Moreover, predicting the values of the electromagnetic field on building facades flats and calculating the net values of propagation from several antennas are also demanding tasks.

Computer simulation tools are very useful for obtaining a more accurate prediction. For this purpose, the problem of generating the form of a radio field (intensive electromagnetic field) has to be solved foreseeing a possibility of employing 3 D GIS data. The article provides technique for simulating electromagnetic field propagation using an antenna by applying a geometrical method – generate of direct visibility rays. The task for determining the distance of ray propagation according to the established strength of radiation is being solved. As a result of simulation, the points of the parameter indicating the intensity of the electromagnetic field are obtained at the intersection with 3 D objects.

2. Review of Previous Researches

As radio wave propagation in the atmosphere is difficult to describe, most of the created expressions employ empirically determined factors. The application of such methods was described by R. V. Pocius (2005) and D. Radis (2001). P. Baltrėnas and R. Bučkus (2009) presented the methods and results of the measurements of indoor non-ionizing radiation. To unify expressions employed for predicting radio wave propagation, International Telecommunication Union recommended using the interpretation and values of parameters predicting electromagnetic field propagation generated from antennas for mobile cellular communications (Propagation Data and Prediction Methods… 2009a, b; Calculation of Free-Space… 1994; Propagation Prediction 2009).

The carried out simulation it is crucial to determine the value of radiation strength of the electromagnetic field generated by the antenna in space, in a specific direction from the antenna. According to the traditional method, such value is the sum of radiation values of the parameters evaluated in horizontal and vertical planes, i.e. presenting the specific values of angles. T. Vasiliadis *et al.* (2005), F. Gil *et al.* (2001) introduced technique for calculating the strength of antenna signal when the significance of net values was different. L. Thiele *et al.* (2009) conducted an experiment validating the fact that the prediction was more realistic when radiation value was employed and calculated using a traditional method in a specific direction.

Waslon *et al.* (2002) presented a method for simulating the electromagnetic field based on turning radiation directivity diagrams around axis z in the vertical plane and evaluating directivity diagrams in the horizontal plane. Hae-Won Son, Noh-Hoon Myung (1999) described a method of hybrid 3 D ray simulation – the combination of geometrical and imagery methods.

3. Algorithm Description

This section describes an algorithm for predicting the value of electromagnetic field radiation generated by the antenna. The geometrical method has been employed for ray simulation. Electromagnetic field propagation has been simulated applying the method of free radio wave propagation in space. The rays, the propagation distance of which is determined applying limited signal strength, have been simulated by the algorithm. The strength is selected according to the receiver or other characteristics of the task being solved.

Initial data on calculation cover the coordinates of antenna centre x, y, z, the direction of the most intensive radiation (azimuth), antenna tilt in vertical and horizontal planes of the directivity diagram, antenna radiation rate, effective radiated power of the antenna. The following expressions are employed for conversion between the effective isotropic radiated power of the antenna (EIRP) and the effective radiated power of the antenna (ERP):

$$EIRP\ (dBw) = ERP\ (dBw) + 2.15, \tag{1}$$

$$EIRP\ (dBm) = ERP\ (dBw) + 30. \tag{2}$$

Wave length is calculated according to the traditional formula: wave length = speed of light / frequency.

Equivalents to every position in the horizontal plane of the directivity diagram are traced in the vertical plane of the same diagram. When applying the known values of antenna orientation and the angle of tilting for the obtained values, the direction of the running ray is determined in space.

Ray propagation is simulated according to the calculation of the free propagation of radio waves in space:

$$L = 20\log\left(\frac{4\pi d}{\lambda}\right), \tag{3}$$

where L – propagation loss (dBm); d – propagation distance (m); λ – wave length (m).

The limit value of the strength of receivable radio signal $E_{lim.}$ is selected empirically. Limit value depends on the solved task when the evaluation of radio signal strength of a specific value has no sense, i.e. when receiver sensitivity is lower than signal strength in the area of measurement. After selecting value $E_{lim.}$, limit loss of signal propagation in space is calculated as follows:

$$L_{lim.} = EIRP - E_{lim.} - L_{dir.}, \tag{4}$$

where $L_{lim.}$ – limit loss of signal propagation in space (dBm); $EIRP$ – effective isotropic radiated power of the antenna (dBm); $E_{lim.}$ – the limit value of receivable radio signal strength (dBm); $L_{dir.}$ – loss of signal propagation in space in direction n (dBm).

