Program for Electrical Field Estimation around Base Stations of Mobile Telephony

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***Abstract*—This paper presents a novel program for electrical field level estimation in the vicinity of base stations of mobile telephony. We have developed the program in Excel. Its performances are comparable to those which are achieved by specialized, usually expensive programs. Systems in 2G, 3G and 4G technology are successfully analyzed. The graphics of electrical field and exposure ratio distribution in the area (±75m)·(±75m) or (±150m)·(±150m) around base stations are obtained. The characteristics related to base station transmitters, emission antennas and signal propagation are included in modelling. The output results present the maximum values, higher than it is in reality. The program is verified by radiation modelling in the vicinity of mobile system which has been already modelled and comparing our results to existent ones. The similar electrical field levels are obtained and therefore similar conclusions may be made in both cases.**

***Index Terms*—Mobile systems, calculation program, electrical field level, exposure ratio, Excel, emission antenna.**

I. INTRODUCTION

MOBILE communications have become the part of our everyday lives. We are surrounded by a multitude of base stations which are a source of electromagnetic radiation. Opinions about the harmful effects of radiation on human health are divided. It is the reason why estimation and measurement of electromagnetic field level in the vicinity of base station (BS) is very important to be investigated before and during this BS operation lifecycle.

BS radiation level is estimated analytically according to the principle of maximum expectable electrical field calculation. It is significantly easier to calculate electrical field than magnetic field and that's why we consider electric field in the rest of the paper. On the contrary, real electrical field level is obtained by measurements. Difference between the maximum electrical field and its measured value depends on the applied mobile telephony technics, traffic variations, fast and advanced power control, discontinuous transmission (DTX), soft handover [1] and so on. The ratio mean to maximum emission power is in the range from 1 for GSM systems with only one frequency carrier [2] (because there is no power control on the first carrier) and 65% or less when there are two or more frequency carriers also in GSM systems [3] over 20-26% for 3G [4] to only 2.2% or even less than 1% for 4G systems [1]. All these percentages are related to mean values. Maximum radiation levels for 5G systems are higher than for 4G systems, but real radiation levels in the vicinity of 5G base stations are not higher than 25% of maximum levels in 95% of cases [5]. Thus if calculation procedures give us the values of electrical field which are only a bit lower than it is defined in recommendations [6], the real radiation levels are considerably lower than allowed in a great majority of situations. The software packages applied for electrical field calculation or simulation in the vicinity of base stations are EMF Planner [7], Astel [8], IXUS, White Tigress (Baby) [9], CST Microwave Studio, HFSS, MAGIC, Orthoslice, EM Simulator [10] and so on. These are specific programs which have to be provided usually for a pretty high price. Our aim was to apply some convenient program, available at each computer (if possible) to calculate electrical field around a base station. The wish was to allow as comfort communication with the program as possible (comfort definition of input parameters, easy reading and presentation of output data). Our choice was to implement Excel because it is available on each computer and figures presenting electrical field distribution may be easily obtained. Program development is based on the experience in Excel implementation for calculation and simulation of complex telecommunication scenarios [11]. Such Excel implementation is not convenient and we haven't found a proof that it has been used for calculations similar or as the ones which are presented in this paper.

Section II lists program input parameters and presents how they are defined. Section III describes how input data are processed to obtain output electrical field characteristics. Section IV explains the techniques of base station emission power decrease in real application related to the maximum power. The two most important output characteristics for total radiation modelling are emphasized in the Section V. The characteristics obtained by our program for one typical location are presented in the Section VI. At the end, conclusions are in the Section VII.

II. PROGRAM INPUT PARAMETERS DEFINITION

Electrical field around base stations depends on a great number of factors. It is possible to define in the program all of them which are usually considered in a majority of realized projects [12]. The parameters which are defined before the program execution are:

- system type – it is possible to calculate electrical field caused by mobile base stations in the 2G, 3G and 4G technologies (mainly GSM900, UMTS2100, LTE800 and LTE1800);
- antenna type 1-8 – in this moment radiation diagram of 8 different antennas may be included into the calculation (for example APX906516, K80010621, AQU4518R4v06, etc.), but the program is opened for the definition of other antenna types;
- signal frequency (f_{BS}) – the number which corresponds to the numerical part of applied system type definition;
- signal attenuation during its propagation through walls

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(a_{wall});

- base station output power for one frequency carrier i.e. for one channel (P_{BS});
- maximum antenna gain (G_{ant});
- signal attenuation in a cable between the base station output module and antenna (a_{cable});
- the number of frequency carriers i.e. channels (n_{TRX}, $n_{signals}$);
- antenna electrical downtilt (δ_e);
- maximum value of antenna mechanical downtilt (δ_{mmax});
- the height over ground or over indoor floor for which calculation is performed (h_m);
- antenna height over ground (h_{BS});
- the azimuth of the antenna maximum radiation beam (*azimuth*);
- coefficient of the signal reflection from ground (Γ).

