AN EFFICIENT REPRESENTATION OF COMBINED INDOOR/OUTDOOR 3D MOBILE RADIO-COVERAGE

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ABSTRACT

This paper describes an efficient method for visualizing the simulated received power levels at a specified site in the form of equipower scatter plots. This approach provides an easy way for inspecting the actual radio-coverage limits of a mobile network, for a specified reception threshold. For an increased degree of accuracy to be achieved, a ray launching technique has been implemented for the propagation simulations. The representation is applicable to both indoor and outdoor applications.

INTRODUCTION

Future mobile communication networks will incorporate even more broadband services in a combined indoor / outdoor environment. Sub-networks based on different radio access architectures will coexist or interoperate in a microcellular installation. There is a need for accurate radio propagation prediction because the approximate coverage limits of such networks are difficult to differentiate.

These networks cannot be confined in a single plane simulation scenario. The third dimension (for example the height of a building in a specified site) is crucial for the effective planning of the wireless network. A 3D simulation scenario takes into account potential obstacles in all directions of the propagation path e.g. buildings in a dense urban environment.

An efficient 3D representation of the radio-coverage is presented in this work, using equipower scatter plots. The proposed method is useful during system planning, since it shows the actual coverage limits of the network compared to traditional two-dimensional contour plots of predicted power levels at the reception point.

Moreover, it can be useful when new base stations are to be added in order to increase the overall network's capacity. In most of these cases, we are more interested in the approximate coverage limits rather than the misleading received power level contours near the transmitting antenna.

PROPAGATION MODELLING APPROACH

The growing need for accurate propagation predictions for different environments has created a boost towards the development and enhancement of several models. An accurate calculation of the field can be achieved through a finite element method. However, this technique cannot be considered for any large area, since it is highly time consuming.

The most widely used technique, in order to simulate a high frequency electromagnetic field is a “ray tracing” approach. This term is frequently used in the relevant bibliography –see Agelet et al. (1)- describing two different approaches. One of them, also referred to as “ray launching”, considers the casting of rays from the transmitter towards several directions and the “tracing” of these rays throughout the simulation area. The other technique, referred to as “ray tracing”, implies the existence of a receiver at each grid point in the study area, and all possible rays connecting these points are calculated. Both techniques are based in geometrical optics. Additionally, the Geometrical Theory of Diffraction by Keller (2) and its uniform extension by Kouyoumjian and Pathak (3) are introduced to remove field discontinuities, especially in the zero field areas predicted by GO – see Athanasiadou and Nix (4). At the receiving point, a sum of the different rays is performed with appropriate phase.

A very interesting technique based on GO was presented by Hoppe et al (5). All the surfaces in the study area are divided in discrete surfaces. In a pre-processing stage of the calculation process a visibility graph is created for each surface (for all angles of incidence there is a specific surface that is “illuminated”). After this stage, the study is performed at fast simulation times (for each different positioning of the transmitter) and the accuracy of the technique depends only on the size of the elementary surface. However, in case of a big study area with many buildings, this approach demands important resources (in terms of memory) for an accurate estimation of the propagation. Therefore it could only be implemented for an indoor study.

Ray Launching Over Ray Tracing

Each of these two techniques shows certain advantages and disadvantages and should be separately chosen depending on the particular study. Ray tracing is more accurate, since all possible rays that connect the transmitter with the receiver are calculated. However, this demands an exhaustive search of all paths for each different grid point; thus leading to extremely high simulation times for a large area. Nevertheless, it is suitable for indoor environments (such a realization was presented in our previous work - Dimitriou et al (6)).

In the present work, a ray launching approach has been implemented. Discrete rays are considered from the transmitter and the field is calculated at each grid point. The calculation for each ray ends, either when the signal strength falls below a predefined threshold or when the ray exits the area of interest. All reflections and transmission coefficients are accurately calculated, and diffraction is also considered. The separation angle between launched rays should be carefully chosen (depending on the distance of the area of interest from the transmitter), in order to obtain reliable results. This technique is very efficient computationally. The simulation time is very small compared to any of the aforementioned approaches.

Implementation Accuracy

In order to achieve higher accuracy during the simulation process, certain strict rules must be imposed. These rules affect mainly the polarization state of the travelling electromagnetic waves as well as the way that all walls and surfaces are treated.

According to electromagnetic field theory –Balanis (7), Paris and Hurd (8), Tsiboukis (9), Siwiak (10)-, the polarization state of an E/M wave is altered when reflected in the boundary surface of a lossy medium. The complex reflection coefficients for both perpendicular and parallel (according to the plane of incidence) components of electric field intensity vector $\vec{E}$ are calculated and the polarization effects are taken into account.

