where $\delta^{(m)}(x)$ is the *m*th-order derivative of the Dirac delta function $\delta(x)$ and a_{mn} are multipole expansion coefficients to be determined. Expansion coefficients a_{mn} may be obtained numerically by point matching at discrete values of the observation angle (θ) from the dual-series equation [7] obtained from the integral in Eq. (12) with the substitution of Eq. (13) as

$$\sum_{m=0}^{\infty} \sum_{n=0}^{\infty} a_{mn} (ik_j \cos \theta)^{(m)} (ik_j \sin \theta)^{(n)}$$

$$= -f_j(\theta), \quad \text{in } \overline{S_j}, j = 1, 2. \quad (14)$$

The total fields are obtained by adding the fields produced by s_i to the PO solution given in Eq. (3).

For comparison, the edge-diffracted fields are calculated after 15 terms of a_{mn} , and are shown in Figures 2 and 3 with those of Maliuzhinets' solution and the heuristic UTD solution. Maliuzhinets' solution deviates considerably from this asymptotic solution for the wedges of low-loss tangents $10^{-5}(\sigma=10^{-6}~{\rm S/m}$ at 1.8 GHz) and 2×10^{-2} shown in Figures 2 and 3, but approaches quite closely for the high-loss tangent 10, as expected. The accuracy of this asymptotic solution is confirmed by the smallness of the values of the extinction integral in Eq. (11), as shown by the lines of empty diamonds in the figures.

4. CONCLUSION

Fields scattered by a lossy dielectric wedge for a plane-wave incidence are obtained. From the tracing of an inhomogeneous plane-wave propagation in the lossy half space, the geometrical-optical solution for the lossy wedge and its corresponding physical-optics solution are obtained analytically. The edge diffraction of the physical-optics solution is then corrected accurately by adding the multipole line sources at the edge of the wedge to the geometric-optical field in the wedge interfaces to satisfy the extinction theorem asymptotically. Numerical results for the scattered fields are shown to give accurate results when the loss tangent of the medium is less than about 10. Maliuzhinets' impedance wedge and the heuristic solutions do not give correct values for the refraction in the lossy medium, and the edge diffractions deviate considerably for a low-loss tangent. The accuracy of this corrected asymptotic solution is checked by the smallness of the extinction integral.

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RAY-TRACING ACCELERATION TECHNIQUES

F. Aguado, 1 A. Formella, 2 J. M. Hernando, 3 and F. Isasi 1

¹Departamento Tecnologías de las Comunicaciones

ETSÍ Telecomunicación E-36200 Vigo, Spain

² HTW des Saarlandes

D-66117 Saarbrüecken, Germany

³ Departamento Señales, Sistesmas, y Radiocomunicaciones

ETSI Telecomunicación 28040 Madrid, Spain

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ABSTRACT: Site-specific software tools for propagation predictions in multipath environments for modern mobile radio communications require computationally efficient procedures. In this paper, an acceleration technique and its associated software package are described. They present a relevant execution time saving. © 2000 John Wiley & Sons, Inc. Microwave Opt Technol Lett 25: 363–365, 2000.

Key words: ray tracing; UTD and propagation tool

1. INTRODUCTION

The increasing need to improve the accuracy of propagation loss predictions and the requirement to assess the wideband characteristics of wireless channels has led to the development of site-specific software tools, based on ray-tracing/ray-launching procedures. The more accurate alternative is the point-to-point ray-tracing approach. Nevertheless, this approach leads to high computation times. Thus, acceleration techniques must be applied in order to make this method computationally efficient. In this paper, such a technique is proposed. It is based on computing the so-called "visibility graph," which is a tree-like list of possible interactions between the ray and the environmental elements.

2. 2-D VISIBILITY ALGORITHM

The visibility algorithm is run to identify all possible transmitter-to-receiver ray paths. This algorithm can be applied to ray-tracing acceleration in microcell and indoor environments because both the transmitter and receiver antennas are located well bellow the surrounding rooftops. The real 3-D case is introduced later, when the actual ray tracing is carried out. This approach is called the 2-D-3-D hybrid method [1]: 2-D multipath search plus 3-D ray tracing. The visibility graph starts at the transmitting antenna, and comprises several layers which contain the environmental elements directly visible from the transmitter, the environmental elements visible from the first layer elements, and so on. To carry out visibility studies on higher order layers, new references are defined. To generate the visibility graphs [2], two approaches are used: 1) a polar sweep algorithm, and 2) bounding boxes.

2.1. Polar Sweep Algorithm. This algorithm is successively applied to all elements contained in one layer of the visibility graph to generate the elements in the next higher order layer. The algorithm is explained with the aid of Figure 1. In this figure, two linear segments (AB and CE) represent vertical walls. In order to produce an ordered list of visible interaction elements, a clockwise circular sweep is performed. An example of the contents of the first layer of a visibility graph is shown in Figure 2. To find the elements in the second layer of the visibility graph, the polar sweep algorithm is applied according to the propagation mode considered. Reflections are handled by the mirror image technique. For diffractions in the first layer, the edges directly visible from the transmitter are included in the visibility graph. To determine the elements of the second layer, the polar sweep is performed, but is limited to the area defined by the segments making up the edge.

