NUMERICAL DOSIMETRY RELATED TO INDOOR HUMAN EXPOSURE FROM WIRELESS COMMUNICATIONS DEVICES

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ABSTRACT

Nowadays installed indoor wireless communication systems differ in terminal and base station configurations that call for application of different exposure evaluation methods. For stationary sources, dosimetry is oriented towards finding compliance boundary and total exposure ratio for all relevant sources across the entire applicable radio-frequency range. In indoor environment, the localized exposure assessment for installed wireless devices is complex, because persons are exposed to non-uniform fields subjected to fading, multiple reflections, diffraction and scattering. A good way to evaluate indoor complex field environment is a ray-tracing method. At University of Zagreb its specific type (beam-tracing) has been developed and optimized.

INTRODUCTION

Although topologies of various short-range devices differ (e.g., one-cell system, overlapping-cells system, collocated-cells system, multi-hop system, or cellular system), the basic structure is always the same, comprised of mobile terminals, stationary base stations, and propagation paths. Differing communications systems and thus different terminal and base station configurations require different exposure evaluation methods. Dosimetry of stationary sources requires finding the compliance boundary and the total exposure ratio for all relevant sources across the entire applicable radio-frequency range. The particular chosen multi-source evaluation approach is important, not only for purposes of human exposure assessment, but also for investigation of possible detrimental interference between various wireless protocols and equipments. When wireless devices in the unlicensed band operate in a medical environment, it is critical for human health purposes to avoid/prevent electromagnetic interference. Therefore, it is of highest importance to evaluate the localized human exposure for installed wireless devices indoors. The exposure is multi-source, and in some cases even multi-frequency (for differing communications systems). Even in the case of single source, exposure is non-uniform, due to the basic electromagnetic wave propagation phenomena, such as multiple reflections, diffractions, refractions and scattering. In our group at University of Zagreb a specific type of ray-tracing method (beam-tracing) was developed and optimized for getting quick results, needed for dosimetry.

BEAM TRACING

Calculations of electromagnetic field are performed using software developed at University of Zagreb. The program considers the basic propagation phenomena of transmission, reflection, and diffraction using geometrical optics to predict signal strength as accurately as possible. The method does not consider single rays like conventional ray-tracing models, but group of rays that encounter the same propagation phenomena. These groups of rays we call “beams”; thus, the method is called **beam tracing**. Each beam is represented by a signal image (matrix containing signal strength values for the whole beam area), and appropriate transformations are applied to the whole beam simultaneously, speeding up the calculation process considerably. Unlike ray-tracing, which calculates signal strength for each map point separately, beam-tracing calculates signal strength for the whole map simultaneously.

Electromagnetic wave propagation is a complex phenomenon, with complexity increased in indoor spaces. Indoor spaces typically contain many objects, meaning that electromagnetic waves experience reflection, diffraction, transmission and scattering effects due to all of the present objects. This produces multi-path propagation conditions, with a possible direct ray between the transmitter and receiver, and a large number of weaker rays reaching the observation point.

Fig. 1 shows the algorithm, which is a tree of all possible propagation paths throughout the whole environment for an example of two walls (w1 and w2) and a transmitter. The left side shows the walls (w1 and w2) and the created beams (bordered by the dotted lines). Position of the original transmitter is labeled AP, the first order reflections are centered on AP’, and the second order reflection on AP’’. The image tree for this environment, as shown on the right side of the figure, gives an insight to the performed calculations for the both walls (w1 and w2) and for the three basic propagation phenomena: transmission, reflection and diffraction. As an example, it is seen that the transmitted beam from w1 goes to w2, where again undergoes through transmission, reflection and diffraction.

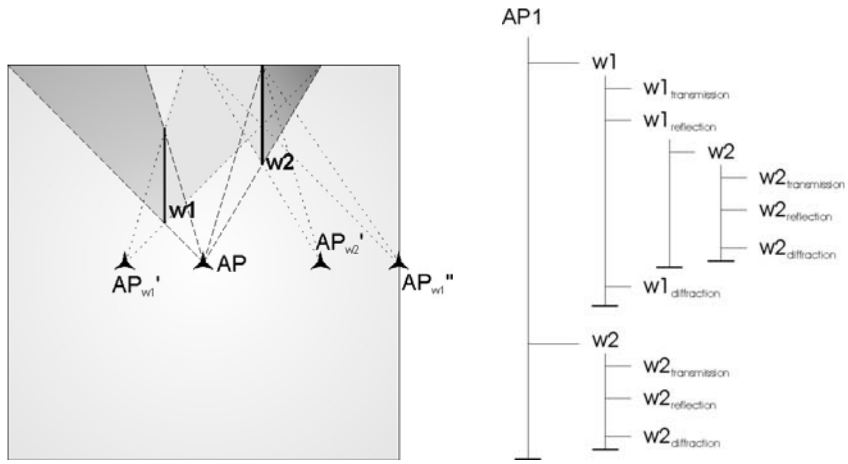

Fig. 1. Environment with two walls and a transmitter (left) and the image tree created (right)

