SIMULATION IN URBAN ENVIRONMENT OF A 3D RAY TRACING PROPAGATION MODEL BASED ON BUILDING DATABASE PREPROCESSING

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ABSTRACT

The analysis and simulation of electromagnetic (EM) wave propagation represent a crucial task in planning cellular networks for mobile communication.

When an adequate building database is available, deterministic 3D ray tracing techniques are quite useful and accurate to face this problem, but since their computational complexity is time consuming, a preprocessing step is necessary. Such a step allows the practical use of 3D ray tracing simulations so as to achieve the same accuracy of the ray optical approach in short simulation time. The preprocessing phase is independent on the position of the transmitter's antenna, consequently it can be run once and for all, independently on EM field strength simulations. This strategy makes the technique practical and useful in common cellular network design, such as UMTS cellular planning. During the preprocessing phase, the mutual visibility between the walls and edges of the buildings are pre-evaluated and stored: the mutual visibility is described by a so called "visibility tree".

In this study a new simulation software is presented. It uses a new technique of preprocessing, which is able to reduce the visibility tree building time of an order of magnitude or more (if compared with a "brute force" approach). In order to evaluate reflections and diffractions, the walls of buildings need to be splitted in smaller faces whose typical size should be about 10 wavelengths. Since the number of visibility relationships increases with the square of the number of faces, the splitting phase makes the time necessary to build the visibility tree unacceptably long. This problem was solved through the following two steps: first, the visibility among the main (large) faces is evaluated; then the obtained raw tree is used to create the full and accurate visibility tree. The output of such a technique is the same as a "brute force" approach, but the computational time needed is one order of magnitude smaller.

The final EM prediction can take into account any number of reflections and diffractions: Geometric Optics allows to evaluate specular reflections while the Uniform Theory of Diffraction is used to estimate multiple diffractions from vertical edges and roof-tops.

Because of unavoidable uncertainties affecting building positioning and dimension in the database (root mean square error of ~6-7 wavelengths at 2 GHz), phase estimate cannot be accurate. Consequently, reflection and diffraction contributions are added up using a MonteCarlo technique, so as to estimate at least the expected value of field strength.

1. INTRODUCTION

Over the few past decades, cellular radio communication systems underwent extensive development: the requirements that a radio system must fulfill are growing from day to day. In order to achieve good quality and cost effective solutions, new systems must be planned carefully from the very beginning. One of the main goals is to optimize cell size according to the expected traffic and land use and to provide a complete coverage using a low number of base stations. Extensive usage of accurate wave propagation models is unavoidable to collect useful information for network plannig: in particular the so called path (propagation) loss is the basic characteristic for a proper selection of base station locations and frequency plan. From the propagation losses it's easy to determine the field signal strength, the signal-to-noise ratio (SNR), the carrier-to-interference (C/I) ratio, etc. An accurate prediction of the field strength and delay spread in very complex environment is a very difficult task: this work presents a new simulation software to be used in very dense urban environment. The developed simulator is based on ray tracing and building database preprocessing. As our interest is turned mostly to the Universal Mobile Telecommunication System (UMTS), simulations are carried on at the frequency range used by the last generation services (i.e. more than 2 GHz).

2. ELECTROMAGNETIC WAVE PROPAGATION APPROACH

When an accurate 3D building database is available, deterministic propagation models are quite useful to simulate EM wave propagation. They are generally based on ray optical techniques where different rays emitted by the trasmitting antenna are subject to reflection, diffraction and scattering at walls and edges of buildings. Typically reflection and diffraction are performed with the help of Geometric Optics and the Uniform Theory of Diffraction and that's the approach we used, based on a standard ray tracing technique. In addition, since building faces are not fully reflecting, the properties of scattering surfaces are taken into account by evaluating a reflection coefficient which depends on the mean value of the dielectric constant of building outer coverings. The most time consuming part of a prediction based on ray optical algorithms is the search for all the relevant paths from the transmitter to the receiver, but, when the physical propagation paths are found, effects such as wave guiding in street canyons can be appreciated with a good accuracy and additional parameters, such as small scale fading or delay spread, can be easily estimated. The main disavantage of the ray tracing approach consists in the sometimes prohibitively large computation time. Such a problem may be partially solved by splitting the path finding process from the calculation of the field strength through a preprocessing tecnique [1], as explained in the next section.