Base station output power is now calculated as a product $P_{BS} \cdot n_{TRX}$.

The electrical field is calculated for the surface of the dimension 150·150 points where the dimensions of each point may be selected as 1m·1m or 2m·2m. Further, it is possible to define parameters for maximum 6 mobile systems, each with maximum 3 antennas. It is possible to select whether calculation is performed for the inner parts of objects in the considered area or for outer surrounding (*out/in*). The total set of input and output data may be deleted before a new calculation cycle or input and output data may be deleted for a single system type during calculation if we conclude that input parameters for the considered system are not well defined. All already defined input parameters are presented during the calculation process and those dealing with one system may be redefined without any influence on other results.

Input parameters are easily selected and changed. However, the most demanding task in actual program version when input parameters definition is considered is the selection of heights in objects and terrestrial height in the area around the base station. It is necessary to enter the height for each point of dimension 1m·1m or 2m·2m inside the object and for terrain. We consider possibility to implement some less time and effort less consuming method in the future.

III. CALCULATION OF PARAMETERS WHICH DETERMINE RADIATION LEVEL

The electrical field level in the area around the base station in the developed calculation program is determined using the expression [13], [14]

$$E = \frac{\sqrt{30 \cdot P \cdot G}}{d} \tag{1}$$

The implemented variables in this equation are:

- P – base station emission power on an antenna;
- G – the implemented antenna gain in relation to the isotropic antenna;
- d – distance between the base station antenna and the point where calculation is performed.

A. Position in the horizontal plane in relation to the base station

The position of each point in the horizontal plane is determined by its x and y coordinates. Its distance r and the angle of its position towards the base station φ are determined on the base of these coordinates as:

$$r = \sqrt{x^2 + y^2} \tag{2}$$

$$\varphi = arctg\frac{y}{x} \text{ for } x \geq 0 \tag{3}$$

$$\varphi = \pi + arctg\frac{y}{x} \text{ for } x < 0 \tag{4}$$

B. Mutual distance between antenna and the point where electrical field is calculated

The radiation level is usually calculated at some height (h_m) over the terrain [15]. The distance of this point in relation to the base station antenna which is situated at the height h_{BS} is determined according to the Fig. 1 as:

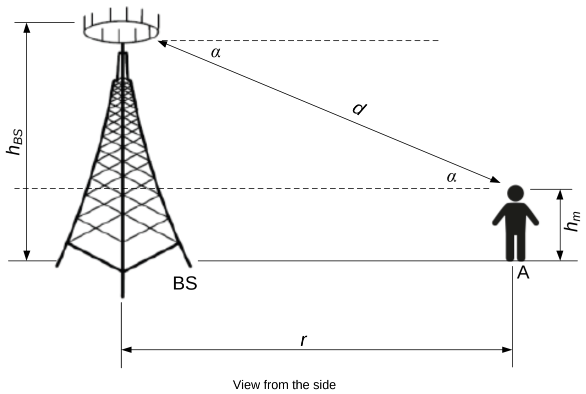

Figure 1 - Calculation of the mutual distance between base station antenna and the measurement point

$$d = \sqrt{r^2 + \left(h_{BS} - h_m\right)^2} \tag{5}$$

where r is already calculated by (2). The angle of the direction of d towards the horizontal plane is

$$\alpha = arctg\frac{h_{BS} - h_m}{r} \tag{6}$$

There are two more components in the calculation which modify the vertical component of the distance between the antenna and the point where calculation is performed. These two components are the height of the room in the object (h_o) where calculation is performed and the height of the terrain (h_t) just below the considered point of calculation in relation to the base station basis. That's why the expressions h_{BS}-h_m in (5) and (6) are replaced by h_{BS}-h_m-h_o-h_t.

