SIMULATION AND MEASUREMENT OF NEAR-GROUND WAVE PROPAGATION FOR INDOOR SCENARIOS

Fikadu T Dagefu* and Kamal Sarabandi
The Radiation Laboratory, Department of Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, MI. 48109-2122
E-mail: fikadu@umich.edu

Introduction

Efficient and versatile wave propagation models for indoor and urban environments can find applications in many areas including wireless channel characterization, environmental sensing and radar applications such as fire and earthquake rescue missions. There are various indoor field prediction techniques available in the literature such as ray tracing, hybrid techniques and empirical models that are based on measurement results [1-2]. Models based on numerical solvers such as MoM,FEM and FDTD are usually not preferred due to high computational cost. Ray tracing techniques, being a high frequency approximation, are not valid for lower frequency (lower UHF and VHF) applications. In addition, existing ray-tracing routines, which are most commonly used for indoor field prediction, are inadequate for evaluating the signal coverage for near-ground networks since the scattered wave from the ground is only approximated by Geometrical Optics (GO) which neglects the more dominant higher order Norton surface waves. Therefore, for near-ground transceivers deployed in indoor and urban environments these higher order waves and their interactions with building walls and other indoor obstacles should be taken into account for accurate field calculations. A semi-analytic propagation model for indoor scenarios that fully takes into account the Norton waves by making use of the Dyadic Green's function for a half-space dielectric medium was recently proposed in [3]. A physical optics type approximation was utilized to handle scattered field from building walls which are the dominant scatterers in indoor settings. The derivation and validation of the technique using a numerical solution for the 2D case were presented. In this work, the method is extended to a more realistic indoor propagation scenarios where multipe scatterers exist. In the first section, the semi-analytic technique for 3D multi-wall scenarios is described followed by measurement results used to validate the new method for 3D single wall-building geometry. To further validate the accuracy of the proposed model, field coverage comparison between the semi-analytic method and a full-wave solver (Semcad X) for various cases is also presented.

3D Semi-analytic near-earth propagation model

In [3], an efficient semi-analytic model for near-ground wave propagation in the presence of a single building wall above ground with infinite extent (2-D problem) was presented and validated using a full-wave numerical solver. In this section, the model is first extended to 3D case and further developed to allow field calculation

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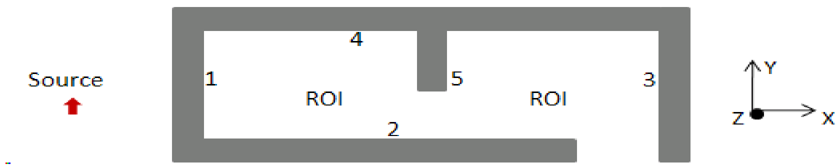

Figure 1: A schematic showing a top view of multi-wall indoor propagation scenario where an infinitesmal dipole is the source and ROI represents region of interest.

in the presence of multiple building walls and other indoor scatterers. It should be noted that, even though the focus here is on near-ground transceiver nodes, the formulation is general and is valid for arbitrary transceiver node heights. For transceivers located in close proximity to the ground (less than a wavelength), higher order surface waves which are neglected in the more commonly used ray tracing routines become dominant component of the received field compared to the direct and GO reflected components. This is particularly important at lower RF bands (VHF and lower UHF) for ad hoc communication scenarios. In order to efficiently calculate the field coverage in an indoor setting such as the setup shown in Fig.1, our approach utilizes accurately calculated 3D Dyadic Green's function for a half-space dielectric medium($\overline{\overline{G}}_{00}$). An accurate and efficient computation of the Dyadic Green's function for a half-space dielectric can be found in [4]. Dielectric blocks with effective dielectric constants are used to model building walls.

The way the scattered field from each wall is calculated in the semi-analytic model is as follows. First the incident field on the surface of the walls that are in the line of sight of the transmitter (e.g. wall 1 in Fig.1) is calculated by integrating the current on the transmitting antenna with $\overline{\overline{G}}_{00}$. The incident field on the wall surface is then decomposed into TE and TM components. By making use of boundary conditions, the incident fields and the dielectric properties of the wall, the total electric field inside the building wall is computed by treating the wall locally as an infinite dielectric slab. Similar to the 2D case, the induced polarization currents are calculated by invoking volume equivalence principle. Once the polarization currents for the first wall are computed, the field from these currents and the original current are computed using the Green's function for any observation point within or outside the building. Geometric optics is used to account for the shadowed walls. Basically near-ground fields from the source and the lit wall are reflected/transmitted at the specular points on the shadowed walls according to the Fresnel law of reflection and transmission to account for the effect of the other walls. This process can be followed multiple times to capture all multipath among the building walls. Since Norton waves decay very fast with propagation distance, one simplifying feature of near-ground propagation is that the convergence in field calculation is reached much faster using ordinary ray tracing. Simulations show that one or two iteration is sufficient to reach convergence. This approximation appears to be more accurate away from the edges of the walls and corners as the near-field edge effects are not properly accounted for in our approximate solution.

