

Guest Editorial

Channel and Propagation Models for Wireless System Design I

I. BACKGROUND

THE AGE OF wireless began at the turn of the 20th century, when Guglielmo Marconi demonstrated the use of electromagnetic waves to transmit telegraph signals from ships at sea to stations on shore. Marconi and his peers knew well the importance of understanding how radio signals propagate between two points for, only with that understanding could systems be designed to have the desired range and performance at the least cost. Throughout the century that followed, physicists, mathematicians, and engineers labored to characterize the relationships that govern radio propagation in different frequency bands and physical environments. Some cases seem quite predictable. For example, on line-of-sight (LOS) routes with elevated antennas and directive beams, propagation generally follows a deterministic free-space model. Even there, however, behavior can be complicated by the effects of rain (especially above 10 GHz) or occasional anomalous multipath (e.g., on long microwave paths). At the other end of the predictability spectrum, perhaps, are the over-the-horizon routes using ionospheric scattering [in the high-frequency (HF) bands] or tropospheric scattering [in the very high-frequency (VHF) bands]. In between are the ultra-high-frequency (UHF), microwave and millimeter-wave paths used in personal communications, and other wireless services, where the end users are in uncontrolled positions, down in the clutter of scattering objects, and possibly mobile. These transmission paths are the wireless channels to which this two-part special issue of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS is dedicated.

Characterizations that are based on actual propagation mechanisms, involving approximations to Maxwell's equations or related laws of physics, are called *propagation models*. Their ultimate application is to site-specific scenarios, wherein ray tracing and diffraction theory are used to predict channel responses within a specified environment. These models are especially useful for system deployments; however, they are less well suited to generic studies, and their utilization is computation-intensive.

Alternatively, *statistical* descriptions of the channel responses, called *channel models*, can be used. These are often based on measurements taken over many environments, though they can also be derived using the outputs of site-specific propagation models. Channel models find use in the design and pretest evaluation of wireless systems in general and of mitigation techniques in particular. They are generic, but their

formation can be quite labor-intensive and they are not well suited to specific deployments.

Taken together, propagation and channel models are essential components of the system simulation software, hardware channel emulators, and wireless system planning and optimization tools that are used throughout the development/deployment process. They support the development of methods for mitigating channel impairments, help in forming regulations and standards, facilitate the making of good design and deployment decisions, and reduce the probability of unpleasant surprises when actual service begins.

As expectations for the performance and reliability of wireless systems expand, the importance of propagation and channel modeling in system design, evaluation, and deployment will continue. This is the primary motivation for the two-part issue that begins in these pages and ends with the August issue. Our aims are to stimulate interest in propagation and channel modeling; increase understanding of major topics and current advances in the field; and promote dialog among propagation experts, systems engineers and equipment designers. We hope and believe the set of papers assembled here will serve those aims.

II. EVOLUTION OF WIRELESS CHANNEL CHARACTERIZATION

The topic of wireless channels spans a range of applications, including, but not limited to, cellular/PCS, wireless local area networks (WLANs), and fixed wireless services. It also spans frequencies from UHF to microwaves to millimeter-waves (and even beyond!), and environments from indoor picocells to urban microcells to local (or even regional) macrocells. To illustrate the growth in demands for modeling these channels, it is instructive to chart the evolution of statistical channel modeling for cellular/PCS systems.

The first-generation of cellular (~1980) used analog frequency modulation in narrowband channels (25–30 kHz bandwidths) near 900 MHz. In these circumstances, temporal dispersion due to multipath was not a concern; only path loss really mattered. Statistical modeling, thus, consisted mostly of characterizing the multipath fading (usually Rayleigh), shadow fading (usually lognormal), and the inverse-distance law.

The second-generation (~1990) featured digital modulations in channel bandwidths of 200 kHz (for GSM) or 1.25 MHz (for IS-95) at frequencies up to 2 GHz. It, thus, became necessary to both characterize temporal dispersion and extend path loss models to higher frequencies. The third-generation, which is upon us, features channel bandwidths up to 5 MHz, which expands the needed precision of dispersion modeling. Moreover,

increasing demands for capacity and quality have led to schemes using multiple antennas at one or both ends of the link, creating the additional need for *angle-of-arrival* modeling.

