

FDTD Techniques for Evaluating the Accuracy of Ray-Tracing Propagation Models for Microcells

Joseph W. Schuster
Remcom, Inc.
State College, PA
E-mail: jws@remcom.com

Raymond J. Luebbers
Department of Electrical Engineering
The Pennsylvania State University
University Park, PA
E-mail: RayL@psu.edu

Abstract

In this paper several techniques are presented for employing a two-dimensional (2-D) FDTD simulation as a tool for evaluating the accuracy of radio wave propagation models based on high-frequency asymptotic methods. In particular, comparisons are made to a GTD based method in the frequency and time domains. The GTD results are calculated using the Uniform Theory of Diffraction (UTD) wedge diffraction coefficients modified for finite conductivity. Because the 2-D FDTD fields spread as cylindrical waves emitted from a line source, a simple technique is introduced for modifying the 2-D FDTD time domain response to approximate the spherical wave spreading of fields emitted from a point source.

1. Introduction

A number of ray-tracing based propagation models have been developed since the early 1990's for making site-specific propagation predictions in urban microcells [1-3]. These models have usually been validated by comparison with measurements of received power and delay spread. However, because of the complexity of the environments in which the measurements are made it is often not clear from the comparisons why the predictions are inaccurate in some areas and how the models can be improved. The purpose of this paper is to introduce some simple techniques by which the finite difference time domain (FDTD) method can be used to evaluate the accuracy of propagation models based on ray-tracing and high frequency asymptotic methods such as GTD.

Of course, even the largest computers do not have nearly enough memory to allow for a full three-dimensional FDTD simulation of UHF propagation in a microcell. However, in high-rise urban areas the transmitting and receiving antennas will frequently be located well below the building heights, and in these situations paths which diffract over the rooftops are usually of negligible power compared to paths which propagate between buildings in the horizontal plane. This is the type of environment and antenna locations to which a two-dimensional (2-D) FDTD simulation can be applied.

At UHF and microwave frequencies the buildings in a high-rise urban environment are electrically very large and this allows for the application of high frequency methods in electromagnetics. It has been demonstrated that it is essential to include diffracted fields in making predictions for an urban environment. Diffraction is often a very important propagation mechanism in this environment, whether

it is diffraction around corners into non-line-of-sight streets or diffraction over rooftops down to street level. Most site-specific models combine some type of ray-tracing procedure with geometrical optics and one of the high frequency methods for calculating diffracted field amplitudes. The most popular method is the Geometrical Theory of Diffraction originally developed by Keller in 1962; and within the framework of the GTD, the Uniform Theory of Diffraction developed by Kouyoumjian and Pathak and modified for finite conductivity as given in [4] is widely used.

The GTD results in this paper are calculated with the 2-D version of the propagation model described in [5]. This model combines the Shooting and Bounce Ray (SBR) method with the GTD. The SBR method is employed as a computationally efficient ray tracing procedure to find the ray paths to the field points. After the paths are found the GTD is used to evaluate the electric field amplitudes using the UTD diffraction coefficients modified for finite conductivity surfaces that are given in [4].

2. FDTD Implementation

Although a two-dimensional approximation to the building geometry can be used in a high-rise urban environment, the fields will still attenuate with distance as spherical waves emitted from a point source. However, in the 2-D FDTD simulation the fields will spread as cylindrical waves emitted from a line source, and therefore in order to compare the FDTD fields directly to measurements or to the GTD predictions it is necessary to modify the FDTD fields to have the correct spherical wave attenuation with distance.

For non-diffracted fields which reflect only from planar surfaces the spreading is as $1/r$ for spherical waves and as $1/\sqrt{r}$ for cylindrical waves, where r is the total path length. For diffracted fields the attenuation with distance is more complicated, but according to the UTD the ratio of the spherical to cylindrical wave attenuation remains $1/\sqrt{r}$. The basic idea for obtaining the correct spreading is to use the fact that $r = ct$ in free space to introduce an additional $1/\sqrt{r}$ of attenuation into the FDTD fields by multiplying the time domain fields by $1/\sqrt{ct}$. This is implemented by exciting the FDTD simulation with a narrow pulse at the source point and then saving the complete time record at each point of interest. In post-processing the fields are multiplied by the correction factor and then Fourier transformed to obtain the amplitudes and phases of the frequency domain fields.