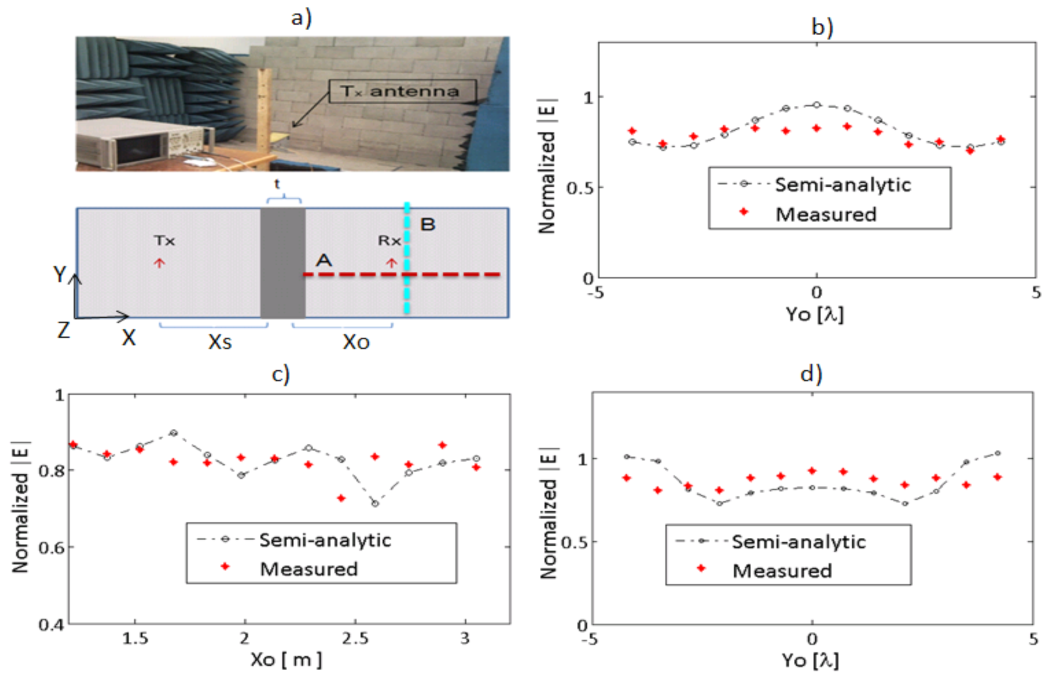

Figure 2: a) Measurement setup, Wall dimensions: h = 1.56m, L= 2.56m and W = 0.09m. Also shown are field comparisons at 1.21GHz for, (b) trace A: $y_s = y_o = 1.37m$, $z_s = 0.24m$ and $z_o = 0.20m$, (c) trace B : $x_o = 0.91m$, $z_s = 0.87m$ and $z_o = 0.79m$, and d) trace B: $x_o = 0.91m$, $z_s = 0.24m$ and $z_o = 0.20m$.

Validation using measurement and numerical Results

To examine the validity of the proposed approach comparison against measurements under controlled environment and computer simulations using a full-wave model is carried out. Controlled experiments under laboratory condition are preferred over realistic settings as all the experimental parameters are well-characterized and features that can lead to uncertainity in the measurements cab be suppressed or removed. As shown in Fig.2a, the experimental setup consists of a single wall build out of bricks and two horn antennas used as Tx and Rx positioned on either side of the wall. The two antennas are then connected to the two channels of a network analyzer via long cables. The whole setup is surrounded by absorbers to minimize unwanted scattering from other objects in the laboratory. The S21 (the ratio of the signal at the receiving channel to the signal at the transmitting channel) is swept from 1GHz to 5GHz with 20MHz frequency step. The measurements were performed for various positions of the receiving antenna in order to characterize the field variation on one side of the wall. The same measurements were also performed without the wall to establish a reference for calibration. Unwanted multiple reflections are first removed by taking the IFFT of the raw data, performing time-domain gating and taking the FFT to obtain the frequency domain response of the transmission through the wall. Finally, the resulting data is calibrated by dividing the transmission measurement obtained with the wall by that obtained without the wall. The comparison results (Fig.2) show very good agreements. The method was also implemented for a setup

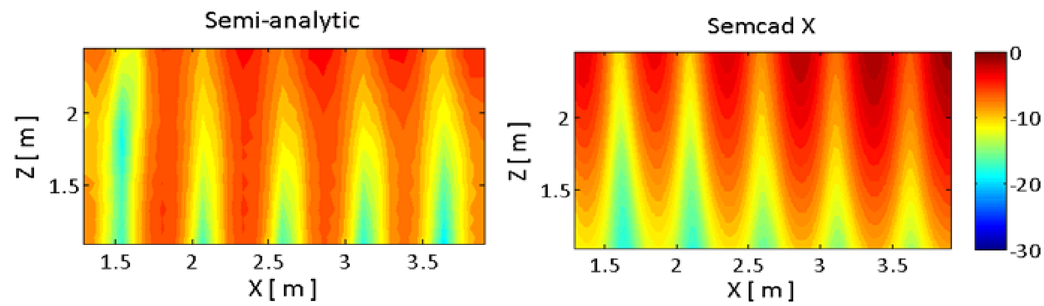

Figure 3: Field coverage comparison inside a room computed using the semi-analytic method and Semcad X ,$(x_s, y_s, z_s) = (-15m, 0m, 0.24m)$ and $(x_o, y_o, z_o) = (1m : 4m, 0m, 0.24m)$ and frequency = 300MHz.

(similar to Fig.1) where an infinitesimal dipole located just above the ground and is radiating outside a room consisting of four walls. It should be noted that the effects of doors, windows and other indoor obstacles are not included in this implementation, but these changes can be integrated in our semi-analytic model. As can be seen in Fig.3, the field coverage results computed using the semi-analytic technique are in good agreement with that of a numerical solver (Semcad X).

Conclusion

A Semi-analytic model for near-ground wave propagation in the presence of building walls that was proposed in [3] is extended to 3D multi-wall propagation scenarios. The extension to 3D and a method to take into account multiple reflections in the presence of multiple building walls is presented. Measurement results under laboratory conditions for validation using a single concrete wall and different transceiver arrangements is discussed. Field coverage comparison between the new semi-analytic method and an FDTD solver for various cases is also included.

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