The loss value of signal propagation in direction n is calculated by summing up loss values in horizontal and vertical planes:

$$L_{dir.} = 10^{L_{horiz.}/10} + 10^{L_{vert.}/10}, \tag{5}$$

where $L_{dir.}$ – the loss of signal propagation in direction n (mW); $L_{horiz.}$ – the loss of signal in direction n in the horizontal plane (dBm); $L_{vert.}$ – the loss of signal in direction n in the vertical plane (dBm).

Maximum ray length is calculated in case of no obstacles:

$$d_{\max} = 10^{\left(-20Log10(4) - 20Log10(\pi) + 20Log10(\lambda) + L_{dir.}\right)/20}, \tag{6}$$

where λ – wave length (m); $L_{dir.}$ – the loss of signal propagation in direction n (dBm).

The determined parameters are sufficient to calculate coordinates x, y, z at the end of the ray. As the task requires determining the points of ray intersection with objects, 3 D spatial analysis is applied to the other part of the algorithm. It is traced, whether the ray intersects any of the adjacent objects (for instance, the building). In order to reduce the number of calculations, first, all the buildings intersected by the 2 D ray are determined. During the next stage, all defined buildings are checked – coordinates x, y, z of the nearest 3 D intersection point are searched (Fig. 1).

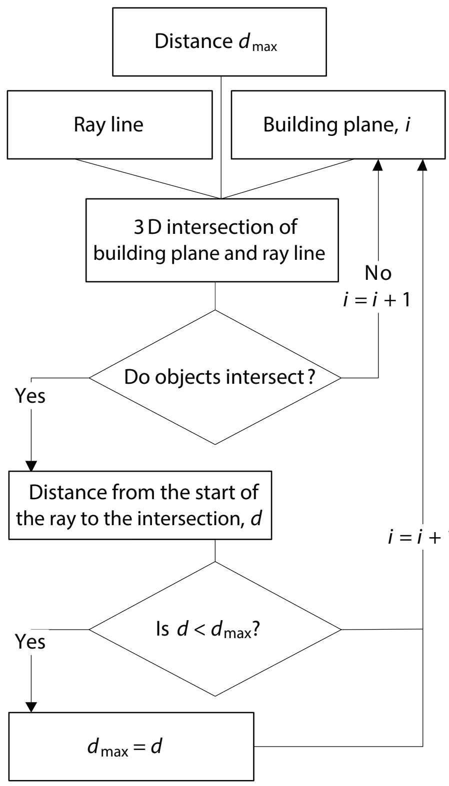

Fig. 1. Algorithm scheme for determining the nearest intersection point

The parameters required for further calculations are established for every determined point: the loss of radiated power up to the intersection with the object, radiated power at the intersection point, the diameter of the circle of the intersection with the object, distance to the antenna, antenna coordinates *x, y, z*.

$$L_{int.} = 20Log10(4\pi) \times d_{\min} / \lambda, \quad (7)$$

where $L_{int.}$ – the loss of radiated power up to the intersection with the object (dBm); $d_{\min}$ – wave length to the nearest obstacle (m); λ – wave length (m).

$$E_{int.} = EIPR - L_{int.} - L_{dir.}, \quad (8)$$

where $E_{int.}$ – radiated power at the intersection point (dBm); *EIRP* – effective isotropic radiated power of the antenna (dBm); $L_{int.}$ – the loss of radiated power up to the intersection with the object (dBm); $L_{dir.}$ – the loss of signal propagation in space in direction *n* (dBm).

$$2r = \sin(\pi / 180)2d_{\min}, \quad (9)$$

where *r* is a ray, given that rays are radiated every 1° in vertical and horizontal planes; $d_{\min}$ – ray length to the nearest obstacle (m).