As inputs the developed software requires three data types: environment map, transmitting equipment parameters, and propagation parameters. The environment map is a file containing spatial coordinates for all objects in the environment, as well as an object type. These parameters are defined by the user using a map editor, which was developed specifically for this purpose. From the input material and environmental properties, reflection and transmission losses are calculated. Equipment parameters required for the calculation include only the most relevant information of the equipment used, i.e., transmitter and receiver. Transmitter parameters include carrier frequency (from which the signal wavelength λ is calculated) and transmitter power (P_{Tx}), as well as transmitter antenna parameters – antenna gain (G_{Tx}), radiation pattern and antenna orientation. Receiver parameters include received power (P_{Rx}), receiver antenna gain (G_{Rx}), receiver noise figure, bandwidth of the received signal, noise figure and receiver temperature. These are used to calculate receiver sensitivity, which determines minimum receivable signal strength. Propagation parameters include definition of fading margin and propagation exponent. Fading margin is an overhead in signal strength required to counter the effects of sudden drops in received signal power caused by changes in the environment (called signal fading). Required fading margin depends on the desired connection quality, and is usually set between 10 dB and 20 dB for mobile communications. The propagation exponent (R) determines the falloff of signal power density with distance from the transmitter. This value equals 2 in free space, and is commonly used in macro cell models to encompass all propagation phenomena. Because the software considers all of these parameters, the propagation exponent is used only for smaller objects within the environment that are not included in the environment map. The propagation exponent should be set to between 2 and 2.5 (the higher values should only be used when a very large number of obstacles are present). The model uses a modification of the Friis free-space transmission formula to calculate the received signal power at a distance d from the transmitter for each ray that reaches the receiver, as given in (1):

$$P_{\mathrm{Rx}} = \frac{P_{\mathrm{Tx}} G_{\mathrm{Tx}} G_{\mathrm{Rx}}}{L_{\mathrm{d}} L_{\mathrm{f}} L_{\mathrm{c}}} \left(\frac{\lambda}{4\pi} \right)^2 \frac{1}{d^R} \tag{1}$$

Influences on received signal strength from obstacles within the environment are accounted for by the attenuation propagation parameters L_{d} (diffraction loss), L_{f} (signal loss due to fading), and L_{c} (cable and connector losses).

The algorithm is based on signal images that cover an area larger than the observed environment. The starting signal image is created first for a free-space environment using the modified free space equation (1), and used to invoke a recursive function. The function searches for objects found in a given signal image for areas where the signal is of sufficient strength for reception. The software then determines which beam encountered the object and separates it into a different signal image, again invoking the recursive function. This is done separately for each propagation phenomenon, resulting in three new images which are combined and used to modify the original signal image. Thus, a tree of all possible propagation paths throughout the whole environment is created. An advantage over standard ray-tracing methods is that this model retains its accuracy even in regions further away from the transmitter.

MEASUREMENT METHOD

Validation of the calculation method was done with a series of measurements. A wireless local area network (802.11b standard) was used in measurements as a typical system for the software application. The limited transmitter range allows measurements over the whole coverage area with relatively high resolution. Measurements were done using a single WLAN access point (AP) operating on the fifth channel at 2.432 GHz with output power of 18 dBm. Two dipole antennas were used for transmission, and the access point was placed at 1.5 m height on a foamed polystyrene platform.

The client device was a laptop computer with a wireless integral-antenna PCMCIA card. The laptop was positioned at 0.9 m height on a wheeled cart, for easier transportation and consistency of measurements. Actual operating conditions were simulated by performing measurements at each observation point over a period of 10 to 20 seconds using a software package obtained from the manufacturer. The results are saved and processed using self-written utility software. Fading effects were seen as 10 dB to 30 dB decreases in signal strength, but effects were reduced by taking average values at each measurement point.