C. Influence of downtilt

An angle α calculated in (6) or its modified version which includes h_o and h_t has to be altered to include antenna radiation pattern in vertical plane. Elevation angle is increased/decreased for the value of electrical (δ_e) and mechanical downtilt (δ_m). The value of electrical downtilt is always the same regardless of the radiation angle towards the maximum radiation angle in the horizontal plane (β=0°) while the value of mechanical downtilt depends on this angle and may be modelled as [16]

$$\delta_m(\beta) = \delta_{m\max} \cdot \cos(\beta) \tag{7}$$

where δ_{mmax} is the maximum tilt at β=0°.

Now an angle of radiation pattern towards the considered point equals

$$\alpha_{rad} = \alpha \pm \delta_e \pm \delta_m \tag{8}$$

The sign + or – in (8) is selected according to the radiation direction related to the horizontal plane (it is + for the direction over this plane and – under it).

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D. Influence of antenna characteristics

Antenna's radiation pattern is defined separately for horizontal and for vertical plane using radiation diagram. Such a definition is not suitable for implementation in our calculations. It is necessary to transform radiation diagram into the analytical expression.

We implement polynomial characteristic of the fourth degree to approximate radiation characteristic in the vertical plane and the polynomial characteristic of the fifth degree in the horizontal plane for angles between 7^o and 180^o while constant gain equal 1 is used for angles between 0^o and 7^o. Total antenna characteristic is expressed as a product of antenna gain in vertical plane and in horizontal plane.

E. Influence of reflection

Problem of reflection is very complex for analysis. We use a simplified reflection model on the base of reflection factor Γ where it is $0 \leq \Gamma \leq 1$. Electrical field in this case is

$$E_\Gamma = E \cdot (1+\Gamma) \tag{9}$$

Typical values of Γ are 0.3 in urban areas and 0.6 in rural areas [12].

F. Influence of signal attenuation when it is transmitted through walls

The model of signal transmission in indoor conditions is very complex. Signal level depends on attenuation through walls, reflection, diffraction and so on. Analysis in our program is limited to attenuation through walls (a_{wall}). The value of a_w depends on the material used for walls. Some typical values are 10dB for concrete walls with windows, 20dB for concrete walls without windows and 7dB for plastered walls.

G. Signal attenuation between base station transmitter and antenna

Signal generated in a base station is attenuated on its transmission to the system antenna. The transmission media are different types of cables (usually optical ones). The signal power before coming to an antenna is expressed by the equation:

$$P = P_{BS} \cdot a_{cable} \tag{10}$$

where P_{BS} is generated signal power in a base station and a_{cable} is signal attenuation between its generator and antenna.

IV. Determination of base station emission power

The special attention when mobile systems are projected is paid to power saving. This is particularly related to saving the power of the transmitter that generates the signal, which then consequently leads to saving the emission power of the antennas responsible for sending mobile telephony signals to mobile users. Power saving is mainly related to implementation of three technics:

1. switching off traffic channels that are not used in the traffic process - no signal is sent through such channels and they do not require energy consumption;

2. application of automatic gain control in busy traffic channels. The signal power is adjusted according to the distance between the antenna of the base station and each individual active user: a higher signal power is generated towards those users who are further away from the base station;

3. application of discontinuous transmission (DTX). The procedure is applied to busy traffic channels in such a way that the operation of the transmitter is turned off on them in time intervals when no signal is being sent during the connection.

As a consequence of implementation of these three technics for power saving, base station emission power in real circumstances is significantly lower than its maximum value. But, for the electrical field modelling related to the radiation level, it is supposed that maximum power is always emitted. This means that users' exposure to the radiation is surely lower than it is obtained by calculations.

V. Total radiation characteristics

All base stations on one location over each of their antennas contribute to the total electrical field level (E_{tot}). It means that E_{tot} may be calculated as:

$$E_{tot} = \sqrt{\sum_{i_{BS}=1}^{n_{BS}} \sum_{j_a=1}^{n_a} E_{iBS,ja}{}^2} \tag{11}$$

because signal powers are added. The designation $E_{iBS,ja}$ means electrical field of the j^{th} antenna in the i^{th} base station. The total number of base stations is n_{BS} and each base station has n_a antennas.