4. Experimental Calculations

Hygiene Norms HN 80:2011 stipulate that the common flow density of microwave electromagnetic radiated energy in residential and work environments, wich not related to the sources of electromagnetic radiation where frequency band varies from 450 MHz to 900 MHz, 1,800 MHz, 1,900 MHz, 2,100 MHz and 2500 MHz, shall be not more than 10 μW/cm^2. The plan of the radio communication base station and locality adjoining in the radius of 300 m is analysed for determining the sanitary protection zone and specific conditions for land use. The net flow density of the electromagnetic field generated by all receivers is calculated at a height of 2 m above the ground surface and roof, the place where transmission antennas are mounted as well as at the central level of the windows of an upper floor of the residential building and at the central level of the windows closest to the available residential or public purpose buildings.

The aim of the conducted experiment is to evaluate the suitability of the created algorithm to predict the strength of the electromagnetic field. The simulation of ray propagation requires considering a limit value of ray propagation that is significant for evaluation in this task. One 53.7 dBm power transmitter operating at a distance of 300 m generates a signal of –31.38 dBm power. Thus, it is possible to calculate the generated flow density of the electromagnetic field at a distance

$$s = 4\pi p / \lambda^2, \quad (10)$$

where *s* – flow density of the electromagnetic field (W/m^2); *p* – signal power at the point of measurement (W); λ – wave length (m). We obtain that the flow density of the electromagnetic field of 0.008 μW/cm^2 would be generated at a distance of 300 m. In the worst case, when the rays of 30 transmitters enter the same object, the flow density of the electromagnetic field shall not exceed 0.25 μW/cm^2 measuring at a distance of 300 m. This empirically bases that there is no sense to examine ray propagation in case of a signal weaker than 31.38 dBm power.

Directivity diagrams of mobile cellular communications antenna *AV2098* (Fig. 2) provided by manufacturer's *Trivec-Avant* were employed for testing the algorithm.

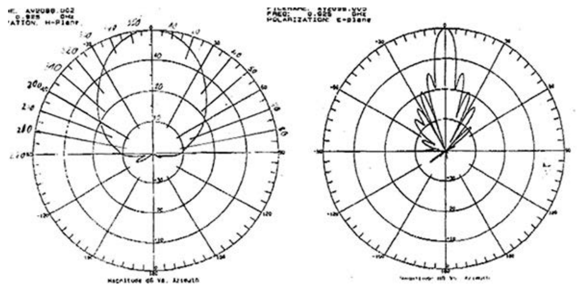

Fig. 2. Directivity diagram of antenna AV2098 for mobile cellular communications

The parameters employed for simulating radio waves include the minimum power of the receivable signal P_{min} – 31 dBm, frequency *f* – 900 MHz, antenna height *H* – 148.5 m, antenna *EIPR* – 50 dBm. Determined intersection points of rays, building walls and power parameters of the electromagnetic field are shown in Fig. 3.

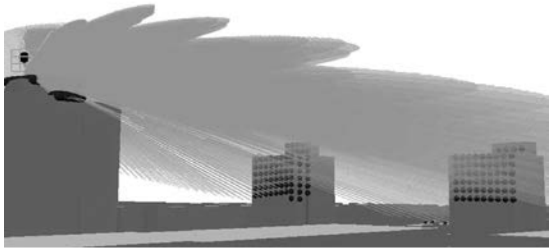

Fig. 3. Intersection points of rays and building walls

88 (calculating different frequencies used in one antenna) radio antennas for mobile cellular communications have been employed in the experiment. The arrangement of antennas is provided in Fig. 4. The aim of the experiment is to determine the areas in space where rays enter from the biggest number of antennas and to calculate the predicted flow density of the electromagnetic field.

The rays (Fig. 5) of radio wave propagation of 88 antennas have been simulated employing the above described method thus determining the intersection points (Fig. 6) of rays and building facades. Obstacles (Fig. 7) have been considered for simulating radio ray propagation. If several intersection points (next to each other) enter a specific facade area from different antennas, they may be summed up, given that several antennas radiate into the same area. For this purpose, the points are sorted according to their dependence on building facades and taking into account the fact that the signal enters from several antennas. The maximum signal power generated from every antenna has been determined. The calculations of EML strength are provided in Table 1.

