HIGH-FREQUENCY / SHORT PULSE METHODS FOR WAVE PROPAGATION

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Abstract: High frequency / short pulse wave propagation modeling and simulation strategies will be reviewed in this presentation invited for the special session honoring Prof. Leopold B. Felsen on his 80th birthday.

INTRODUCTION

Narrow and broad band wave propagation either natural or man-made environments are of interest for many decades, since the success and quality of any communication depends directly on the propagation characteristics. The applications may range from wireless communication (indoor/outdoor propagation) to satellite communication, from subsurface imaging to radars, waveguides, optical fibers, microstrip networks, etc. The availability of massive computational resources has made it possible to go from the early, idealized, analytically tractable models to the new, sophisticated numerical models with realistic approaches for nearly a decade. This presentation aims to summarize these methods, their current status, and challenges, and to discuss future trends. The focus will be on the propagation scenarios pictured in Fig. 1; propagation through guiding environments with transversely as well as longitudinally varying refractivity, and with varying boundary contours (rural propagation), and vertical- and/or horizontal-plane propagation along a chosen street among the buildings (urban propagation).

Figure 1: (a) Rural (b) urban radiowave propagation scenarios. The problem is to predict path loss between any specified two points (a) above the 3D, spherical Earth’s surface having lossy, irregular terrain, and above which exists inhomogeneous, time-varying atmosphere layers, from troposphere up to ionosphere and above, (b) among the buildings with imperfect, penetrable boundaries, including edges and tips that cause reflection, refraction, diffraction, surface and traveling waves, and shadowing.

Because of the difficulty and impossibility of the inclusion and citation of all of the studies on this subject, here, only a short list with a few classical books [1-5], and papers are given in the references from which one can reach almost all major contributions in this area.

MODELING AND SIMULATION STRATEGIES

Major modeling and numerical simulation strategies are listed in Fig. 2 [6], which varies from mathematical exact representations for idealized geometries, to pure numerical ones, from purely empirical ones, based on extensive path loss measurements to hybrid techniques that combine two or more methods to extend their range of validity and accuracy.

Early efforts for determining field behavior in a guiding environment were to express propagation characteristics in terms of progressing (ray-type) or oscillatory (mode type) constituents, from which rigorous analytical algorithms can be developed. Normal modes (NM) are the solution of strictly-separable wave equations [6]. They are orthonormal wave functions with finite energy and are tagged by distinct longitudinal propagation constants. The mode concept can be extended to weakly non-separable environments with slowly varying longitudinal characteristics. This gives rise to adiabatic modes (AM),...
which are the solutions of weakly non-separable wave equation [7], and intrinsic modes (IM), which, in turn, extend the AM concept [8]. There are also analytical studies based on edge and/or tip diffraction effects, surface waves, traveling waves, etc.

Propagation of general source-excited wave fields can be synthesized in terms of these building blocks, and may serve as reference for validation, verification and calibration purposes. To go beyond in more realistic environments, one has to resort to numerical modeling simulation approaches. Pioneering numerical modeling studies are in frequency domain, and one of the well-known methods is the parabolic equation (PE) (see, for example, [9] for details). The PE has been in use for many decades, first applied in two-dimensional (2D) underwater acoustics and then in electromagnetics and optics with various names (e.g., SSPE, IFD-PE and BPM as given in Fig. 2). The PE techniques have been improved to handle propagation effects over irregular terrain as well as lossy boundaries. Three-dimensional (3D) PE techniques, either in scalar form or in vector form, have also been developed to study HF, VHF, UHF, and microwave propagation for the last couple of years [10,11]. Today, the PE method that is used to analyze radiowave propagation in radar and radio communication systems has become a dominant, frequency-domain tool for assessing clear-air and terrain effects on propagation. Its applicability has been extended to regions where regular PE does not work by including domain truncation, impedance boundaries and the implementation of fast hybrid methods combining ray-tracing and PE techniques [9].

Recently, time domain techniques such as the finite-difference time domain (FDTD) and the transmission line matrix (TLM) have started to be applied to realistic propagation problems [12-14]. The entire propagation domain can not be discretized in the FDTD or TLM scheme when long-range and/or high frequency propagation is of interest. One approach for modeling propagation of localized wave objects through complex environment is to apply a sliding window technique via the FDTD or TLM. Since the propagation (sliding) window traces a semi-open region, powerful free-space simulators, such as the perfectly matched layer (PML) routines, are essential for the success of the FDTD and TLM simulations. The two simulators, TDWP and TLM-WP, based on the FDTD and TLM, respectively, have been tested (i.e., validated and calibrated) against analytical exact as well as measurement results for a variety of different rural and urban propagation scenarios in 2D [14]. Their extension to 3D scenarios is quite straightforward, but requires massive computer resources, even parallel processing techniques. Hybrid methods that combine the asymptotic ray technique and the FDTD have also been presented [15], with several alternative moving window formulations for a pulsed, plane wave propagation in planar stratified media.

Empirical studies based on statistical evaluations of long term measurements have also been of interest since early days of mobile communication [16]. There are many empirical models that are in use today, unfortunately, they are site-, and frequency-specific. For example, Okumura model is based on a number of measurements at various frequencies in urban areas in Japan, and is recommended for use for frequencies between 150 MHz – 1GHz; Hata model uses Okumura’s measurements and introduces approximate
equations that are valid to ranges up to 15-20 km. Moreover, either empirical or not, deterministic models are not expressed in terms of parameters, such as delay spread, direction of arrival, bit error rate (BER), etc. If a propagation simulator is desired to be used in wireless communication it is important to incorporate these parameters (the final report of the EU project Cost 231 is a good source which outlines those empirical models with various comparisons against practical data [17]).

The parameterization of general transient fields in terms of localized pulsed-beams (PB), wave packets, and time-domain Green’s functions in various media are also being investigated by Felsen and his colleagues [19,20].

CONCLUSIONS AND DISCUSSIONS
Designing effective communication and radar systems, and planning reliable coverage maps for radio and cellular communication links necessitates a good understanding of electromagnetic wave propagation in 3D realistic environments. The computer technology (i.e., memory and speed) is in a level to supply basic requirements for the numerical simulations. Both frequency and time domain numerical simulation techniques have become mature enough to handle propagation in 2D environments. Current efforts and the trend in modeling and simulation strategies are to extend those studies into 3D environments. These issues will be addressed in this presentation.

REFERENCES