3 BUILDING DATABASE PREPROCESSING

In this section it's presented a 3D optical deterministic model based on a new implementation of database preprocessing which allows to reduce the computation time of an order of magnitude, if compared with a brute force approach. Most of the tecniques used to simplify the ray tracing problem do not separate the path finding process from the calculation of the field strength. Models based on database preprocessing, instead, try to exploit the fact that, since the database of buildings remains the same and only the position of the transmitter changes, the overwhelming part of the different rays remains unchanged: only the rays between the transmitting antenna and primary obstacles or receiving points in line-of-sight change [1]. This is the basis for a building Database Preprocessing. In a first step the walls of the building (or other obstacles) are divided into smaller tiles with or without edges. Then, visibility conditions between different tiles (possible rays) are determined and stored in a file. We may find what elements (faces or receivers) a face sees, by extracting profiles (i. e. the altimetry of the path) between two faces or between a face and a receiver. The result of such preprocessing can be represented in the shape of a visibility tree whose leaves are receivers and tiles (sub-faces). For a different transmitter location only the uppermost branches in this tree must be computed again, i.e. determining which elements are in line-of-sight to the transmitter and consequently all other relations have to be computed only once. The remaining computation time after the preprocessing step is many orders of magnitude lower than the one needed for the conventional analysis without preprocessing. In this way, 3D deterministic models with their supreme accuracy can be actually used for practical applications with computation times in the order of empirical models. Such an approach has another interesting characteristic: the prediction algorithm can be easily changed without modifying the preprocessing technique. As a matter of fact, the model we apply to the singular tile (in order to predict the scattered field) does not influence the visibility tree and this property can be used to apply and test different scattering models (which can take into account balconies and architectural elements on a statistical basis, for example).

4 A NOVEL APPROACH IN ORDER TO REDUCE PREPROCESSING COMPUTATION TIME

The main advantage of the model described in the previous section is that preprocessing must be run once and for all, but such step (i.e. the creation of the visibility tree) is a time consuming operation: all the profiles between all the faces and between faces and receivers have to be evaluated. Besides, in order to reach a good precision, faces should not be too large (no more than 10 wavelengths) and so a wall should always include more than a face. Since the number of visibility relationships increases with the square of the number of the faces, splitting determines a great increment of the time necessary to produce the visibility tree. If the number of buildings is great, a preliminary split of the faces makes the creation of the visibility tree very hard. Since the model has to be applied to a large area in a dense urban environment without giving up a good resolution (e.g. 5 meters), computation time becomes unacceptable (order of months) and the result file may reach an unacceptable size. To solve such a problem, a new preprocessing algorithm which minimizes the visibility relationships to evaluate has been developed. The new approach is based on the reasonable hypothesis that a singular faces "sees" a number of faces which is very small in front of the whole database. From some tests on a building map of the inner city of Turin, we can argue that the number of faces seen by a singular face is about the hundreth part of the total. Such observation leads to the new approach: first, the visibility for the main large faces of buildings is evaluated, then walls are splitted and the visibility is evaluated only for the tiles which belong to walls in mutual visibility. In this way, the computation time depends only on the original number of buildings and not on the minimum size of the tiles that the field prediction model needs. Hence, the first step produces a "raw" tree file which specifies, for each face, its visible faces and receivers. These data are usually too inaccurate because of the low resolution, but, at this point, additional information is known, i.e. we can start from the first raw tree file, modify it and create the new and more precise visibility tree. Even if faces are splitted, the second step does not take much time, on the contrary, it is faster than the first step because visibility is evaluated only between tiles belonging to walls in mutual visibility. Referring to the test on the Turin map, the results are shown in Table 1.