3. EXTENSION OF THE VISIBILITY STUDIES TO THE 3-D CASE

The visibility algorithm can be extended to the 3-D case (macrocellular and LMS environments) in a straightforward way. To carry out visibility studies in the 3-D case, a combination of a full azimuth angle plus elevation scans carried out at the azimuths where a change in visibility conditions are likely to occur must be implemented. In this 3-D case, horizontal diffractions have been accounted for.

4. BOUNDING BOXES

Speeding up visibility graph computations can be achieved by reducing the segments and endpoints to be tested. This can be done by splitting the whole study area into smaller areas

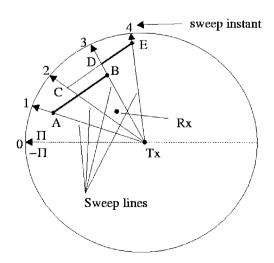


Figure 1 Polar sweep algorithm example

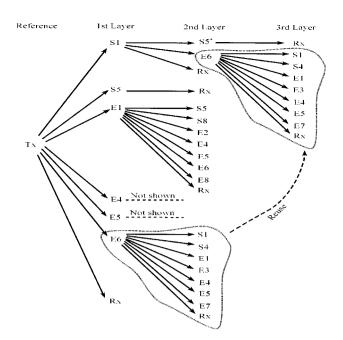


Figure 2 Visibility graph computation

defined by rectangular flat-top boxes, the height of each bounding box being that of the highest wall within it. The algorithm starts within the box where the transmitter is located. From the current bounding box, visibility is determined to the same box and the outer walls of the surrounding ones. When an outer wall of the neighbor box is visible, a detailed visibility study will be carried out.

One method to split the study area into bounding boxes is the use of quadtrees [3]. In Figure 3, we show an example in which a maximum number of ten walls is set. If a box exceeds the limit preselected, it must be split into four smaller boxes. With this method, the processing time for each box is bounded, and the total computation time will be limited by the number of bounding boxes visited by the algorithm.

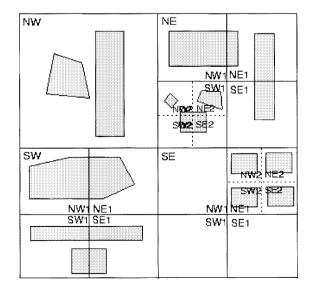


Figure 3 Quad-tree splitting division

5. A RADIO TRACING PROPAGATION PREDICTION TOOL

Radio-Tracer is a software package that uses the above-mentioned methods in combination with the high-frequency techniques such us UTD to compute the amplitude, phase, delay, and polarization of each ray in a multipath propagation environment [4]. Having identified the dominant rays that reach the receiver, they are coherently combined, taking into account receiving antenna patterns and system bandwidths. The package has four main modules: 1) the visibility graph generation module, 2) the ray-tracing module which verifies and computes trajectories of those ray paths which appear in the visibility graph, 3) the UTD module which computes the propagation parameters and transforms the combination of the rays, and finally, 4) the postprocessor module which allows the computation of a comprehensive number of channels parameters both for the narrow- and wideband cases.

6. VALIDATION OF THE TOOL

The tool has been tested against measurements made in the town of A Coruña, Spain, using a digital terrain base of 1635 buildings. A drive test of 1309 samples was used. Several program runs were executed considering different propagation models. A brief summary of execution times (Pentium II 400 MHz and 128 Mbytes RAM) is given in Table 1 (V, H, R stand for vertical diffracted, horizontal diffracted, and reflected rays).

TABLE 1 Tool Execution Times in Seconds

Interaction	Without Ground	With Ground Reflection
LOS	0.12	0.21
LOS + V	7.73	15.11
LOS + R	4.08	4.29
LOS + H	4.45	5.32
LOS + H + H	6.20	9.67

The times are on the order of 15 times better than the ones without applying the bounding box acceleration technique. The method and the tool also have been tested against measured power delay profiles made with a repetition pulse sounder at 1800 MHz. Measurements were carried out in indoor environments: corridors with LOS and NLOS conditions. A good agreement between measured results and calculated PDP using the tool was obtained.

7. CONCLUSIONS

Site-specific propagation tools include, as a fundamental element, a ray tracer. Point-to-point ray tracing is the preferred methodology due to its accuracy. This technique requires some means of reducing the computation times in order to make the tool practical for use. In this paper, two methods are presented for this aim: the 2-D polar sweep technique, and its extension to the 3-D case with the use of bounding boxes. From the run times registered in the simulations performed, it can be concluded that the acceleration techniques proposed are practical and feasible. A software tool (Radio-Tracer) implementing a ray tracing plus UTD propagation model has been designed and validated in two scenarios: an indoor environment and an urban microcell.

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