The second factor whose total value is determined is Exposure Ratio (ER). Its value for the i^{th} radiation source is calculated as [17]

$$ER_i = \left(\frac{E_i}{E_{L,i}}\right)^2 \tag{12}$$

where E_i is electrical field level caused by the source on the frequency i and $E_{L,i}$ is the value of reference limiting electrical field intensity at the frequency i.

Now the total ER (TER) is calculated as the sum of single ERs. The value of TER must be less than 1, i.e.:

$$TER = \sum_{i=1}^{N} ER_i \leq 1 \tag{13}$$

where N is the total number of radiation sources. In principle, $N=n_{BS} \cdot n_a$.

It is interesting to emphasize that Serbian national recommendations dealing with radiation (especially when considering ER) [18] are more demanding than most often used international ones from International Commission on Non-ionizing Radiation Protection (ICNIRP) [6]. That's why we have referenced in this program to [18] when ER is calculated.

VI. The results of calculations

Functions of our calculation program are tested on a mobile system which consists of four base stations realized in technologies GSM on 900MHz (GSM900 - 2G), UMTS on 2100MHz (UMTS2100 - 3G) LTE on 800MHz and LTE on 1800MHz (LTE800 and LTE1800 - 4G). In the area of surface (±150m)·(±150m) around the base stations there are total 17 objects. Reflection factor Γ=0.3 and attenuation when signal is penetrating through walls is a_{wall}=4dB (significantly lower value than it is in reality meaning that we obtain highly pessimistic results). The height over terrain or over a floor in objects is h_m=1.7m. The parameters of each base station, which are used in calculations, are presented in the table I separately for transmitting signal over each antenna. The considered parameters are: base station power (P_{BS}), antenna gain (G_{ant}), cable attenuation on

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the connection between transmitter and antenna (a_{cable}), a number of frequency carriers i.e. a number of signals (n_{TRX}, $n_{signals}$), electrical tilt (δ_e), maximum mechanical tilt (δ_{mmax}), antenna height on a pillar over terrain (h_{BS}) and azimuth of maximum antenna beam.

The characteristics which are important to illustrate radiation level in the vicinity of a mobile system are presented in the figures 2-5. The presented characteristics are the total electrical field (figures 2 and 4) and the exposure ratio (figures 3 and 5). The characteristics are presented separately for inner parts of objects - indoor at the objects' highest floors (figures 2 and 3) and for outer space – outdoor (figures 4 and 5). The heights of all objects are displayed in each figure.

TABLE I
BASE STATION PARAMETERS USED FOR CALCULATIONS

BS type	P_{BS} (W)	G_{ant} (dBd)	a_{cable} (dB)	n_{TRX}, $n_{signals}$	δ_e (°)	δ_{mmax} (°)	h_{BS} (m)	*azimuth* (°)
GSM900	32	16.35	4	2	0	-2	33.3	90
	16	15.85	4	2	-6	0	33.4	170
	32	15.85	4	2	-6	-2	33.4	250
LTE800	80	14.25	1.15	1	-2	0	28.1	90
	80	14.25	1.15	1	-5	0	28.1	170
	80	14.25	1.15	1	-7	0	28.1	250
UMTS2100	20	15.85	3.98	2	-4	0	28.1	90
	20	15.85	3.98	2	-7	0	28.1	170
	20	15.85	3.98	2	-6	0	28.1	250
LTE1800	80	15.25	1.2	1	-2	0	27.9	90
	80	15.25	1.2	1	-5	0	27.9	170
	80	15.25	1.2	1	-6	0	27.9	250