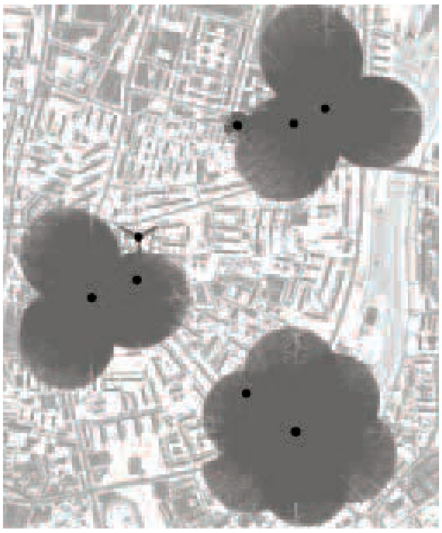

Fig. 4. Arrangement of antennas and ray propagation in experimental locality

Fig. 5. Rays of radio wave propagation generated by antennas

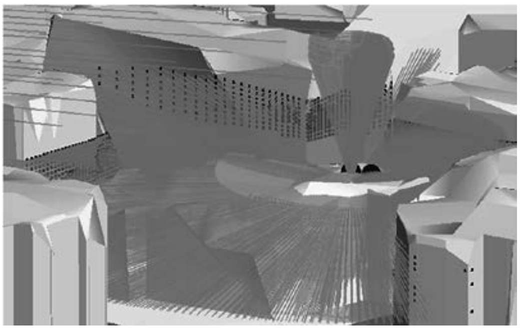

Fig. 6. Intersection points of rays and building facades

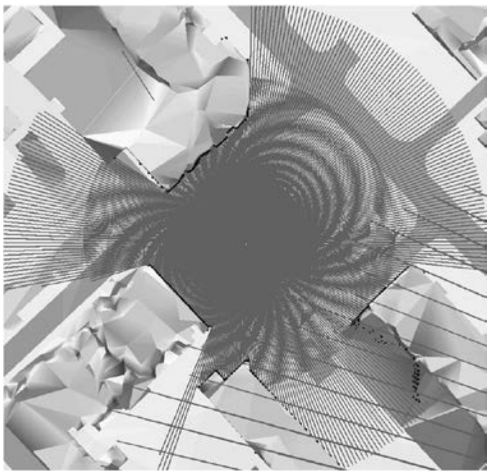

Fig. 7. Obstacles for ray propagation

Calculation results show that, in case of researched building facades, the predicted strength of the electromagnetic field is between 0.2 and 0.4 μW/cm^2.

Table 1. Calculation of the predictable value of EML

Facade	Signal receivable from antennas, units	Maximum power next to the facade, mW	EML generated by one antenna, μW/cm^2	Net EML μW/cm^2 <0}
1	5	0.005	0.06	0.3
2	5	0.006	0.07	0.4
3	6	0.002	0.03	0.2

5. Conclusions

The established method for predicting the strength of the electromagnetic field allows foreseeing EML next to building facades.

Parameters affecting prediction accuracy, i.e. antenna orientation, height and target position, now is characterize with low accuracy. Orientation errors were not known during the experiment; the established height error is about 2 m and the established target position errors make up to 20 m. In order to perform monitoring EML in the nearest antenna zone, the quality of parameters has to be additionally controlled.

The quality of 3 D geometry expressing obstacles to radio rays is another important factor affecting the accuracy of EML prediction. The performed experiment has determined that 3 D geometry created based on laser scanning from the air (minimum 1 point m^2) is suitable for simulation, although the structures, on which antennas are mounted, have to be simulated more precisely. Thus, the establishment of nonexistent obstacles to ray propagation in the locality is prevented.

The experiment has demonstrated 3 places where rays from 5–6 antennas enter building facades in the near zone of the antennas (at a distance of about 300 m). Net predictable EML generated by all antennas amounted to 0.4 μW/cm^2. The simulated results allow certifying it is purposeful to perform EML monitoring by measuring EML in the planes of neighbouring building facades.

Radio rays (receivable P_{min} = 31 dBm,) simulated in the locality of the experiment do not form the intersection with ground surface (in the height of + 2 m). This shows that the value of EML on the ground surface must be close to 0, because during simulation, radio ray reflection from surfaces has not been considered.

Research has disclosed that antenna orientation and position have the greatest affect on the EML value of neighbouring building facades. Critical values of EML may be attained, only if a big amount (due to the transmitters of different power and different distances between antennas and buildings, it is impossible to predict a specific number) of antennas is oriented into one and the same building facade. In order to prevent such situations when installing new antennas and to adjust orientation parameters of the available antennas, it is necessary to perform EML monitoring.

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