Moreover, the dielectric constant for all lossy materials is considered complex –see von Hippel (11), therefore the phase velocity of a travelling wave inside a thick wall is affected and calculated accordingly.

The implemented algorithm for the calculation of all reflection and transmission coefficients is easily adaptable to a set of N intermediate layers inside a wall by using a recursive formula (7)-(8).

PROPAGATION PREDICTION RESULTS

Proposed 3D Representation Method

The proposed method for visualizing the predicted strength levels is not using all calculated data points on the predefined grid but plots only those in a narrow range that the user selects. Thus, specific equipower 3D scatter plots can be easily extracted and efficiently illustrated in conjunction with all available buildings in the site under consideration (building penetration). The radiation solid can be extended by altering the equipower threshold level.

The view for all extracted 3D plots is handled by utilizing the standard OpenGL graphics acceleration routines (fast redrawing and changing of viewpoints).

The implemented propagation prediction software can be used also for extracting common two-dimensional plots for received signal strength levels on any plane defined by the user.

Results

In the following plots we present some results from the predicted radio-coverage in typical urban environments. Discussion for each case of the combined indoor/outdoor representation is presented in the following paragraphs. In all cases the TX power is 0dBm at a frequency of 1800MHz.

Case A. A 3 buildings block with uniform wall materials. As illustrated in figures 1 and 2, the TX antenna, which is a 3 element Yagi array, is located approximately 100m away from building 1 illuminating the whole block. The antenna height is 20m (building heights: bld.1=15m, bld.2=10m, bld.3=10m). Figure 3 shows the same installation but TX height is now 12m. The line-of-sight equipower points are forming the main beam of a directive Yagi pattern. Behind the buildings there is a shadowed area which forms an equipower area away from the main beam (fig. 1).

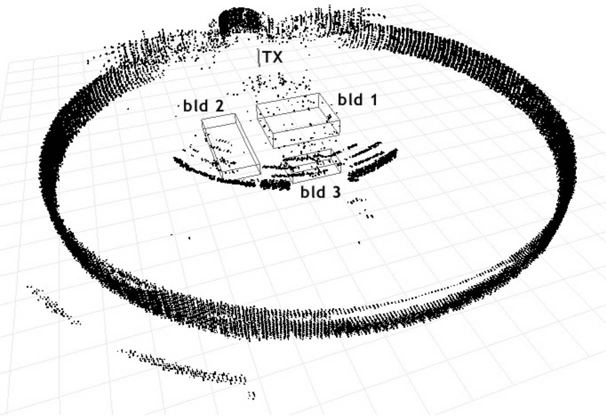

Figure 1. Equipower plot for -54dBm RX level

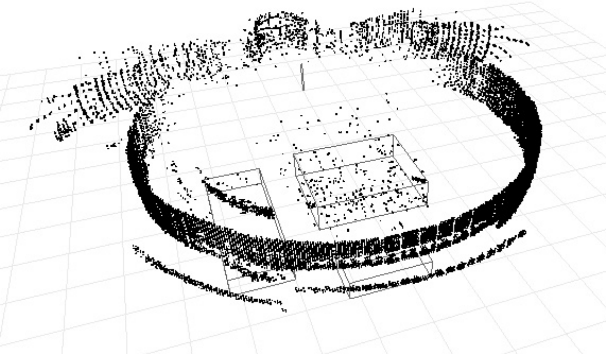

Figure 2. Equipower plot for -49dBm RX (TX 20m)

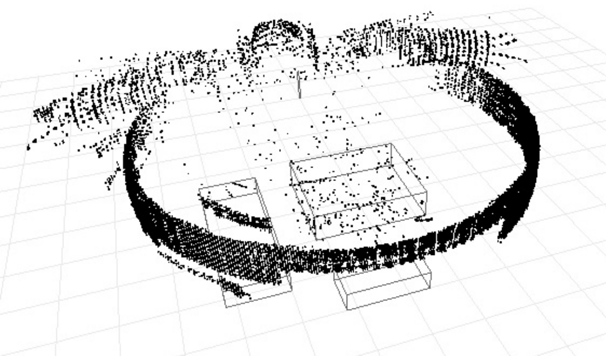

Figure 3. Equipower plot for -49dBm RX (TX 12m)

In figures 2 and 3, the building penetration is more apparent (bld 2). Outside the main beam of radiation there are equipower areas formed by constructive interference between LOS rays and the rays reflected on the roof of buildings 1 and 2 (very low angles of incidence). In figure 3 where the TX height (12m) is lower than the height of building 1 (15m) the influence of bld.1 has disappeared.