It is also possible to take the interference with the ground reflected wave into account. To obtain the correct interference pattern it is necessary to include the time shifts due to the different propagation distances. The field not reflected by the ground is given by

$$E(t') = E_{FDTD}(t) \frac{\sqrt{ct}}{ct'} \quad (1)$$

and the ground reflected field by

$$E_G(t'') = E_{FDTD}(t) R_G(\theta) \frac{\sqrt{ct}}{ct''} \quad (2)$$

where $R_G(\theta)$ is an angle dependent reflection coefficient, $ct' = \sqrt{(h_R - h_T)^2 + c^2 t^2}$,

$$ct'' = \sqrt{(h_R + h_T)^2 + c^2 t^2}, \tan \theta = (h_R + h_T)/ct, h_T \text{ and } h_R \text{ are the heights of the transmitter and receiver.}$$

Figure 1 shows a simple geometry consisting of four buildings with a rectilinear street pattern. Each building consists of a perfect electrical conducting core with a 0.3 m thick lossy dielectric coating ($\epsilon_r = 4$, $\sigma = 0.05$ S/m) on all sides. A cell size of 1.5 cm (20 cells per wavelength at 1 GHz) was used in the FDTD simulation. The ground reflection is calculated using a perfectly conducting ground plane.

A vertically polarized field was excited at $x=37.5, y=6.2$ m. To prevent the excitation of unwanted low frequency fields which GTD cannot predict, the FDTD simulations were excited with a truncated derivative of a Gaussian having the form

$$E(t) = \begin{cases} -2A_0 \alpha (t - \beta \Delta t) e^{\alpha(t - \beta \Delta t)^2} & 0 \leq t \leq 2\beta \Delta t \\ 0 & t > 2\beta \Delta t \end{cases} \quad (3)$$

where $E(t)$ is the electric field at the source point, $\alpha = [1/(\beta \Delta t/4)]^2$ and $\beta = 48$.

3. Numerical Results

In Figures 2 and 3 the FDTD calculated fields are compared to the GTD fields at a frequency of 900 MHz. The GTD results include ray paths with up to 8 reflections and 2 diffractions. The fields are compared along the lines AB and CD with the field points at a height of 2 m. The scaling factor E_0 used in the plots is the field at 1 m from the transmitter in the absence of the buildings. The electric field in free space is also shown in order to illustrate the large attenuation produced by the buildings.

An alternative is to compare the GTD predictions directly to the FDTD calculated time domain electric fields. Comparing the results in this way makes it possible to examine properties of specific propagation paths between the source and field points. Although it is not possible to determine from the FDTD simulation the full geometrical path by which energy traveled from the transmitter to the field point, it is possible, by choosing the excitation properly, to isolate specific propagation paths in the FDTD time domain response and to compare the strength and arrival time of these paths to the values predicted by the GTD model.