Table 1. Performance of the developed preprocessing algorithm. The estimate is based on the available 3D building databese, in an area in the center of Turin around Politecnico: the total number of visibility relationship to evaluate is smaller of more than one order of magnitude if compared with a “brute force” approach

<table>
<tr><td colspan="2">Total number of building faces in the investigated area (3Km by 3Km in the center of Turin)</td></tr>
<tr><td colspan="2">$N_{f\ tot} = 60.000$</td></tr>
<tr><td colspan="2">Total number of tiles (obtained by dividing every face by 4)</td></tr>
<tr><td colspan="2">$N_{t\ tot} = 240.000$</td></tr>
<tr><td colspan="2">Total number of visibility relationship to be evaluated ($N_{vr\ tot}$)</td></tr>
<tr><td>Brute force approach</td><td>Developed Algorithm</td></tr>
<tr><td rowspan="2">$N_{vr} = (N_{t\ tot})^2 = 5,76e10$</td><td>First Step
$N_{vr1} = (N_{f\ tot})^2 = 3,6e+9$</td></tr>
<tr><td>Second Step
Number of faces seen by a single face (N_{f1})
$N_{f1} = \sim 400$
Number of tiles seen by a single tile (N_{t1})
$N_{t1} = 4 \times N_{f1} = \sim 1600$
$N_{vr2} = (N_{t\ tot} \times N_{t1}) = \sim 3.84e+8$</td></tr>
<tr><td colspan="2">$N_{vr\ tot} = \sim 5,8e10$ >>>>> $N_{vr\ tot} = N_{vr1} + N_{vr2} = \sim 4e+9$</td></tr>
</table>

5. THE PROPAGATION ALGORITHM

Face by face, the algorithm determines the visibility relationship by using standard ray tracing techniques and then it evaluates the field scattered (i.e. reflected and diffracted) from each face; multiple reflections and diffractions are evaluated by repeating this process. Reflections are performed by using geometric optic, while diffraction (from vertical building edges and roof-tops) are evaluated through Uniform Theory of Diffraction. At last, for each receiver (i.e. for each pixel of the map) the field contributions from the various tiles have to be summed up to get the value of field strength in each point. As a matter of fact, phase information is not meaningful because wavelength is 0.15 m (at 2 GHz) while building database resolution is not usually better than 1m: to get useful phase estimate, accuracy on building dimension and positioning should be much better than wavelength and nowadays such an accurate database is unavailable. So we can only estimate the expected value of field strength by considering the phases of the various contributions uniformly distributed (there’s no reason to use another statistical distribution, even if it would be easy with the used technique). Given n vectors with uniform phase between 0 and $2p$, the phase distribution of the resultant vector has no analytical expression, and so the expected value of field strength cannot be evaluated in a close form. Therefore a numerical analysis was carried out and the problem was solved through a Montecarlo technique. The extractions are performed as follows: the field contributions with the greatest absolute values are associated to a set of uniformly distributed phases and then they are summed up (taking into account all the random phases) to get the absolute value of the resultant field vector (that is the result of the MonteCarlo extraction). The arithmetic mean of all the MonteCarlo extractions is the expected value of field strength. The trial is repeated until the result is stable (usually about one thousand extractions are enough). Fig. 1 shows an example of prediction on an area in Turin around Politecnico: the building database used is very accurate (better than 1 meter) and the simulation was performed at a height of 1,5 metres taking into account 2 levels of reflections and diffractions and using 1,5 dB as antenna gains and 10W as transmitting power.