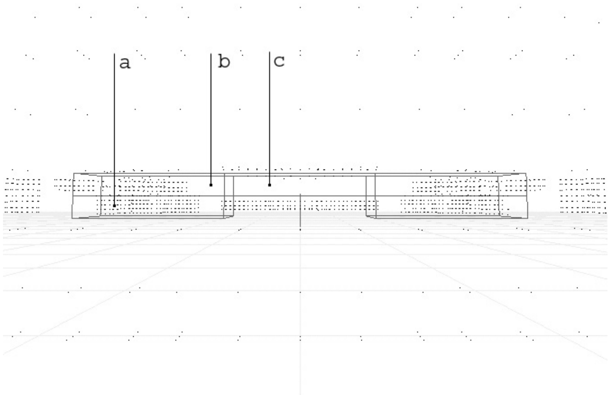

Figure 4. Front view from the antenna

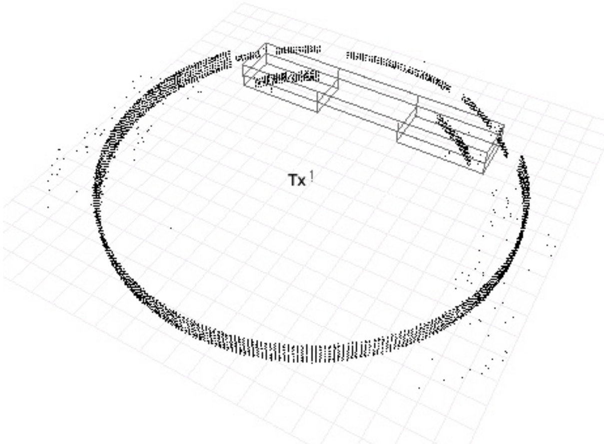

Figure 5. Perspective of the equipower scatter

Case B. Alterations of the equipower scatter plots due to the materials in the propagation path. Figure 4 shows the building from the antenna's point of view. At the first floor the surface denoted as *a* represents an outer wall (reinforced concrete) of the building. Surface *b* represents windows and surface *c* a metal. The area below surface *c* is empty.

The effect of the different types of materials is shown in figure 5. The part of the signal that is shadowed by the wall, suffers from greater attenuation than the signal through the windows. Furthermore, the metal completely shadows the area at that height behind it. This is also illustrated in figure 4. The dielectric properties of all materials used are given in Table 1. All metal surfaces have very high conductivity ($\sigma/\omega\varepsilon_r >> 1$)

It is clear a this point that a potential 2D representation of the power contours at low height would give an entirely erroneous estimation about higher planes.

TABLE 1 – Dielectric properties of materials

Material	Width (m)	ε_r	tanδ
a. wall	0.4	2.4	0.015
b. glass	0.1	6.0	0.0025

Large Scale Predictions

Finally the result of a big scale simulation is presented. Each block shown here represents a 40m building. The distance between adjacent buildings is 15m. The antenna is a dipole, positioned at the centre of the drawing. The calculated equipower scatter plot is at –60dB from the transmitting power (0dBm).

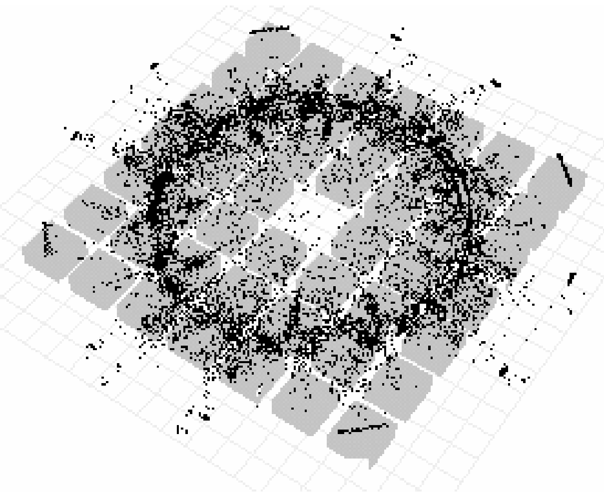

Figure 6. Perspective of results for a dense building environment

CONCLUSIONS

The results presented in this work, show a significant variation of the expected field at different heights, a fact that strengthens the necessity of 3D representations of the resulting field. This is achieved by selecting and visualizing any wanted signal threshold, after carefully and accurately predicting the received signal level. This representation aims in aiding network designers/providers and especially in areas where different technologies coexist.

ACKNOWLEDGEMENTS

The authors would like to thank Konstantinos Panoulas for his assistance in the implementation of the graphical interface.

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