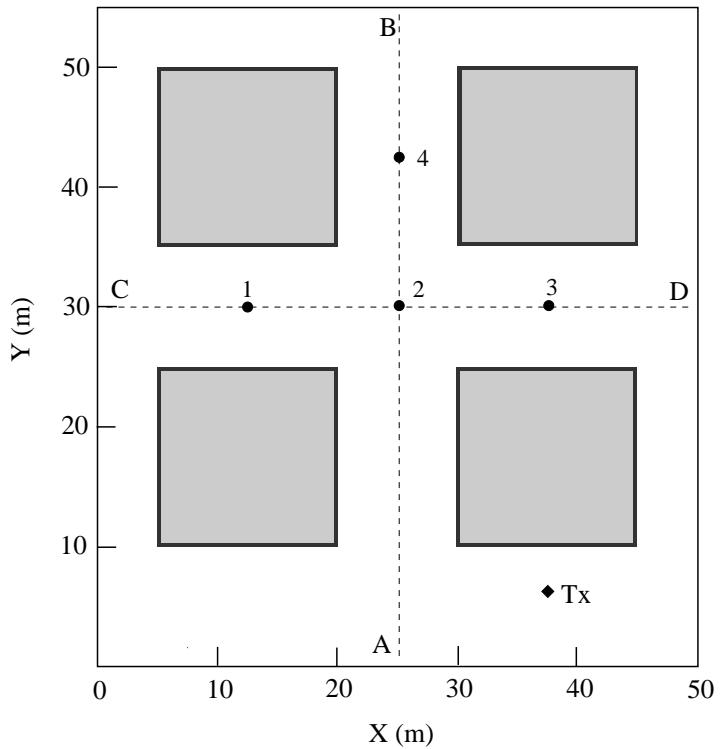


Figure 1: Four building geometry used for the numerical results

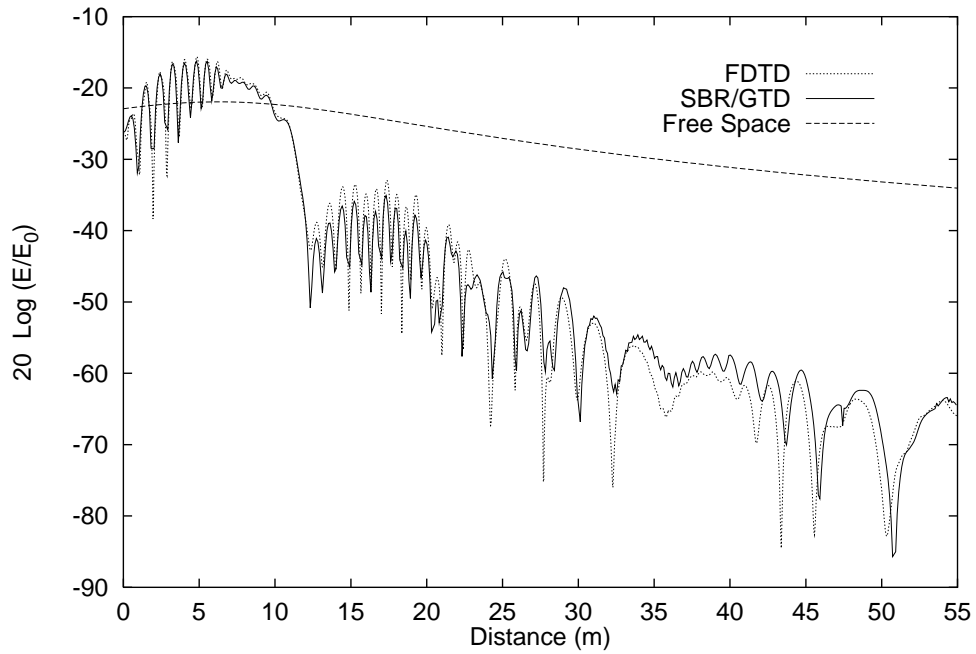


Figure 2: Comparison of the GTD and FDTD calculated electric fields at 900 MHz along line AB in Fig. 1.

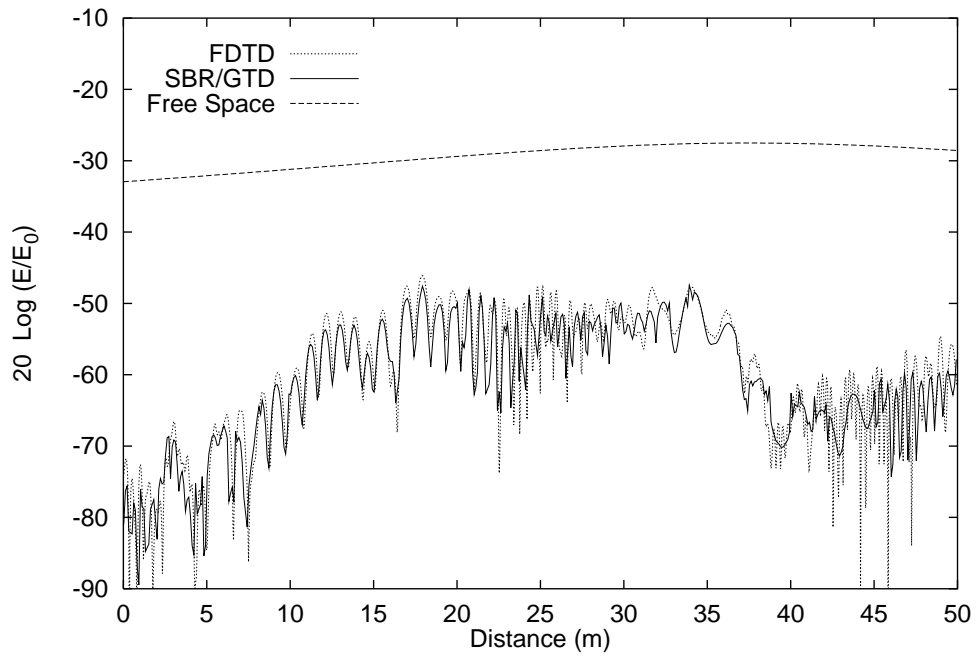


Figure 3: Comparison of the GTD and FDTD calculated electric fields at 900 MHz along line CD in Fig. 1.