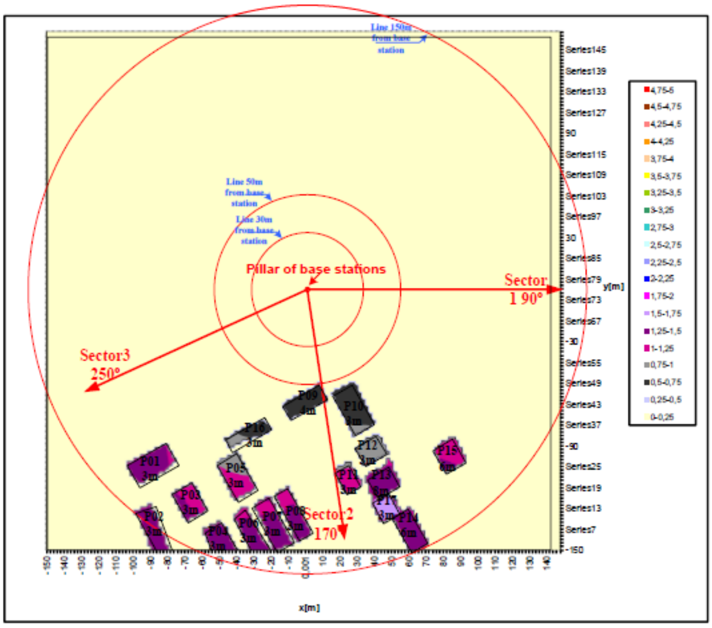

Figure 2 – Total electrical field on the most exposed floors of objects in the vicinity of the system which consists of GSM900, UMTS2100, LTE800 and LTE1800 base stations

In this paper we do not consider estimated characteristics for singular base stations. When considering the total system electrical field level and exposure ratio, we may emphasize that maximum values are obtained for the object P17 for the analysis of indoor conditions (E_{tot}=1.69V/m according to (11), *TER*=0.0083 according to (13)). For outdoor conditions the calculated maximum values are E_{tot}=2.48V/m and *TER*=0.0193. This means that radiation level at the considered location is significantly lower than the limiting allowed level. The program allows us to have insight into the electrical field level at each space of dimensions 1m·1m or 2m·2m both in outdoor conditions and in all objects at the location.

VII. Conclusions

In this paper we have presented the initial realization of a program for calculation of mobile systems radiation characteristics in the vicinity of radiation sources. Two main representative characteristics are calculated: electrical field level and exposure ratio. The first one is calculated separately for each implemented base station and then for the whole system. The second one is calculated only for the whole system. Our main goal has been to develop a program in some easily available programming language thus eliminating the need to provide some specialized, expensive program. We selected Excel because it allows us to easily obtain necessary graphical presentations. We succeeded to

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include in calculations parameters which are also available in other programs highly intended for such modelling [12]. Instead of modelling effects which are not easily evaluated (as reflection), we have implemented approximate expressions in such a way that higher values of electrical field are estimated than it is in reality. Thus it may be concluded that the results of calculation are on the safe side, towards overestimated electrical field and exposure ratio levels.

Definition of input parameter values is easily performed. Calculations are realized step-by-step for each base station while in each step calculating the instantaneous total variables values. This first program version is limited to 2G till 4G systems generations. Future program development will include also modelling of 5G systems. These systems have specificities which are not present at mobile systems of previous generations, as, for example, beam forming [19], [20]. The second direction of program future development is towards improving the comfort of objects position definition in order to achieve their easier, eventually automatic coordinates input to the program.

The program execution is verified on an example of a real mobile system. The calculated characteristics are near to the characteristics obtained by other program for the same location and for the same implemented input parameters.

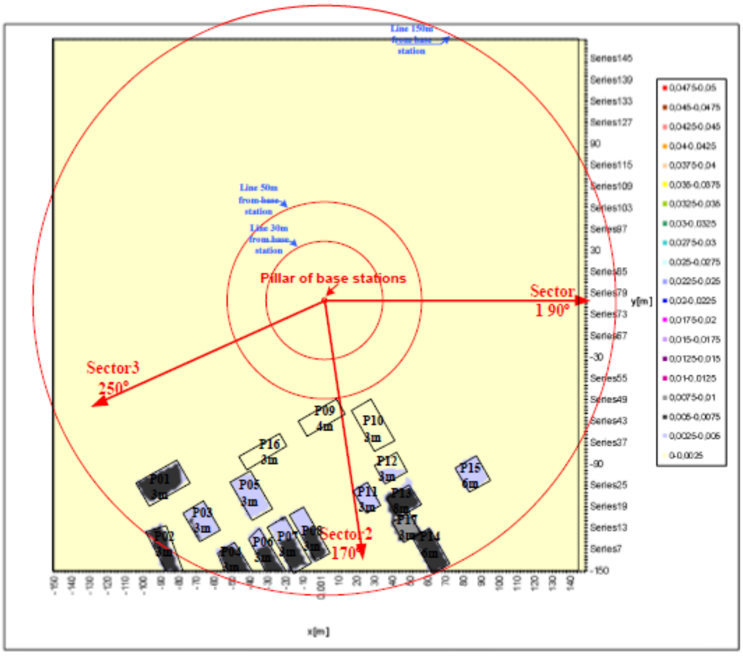

Figure 3 – Exposure ratio on the most exposed floors of objects in the vicinity of the system which consists of GSM900, UMTS2100, LTE800 and LTE1800 base stations

