Application of Moving Window FDTD to Predicting Path Loss Over Forest Covered Irregular Terrain

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Abstract

A new wave oriented approach to modeling radiowave propagation based on extended finite difference time domain (FDTD) method has been developed. The new approach takes advantage of the fact that when a pulsed radio wave propagates over a long distance the significant pulse energy exists only over a small part of the propagation path at any instant of time. This allows the use of a relatively small FDTD computational mesh that exists only over a portion of the propagation path and move along with the pulse. At the leading edge of the FDTD mesh inside the moving window the appropriate terrain and foliage parameters are added to the mesh. At the trailing edge the terrain and foliage that have been left behind by the pulse are removed. The Moving Window FDTD (MWFDTD) method has previously been applied to propagation over different types of irregular terrain. This paper extends this approach to forest covered terrain by treating the foliage as a lossy dielectric layer. Comparisons with path loss measurements show good accuracy and illustrate the advantages of a full wave method.

1. Introduction

A variety of methods have been applied to the prediction of radio propagation over irregular terrain. For ray models, it is recognized that the results must be based on several levels of approximations. These approximations typically include homogeneous atmosphere, a bare earth, and a simplified (typically linearized) approximation to the terrain variations, and approximate reflection and diffraction coefficients. For some situations the ray-based methods provide sufficient accuracy. In other situations they do not, and must be augmented by other calculation methods.

The full wave electromagnetic calculation method that is most efficiently applied to electrically large problems is the Finite Difference Time Domain (FDTD) method. FDTD offers several advantages over the commonly used ray and parabolic equation (PE) methods. It is full wave, so that the approximations and assumptions needed for application of PE and ray methods do not limit its accuracy. It can include all of the pertinent information available for the propagation path, including terrain profile, terrain permittivity and conductivity and vegetation features.

A straightforward application of FDTD to propagation is very wasteful of computer memory, since for a propagating pulse the energy is essentially confined to a localized portion of the entire path. All of the FDTD mesh that is outside of the region containing the significant pulse energy is wasted memory and computation time. A significant improvement in efficiency is obtained by allowing the FDTD mesh to move with the pulse. Thus the FDTD mesh needs only to be long enough in the dimension along the propagation path to contain the dispersed pulse, and high enough to include the terrain profile and a few Fresnel zones above the highest elevation. As the pulse propagates toward the receiving antenna at the velocity of light, the FDTD mesh moves along with the pulse. At the leading edge of the FDTD mesh the appropriate parameters (terrain elevation, forest height, constitutive parameters of terrain and foliage) are added to the mesh. At the trailing edge the terrain and foliage that have been left behind by the pulse are removed. Absorbing boundaries are used appropriately at the borders of the computational space. This approach is described in more detail in [1], and other applications of this approach are presented in [2,3].

2. Lossy Dielectric Slab Foliage Model

At VHF and UHF radiowave propagation through a forest can be modeled by treating the leaves and branches as a collection of randomly oriented scatterers. It has been shown that the forward scattered field can be determined by replacing the randomly distributed scatterers by an effective complex permittivity. The effective permittivity can be determined from the size, orientation, density, and dielectric constitutive parameters of the branches and leaves using the approach in [4,5]. This yields an effective permittivity for the foliage which is frequency and polarization dependent. The upper frequency limit of this model is not well established, but good results have been obtained up to 500 MHz and the model may be applicable in some cases at higher frequencies.

Applications of a lossy slab forest model to path loss prediction have usually been limited to a flat ground with a uniform forest cover. One of the advantages of the moving window FDTD (MWFDTD) method is that no additional assumptions are required to apply this model to propagation over highly irregular terrain with a discontinuous forest cover with variable height and tree types.