To demonstrate how this can be done, we will consider the paths from the transmitter to field point 1. The building interactions and the times of arrival for the first ten significant GTD calculated paths to arrive at point number 1 are listed in Table 1, and in Fig. 4 the first five of these paths are plotted with the building geometry. Several paths (mainly double diffractions) which are of very low amplitude have been omitted from the figure and the table. To give some indication of the relative strength of each path, the power in dBm for a transmitted power of 0 dBm are given at 500 MHz, which is approximately the center frequency of the excitation pulse. These results were obtained using the model described in [5], and the diffracted fields were evaluated using the finite conductivity UTD diffraction coefficients given in [4].

The first path to arrive at point 1 is one which diffracts twice, first from the lower left hand corner of building 2 and then from the upper right hand corner of building 1. There are several paths listed in Table 1 which travel nearly the same distance and arrive at nearly the same time as other paths. For instance, paths 2 and 3 differ only by path 3 having a second diffraction from building 1. Paths 5 and 6 are another such pair which follow nearly parallel paths. It is interesting to note that path 10 is the first path to arrive at point 1 which undergoes only reflections and no diffractions, and due mainly to presence of the lossy surfaces, this path is 10 dB weaker than path 5, which undergoes a diffraction but two less reflections. This demonstrates why diffraction rather than multiple reflection is often the most important propagation mechanism in the outdoor environment

Path	Sequence of Building Interactions	Time (ns)	Power (dBm)
1	Tx - D(2) - D(1) - Rx	118	-102.5
2	Tx - D(2) - R(3) - Rx	144	-91.8
3	Tx - D(2) - D(1) - R(3) - Rx	144	-101.2
4	Tx - D(2) - D(3) - Rx	148	-129.6
5	Tx - D(2) - R(1) - R(2) - Rx	170	-81.8
6	Tx - D(2) - R(1) - R(2) - D(1) - Rx	170	-90.9
7	Tx - D(2) - R(3) - R(2) - Rx	174	-103.5
8	Tx - D(2) - R(1) - D(2) - R(3) - Rx	188	-102.3
9	Tx - D(2) - R(1) - R(2) - D(1) - R(3) - Rx	196	-110.7
10	Tx - R(1) - R(2) - R(1) - R(2) - Rx	231	-91.6

Table 1: Arrival time and building interactions for the first 10 significant paths to arrive at point 1. In the second column, “D” denotes a diffraction, “R” denotes a reflection, and the numbers refer to the buildings in Fig.4.

To compare the GTD time domain response directly to the FDTD time domain results, the GTD time domain fields are determined from

$$E_{GTD}(t) = F^{-1}\{E_{GTD}(f) \times E_1(f)\}, \quad (4)$$

where F^{-1} denotes the inverse Fourier transform, $E_1(f)$ is the Fourier transform of the excitation pulse at one meter from the source point, and $E_{GTD}(f)$ is the frequency domain response evaluated using an electric field amplitude of 1 V/m at one meter from the source. The GTD time domain predictions are compared to the FDTD time domain fields in Fig. 5. By referring to Table 1 and Fig. 4, it is possible to associate specific paths with the peaks in the FDTD response. For example, the doubly diffracted path which arrives first at point 1 at 118 ns is clearly present, and the amplitude and overall shape are in good agreement with the FDTD results.