COMPARISON OF THE NUMERICAL AND MEASUREMENT RESULTS

A comparison between calculated [5] and measured [6] results was performed with an environment map of the Dept. for Radiocommunications, Faculty of Electrical Engineering and Computing in Zagreb, Croatia. The environment consists mainly of concrete walls, wooden doors, and large glass windows on outside walls, consisting of a total of thirteen offices, four large classrooms, one kitchen, two toilettes, one entry hallway, one main corridor and four elevators. The whole area is 15 m wide and 52 m long, and the resolution used was 0.25 m. Field measurements were made at a number of key locations and along several routes to accumulate a sufficient amount of data for model validation. Other calculation parameters were as follows: P_{Tx} = 18 dBm, G_{Tx} = 2 dBi, f = 2.432 GHz, R = 2, fading margin = 10 dB. The corresponding beam-tracing calculation results are shown in [5].

The model was calibrated using measurement results in the classroom and in the main corridor. In the room where the WLAN AP was placed, the measured points were spaced one meter from the access point and used to derive the model input parameters. Standard deviation between measured points and neighboring calculated points was 4.2 dB. The model parameters were set to fit the measurements as best as possible, and a comparison was performed for the main corridor. The standard deviation between measured points and neighboring calculated points in the corridor was 3.5 dB, showing a good correlation between measurements and calculations.

DOSIMETRY RELATED TO HUMAN EXPOSURE

Electromagnetic dosimetry is a methodology used for determining compliance with specific absorption rate (SAR) limits applicable for portable and mobile wireless devices intended to be used with the radiating part of the device within 0.5 and 20 cm to the human body. The convenient approximate formula is proposed in [2] for a calculation of the SAR induced at the surface of the standing human for the case of a monopole antenna with radiated RMS power P_{RMS} and feed point impedance Z.

The electrical properties of a human model are described by σ (conductivity), ε (permittivity) and μ (permeability). Medium density (ρ) refers to tissue density, whereas γ_{pw} is the plane-wave reflection coefficient for the incident magnetic field and c_{corr} is a correction coefficient that takes into account reflection properties for small distances d from the dielectric surface. The frequency considered was 2450 MHz, which means that the c_{corr} can be taken as 1. As in [10], the final expression is

$$SAR_{surf} = \frac{\sigma}{\rho}\frac{\mu\omega}{\sqrt{\sigma^2+\varepsilon^2\omega^2}}\cdot\left(\frac{2\left|\sqrt{\varepsilon'}\right|}{\left|\sqrt{\varepsilon'}+\sqrt{\varepsilon_0}\right|}\right)^2\left[\frac{E_{inc}}{Z_0}\right]^2 \tag{2}$$

Used electrical parameters are at 2450 MHz for the homogeneous all-muscle model of ε=53.57, σ=1.81 S/m and ρ=1040. The values in the anatomically correct heterogeneous body model have been calculated at specific frequency on FCC Internet Site [8] from the Gabriel [9] using the 4-Cole-Cole analysis.

Depending on distance, values go from 465 pW/kg to 0,2 nW/kg. ICNIRP values of whole-body exposure SAR in the frequency range from 10 MHz to 10 GHz [7] for general public exposure is 0.08 W/kg. Comparison of the highest value of the calculated SAR with the mentioned ICNIRP value shows that it is eight orders of magnitude lower.

CONCLUSIONS

In this paper, the software for a numerical simultaneous calculation of signal strength, developed on the basis of ray-tracing method, shows very good properties for an application in numerical dosimetry of indoor communications systems.

In the presented example, software has been applied to a calculation of 160.801 map points, which was performed in 513 seconds. at Pentium 4, operating at 1.8 GHz. This gives an average calculation speed higher than 300 points per second.

Comparison with measurements gives very encouraging results. The highest standard deviation between measured points and neighboring calculated points has been 4.2 dB. Thus, the combination of numerical model and measurement method has been applied not only for verification of the both results, but also for "tuning" numerical parameters.

The maximum SAR value is 0,2 nW/kg, which is eight orders of magnitudes lower than the whole-body average SAR value in ICNIRP Guidelines (0,08 W/kg). This means that the exposure of human being to an average coverage of one Wireless Local Area Network Access Point at operating frequency of 2450 MHz is negligible. For the case of multiple access points or a combination of multiple access points and other RF sources the calculation has be repeated.

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