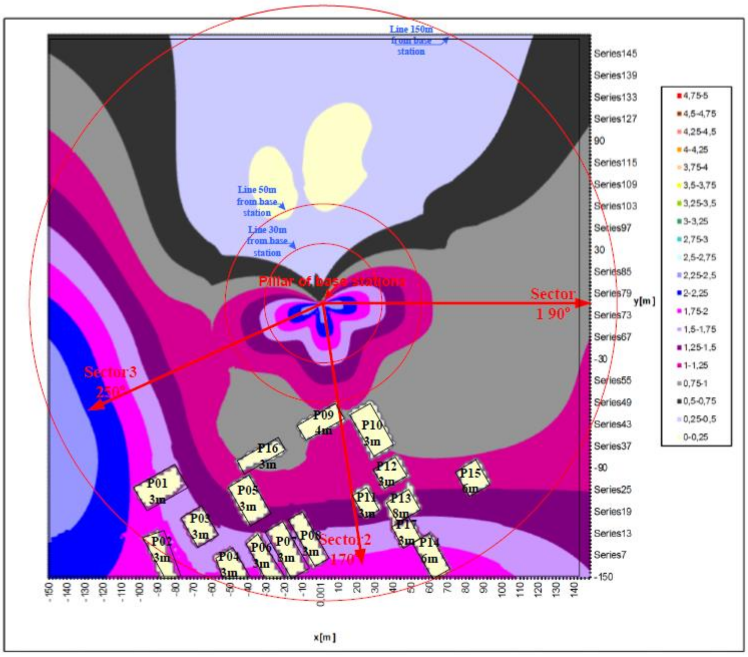

Figure 4 – Total electrical field in outdoor conditions at the height 1.7m over terrain in the vicinity of the system which consists of GSM900, UMTS2100, LTE800 and LTE1800 base stations

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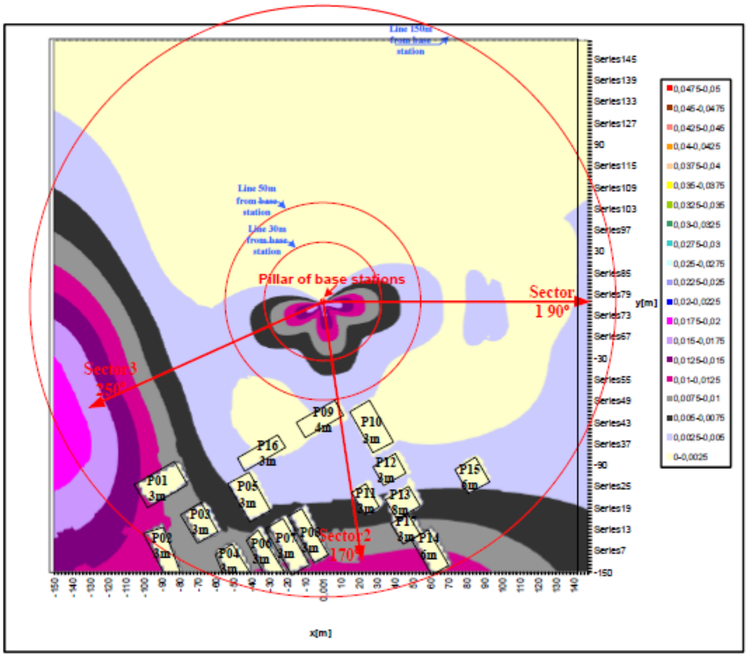

Figure 5 – Exposure ratio in outdoor conditions at the height 1.7m over terrain in the vicinity of the system which consists of GSM900, UMTS2100, LTE800 and LTE1800 base stations

The difference for the maximum electrical field level between the two compared results both in indoor and outdoor scenario is less than 35% taking the value obtained by other program as a reference. This limit is tolerable because the calculated values are significantly lower than it is allowed. The output graphics are presented with even higher resolution than it is with the program which is used as a reference for comparison.

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