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EDITORIAL

Toward Ubiquitous Real-Time Radio Propagation Modeling: The Exploitation of Cyber Resources, GPU and Fast and Accurate EM Algorithms

Radio propagation modeling and prediction play an important role in the understanding of electromagnetic (EM) wave propagation in complex environments, as well as in the design of wireless communications and radar systems.

Propagation modeling can be traditionally classified as theoretical, empirical, and numerical. Theoretical propagation modeling is aimed at finding ways to describe basic physical processes such as wave interaction with surfaces, slabs, wedges and other structures through proper mathematical formulations. Such formulations are accurate and fast but only applicable to simple and ideal cases. The empirical approach is based on extensive measurements carried out in a typical environment and provides a set of formulas for propagation prediction in similar environments. The third approach, the numerical approach, where theoretical or semi-empirical formulations are applied to complex problems with the aid of numerical methods, is the focus of this Special Section of IEEE Access. It is well known that in modern science and engineering, numerical simulation is as important as theoretical and experimental research.

Radio propagation modeling using numerical simulations is facing several challenges. First, the description of the propagation environment (including high resolution 3D terrain and building structures, weather conditions, vegetation, traffic, and others) is often not accurate or non available. Second, the frequency-dependent characteristics of the propagation of EM waves make it almost impossible to develop a single simulation method that covers all frequency bands in wireless communications and radar applications with good accuracy and efficiency. Third, the computational resources, although increasing rapidly, are still a bottleneck for radio propagation simulation in complex environments. This is especially true if the goal is real-time simulation, i.e. the real-time use of propagation models within communication systems to assist their functioning and optimize performance.

Nevertheless, numerical methods are necessary for accurate propagation modeling in complex scenarios, and for extending capabilities toward the prediction of the space–time distribution of the received signal in multipath environments. Such capabilities will assist in the design and in the functioning of future wideband, multi-gigabit radio systems, which will heavily exploit the multipath nature of the radio channel.

Within numerical methods for EM propagation modeling, Ray Tracing (RT) models and full-wave EM models are of great importance. In the former case Geometrical Optics and its extensions provide a ray-based representation of radio wave propagation. In the latter, exact field representations using Maxwell's equations or other formulations are solved by means of numerical methods.

In this special section, a wide variety of papers are collected covering various studies on Propagation, Channel Modeling and applications.

A review of RT propagation modeling is given in *Yun et al*. (Ray tracing for radio propagation modeling: Principles and applications). Fundamental RT concepts and most recent progress are described. A perspective of RT is given in the paper where the Authors argue that RT will play a key role in the forthcoming development of intelligent, accurate, and real-time propagation models.

GPU acceleration for RT models has been widely studied in computer graphics. In the paper of *Cadavid et al.* (Using 3-D video game technology in channel modeling), GPU's are exploited for radio propagation using RT. Different game engines are surveyed and data formats for 3D propagation environments are proposed.

In the paper by *Degli-Esposti et al*. (Ray-tracing based mm-wave beamforming assessment), RT is considered as a propagation modeling engine and, more importantly, as a real-time tool to assist future beamforming techniques at mm-wave frequencies, which will be necessary to foster gigabit wireless data applications.

Ray-based modeling of diffuse scattering at millimeter wave frequencies and its incorporation into RT models may be necessary to achieve good prediction accuracy. In the paper by *Pascual-Garcia et al.* (On the importance of diffuse scattering model parameterization in indoor wireless channels at mm-wave frequencies), the characteristics of diffuse scattering at 60 GHz are investigated and an experimental procedure is used to parametrize diffuse scattering models based on the Effective Roughness approach.

Full wave methods such as the method of moments (MoM) can also play an important role. In the invited paper by

Pham-Xuan et al. (Modified multilevel fast multipole algorithm for stationary iterative solvers), a modified MLFMA is developed to speed up the simulation of wave propagation by using two simple algorithms to determine the small subsets of cubes to be recomputed.

When describing multipath propagation, it is important to group paths into clusters for optimal and computationally efficient channel modeling. In the work by *Cheng et al.* (Performance of a novel automatic identification algorithm for the clustering of radio channel parameters), a new algorithm is developed for automatic paths clustering. The algorithm is found to outperform the well-known K-means method.

A key part of propagation modeling is represented by measurements which not only can be used to derive empirical models but also serve as the ultimate validation of theoretical and numerical model. The topic of path clustering is treated from the experimental point of view in *Yin et al.* (Experimental multipath-cluster characteristics of 28 GHz propagation channel). In this work channel measurements are carried out at 28-GHz using wideband sounding signals and the SAGE algorithm is used to extract the delay and angular cluster parameters. It is shown that a higher number of multipath clusters can be identified using the proposed method with respect to traditional methods.

Finally in Zhang *et al.* (Dynamic channel modeling for an indoor scenario at 23.5 GHz), RT and measurements are used to characterize dynamic channels in an indoor environment at 23.5 GHz. Results show that most paths have life durations within 5 m, with dominant paths (i.e. direct and single-bounce paths) lasting much longer than the average. The authors point out that such values seem consistent with the effective design of adaptive beam tracking algorithms based on the spatial consistency of the strongest propagation paths.

We thank all the contributors of this special section, which we hope will be of interest not only for the radio propagation and channel modeling community, but also for other areas such as communication systems and computer graphics. We appreciate the encouragement of the Editor-in-Chief and the continuing help of Staff Members, which helped make this special section a success.

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