6. CONCLUSIONS

The developed simulation software is based on database preprocessing which allows to separate the propagation path finding process from field prediction. A new preprocessing technique was developed which deeply reduces computation time. The algorithm has been tested on an area of the inner city of Turin centered on Politecnico: the reduction of computation time given by this new approach is more than one order of magnitude, if compared with a “brute force” approach. Field coverage predictions can take into account whatever level of diffraction and reflection with a linear (no more exponential) growth of calculation time (both for preprocessing and field estimate). In order to validate the predictions, an heavy measurement compaign is nowadays in progress. Since the measured signal may have high fluctuations (until 10dB), even on short distances, to evaluate the accuracy of predictions some kind of statistical analysis has to be thought up, but it is clear enough that a very low standard deviation of the error cannot be achieved: fading phenomena, vehicular traffic conditions and atmosphere influence cannot be estimated with deterministic tecniques. In addition, building faces are not smooth: since nowadays it isn’t possible to know the true buildings geometry, when measurements will be available a statistical model of the scattering surfaces will be developed in order to adjust the box model. Statistical analysis on the influence of vehicular traffic conditions will be carried out, too.

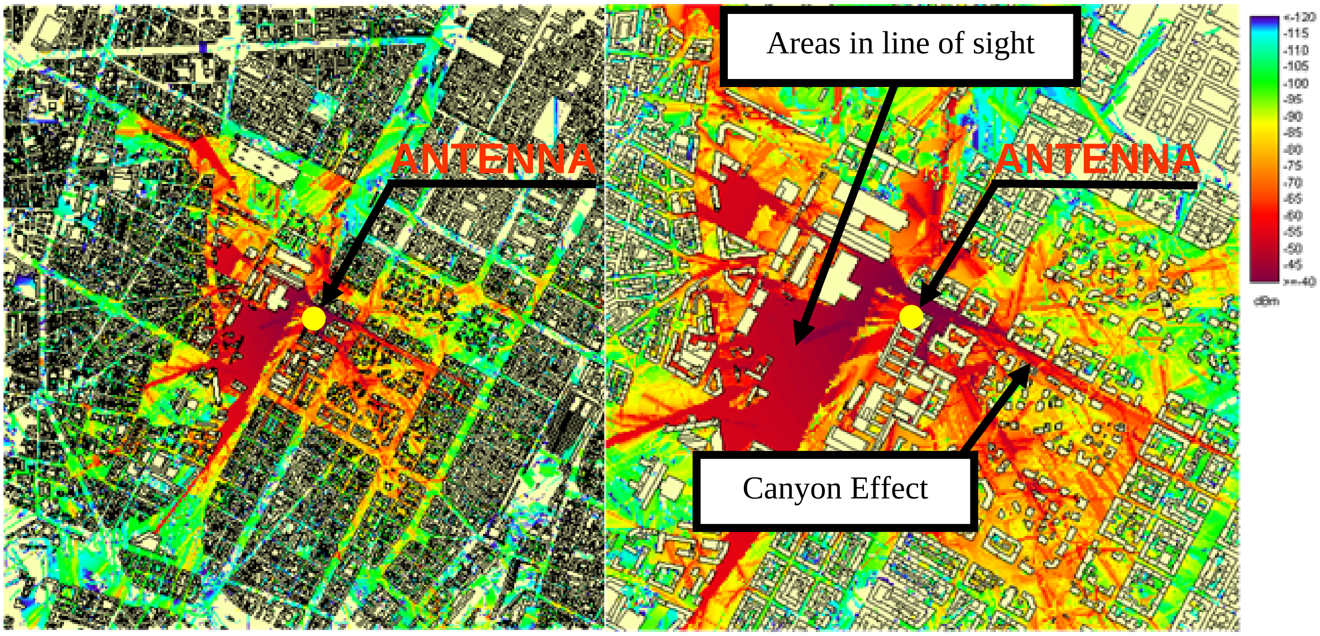

Fig. 1 – An example of simulation output in Torino, on an area around the Politecnico of about 3Km by 3Km: field levels were placed over the building database. Two reflections and two diffractions were considered in this example, but whatever level of diffraction and reflection can be evaluated with a linear growth of calculation time. The zoom on the right point out the radio coverage details which can be evaluated by using the developed simulation software. This example was performed at a height of 1,5 metres by using as simulation parameters discone antennas at the transmitter and at the receiving pixels (characterized by a gain of 1,5dB) and 10W as transmitting power.

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