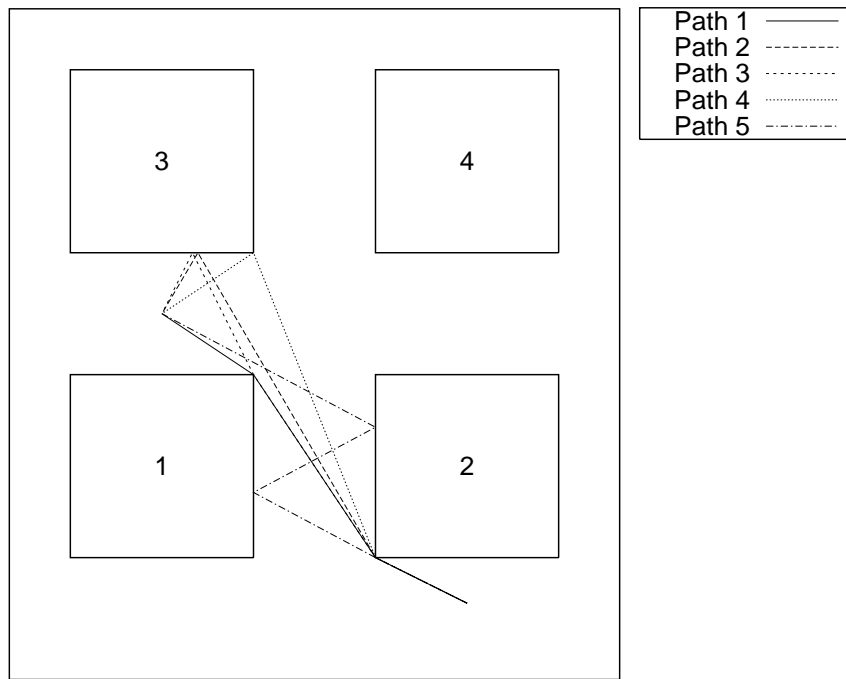


Figure 4: Ray paths to point 1

4. Conclusion

In this paper techniques are presented for introducing the correct spherical wave spreading into 2-D FDTD fields and for comparing the propagation paths predicted by GTD to the FDTD calculated time domain response. An application to a simple geometry has shown that the diffracted fields calculated with the UTD finite conductivity diffraction coefficients are shown to be in good agreement with the FDTD calculated electric field strength. The FDTD calculated time domain fields are found to be in good qualitative agreement with the ray optics picture of high frequency propagation. As the propagation prediction methods are improved in the future, FDTD simulations may prove to be a useful tool for evaluating the accuracy of these methods.

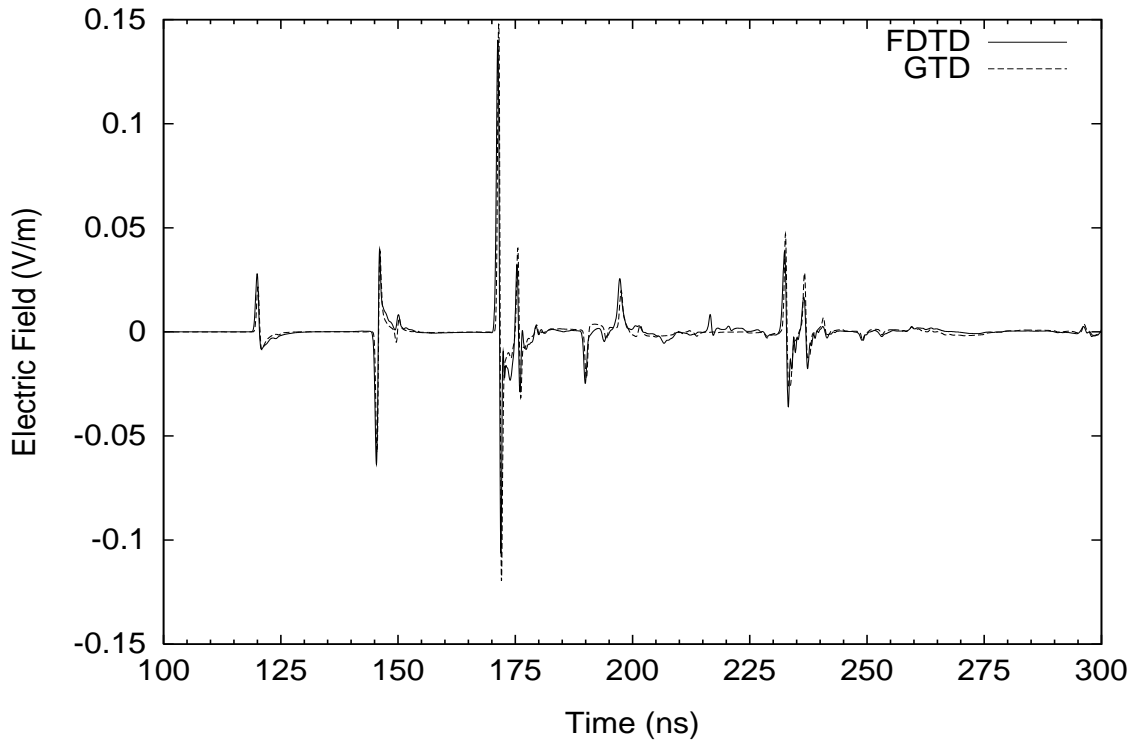


Figure 5: Comparison of FDTD and GTD time domain fields

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