3. Comparison to Measured Path Loss

In order to validate MWFDTD's ability to model propagation over irregular terrain with vegetation, MWFDTD results were compared to path loss measurements taken by the Institute for Telecommunication Sciences (ITS) in Colorado mountains [6]. Two propagation paths are considered – one with the transmitting antenna located in an open meadow (R2-003-T5-Open), and the other with the transmitter located several hundred meters away within a dense grove of pine trees (R2-003-T5-Concealed). The terrain profiles for the open and concealed transmitting sites are shown in Figures 1 and 2. The forest covered sections were determined from ITS descriptions of the sites and information given on a topographical map of the area. In both profiles, the transmitter is located at the left-hand edge at a height of 6.6 m above the terrain. The receiver lies at the right end of the terrain profiles, and extends vertically from 1 to 13 m above the terrain.

Using a window of 75 meters wide by 360 meters tall, the MWFDTD method calculated the propagation of a horizontally polarized modulated pulse with a frequency centered at 230 MHz over the terrains. The FDTD grid spacing of 5 points/wavelength (26 cm) was used with a time step of 0.167 ns.

The ground was assumed to have a relative permittivity of 4, and conductivity of 0.01 S/m. The foliage was modeled using a single layer effective permittivity model using a relative permittivity of 1.03 and a conductivity of 4.9×10^{-4} S/m. All trees were assumed to have a height of 9 m.

Figure 3 shows the path loss at 230 MHz predicted by MWFDTD and the ITS measurements for both transmitting sites. The path loss data is given as a function of height at the common receiver location. The MWFDTD calculations show very good agreement with the measurements for the open transmitting site. The measurements for the concealed site show an oscillation not present in the MWFDTD results, but the calculated values match the average of the measurements quite well and predicts the additional 10 dB of loss due to placing the transmitter inside the forest.

4. References

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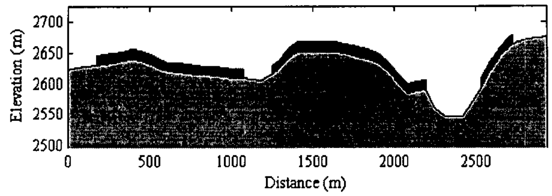

Figure 1: The R2-003-T5-Open terrain profile for which the transmitter is outside the forest is show above. The dark layers indicate the sections of the terrain covered by forest.

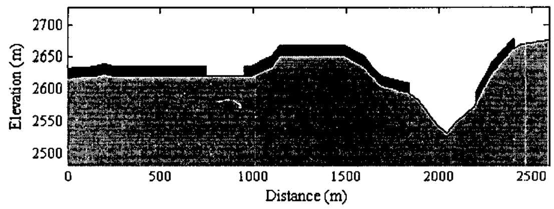

Figure 2: The R2-003-T5-Concealed terrain profile in which the transmitter is inside the forest is shown above.

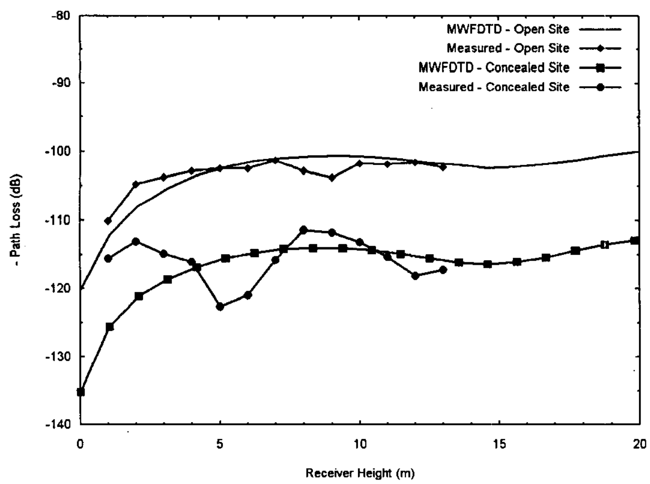

Figure 3: Comparison of MWFDTD calculations and ITS measurements for R2-003-T5-C (concealed site) and R2-003-T5-O (open site)