Thus, we see how changing requirements and approaches to cellular services have expanded the demands on channel modeling. In the same spirit, we can expect new demands for every new wireless service deployed in every new frequency band and physical environment. The papers in this special issue span a considerable range along each of these dimensions.

III. ABOUT THE SPECIAL ISSUE

Over 60 papers were submitted from the worldwide community of experts on propagation and channel models. Given limitations in both time and size, hard choices had to be made, resulting in a set of 29 papers, 16 of which are in this issue. The total set divides into four main categories, each having representation in both issues. The categories are as follows.

Path Loss and Dispersion Modeling: Specifically, advances and insights in path loss and dispersion modeling for the UHF and microwave bands.

Spatio-Temporal Channel Modeling: Featuring the channel properties that need to be understood for systems using transmit diversity, multiple-input/multiple-output (MIMO) techniques, and other multiple-antenna scenarios.

Higher-Band Channels: Specifically, modeling in frequency bands above 10 GHz, as used for some indoor wireless applications and for some outdoor, short-range, narrow-beam, fixed wireless services.

Other Wireless Channels: Featuring topics that expand the domain of wireless, notably, high-altitude-platform systems (HAPS), infrared (IR) systems, ultra-wideband (UWB) systems, and land mobile satellite (LMS) systems.

This special issue was put together in less than a year, and many people deserve our thanks for helping to make it possible. Foremost, we are grateful to all the authors who submitted papers and who accepted our editorial decisions and guidance, including sometimes-demanding deadlines. Special appreciation goes to all of the reviewers for their expertise, diligence and timeliness. Finally, our sincere thanks to M. Pursley, who suggested this issue and gave his advice and help at every stage; and to S. McDonald and J. Cichocki, who gave information and valuable support whenever they were needed.

LARRY J. GREENSTEIN, *Guest Editor*
AT&T Labs-Research
Middletown, NJ 07748 USA

JØRGEN BACH ANDERSEN, *Guest Editor*
Aalborg University
Center for Personkommunikation
Aalborg 9220, Denmark

HENRY L. BERTONI, *Guest Editor*
Polytechnic University
Department of Electrical and Computer Engineering
Brooklyn, NY 11201 USA

SHIGERU KOZONO, *Guest Editor*
Chiba Institute of Technology
Department of Electronics
Narashino-shi, Chiba-ken 263-8522, Japan

DAVID G. MICHELSON, *Guest Editor*
University of British Columbia
Vancouver, BC, V7K 1X4 Canada

WILLIAM H. TRANTER, *J-SAC Board Representative*



Larry J. Greenstein (M'59–M'67–SM'80–F'87) received the B.S., M.S., and Ph.D. degrees in electrical engineering from Illinois Institute of Technology, Chicago, in 1958, 1961, and 1967, respectively.

From 1958 to 1970, he was with IIT Research Institute, Chicago, IL, working on radio interference and anti-clutter airborne radar. He joined Bell Laboratories, Holmdel, NJ, in 1970. Over a 32-year AT&T career, he conducted and led research in digital satellites, point-to-point radio, lightwave transmission, and wireless communications. His interests in wireless communications have included measurement-based channel modeling, microcell system design and analysis, diversity and equalization techniques, and system performance analysis and optimization. He recently retired from AT&T Labs-Research, Middletown, NJ, as a Technology Leader.

Dr. Greenstein is an AT&T Fellow, has won two best paper awards, and has been a Guest Editor, Senior Editor, and Editorial Board Member for numerous publications.



Jørgen Bach Andersen (M'68–SM'78–F'92) received the M.Sc. and Dr. Techn. degrees in engineering from the Technical University of Denmark (DTU), Lyngby, in 1961 and 1971, respectively.

He was a Research Assistant and Associate Professor at DTU until 1973. Since 1973, he has been with Aalborg University, Aalborg, Denmark, as a Professor, since 1993 in radio communications. He has been a Visiting Professor at the Polytechnic University, Brooklyn, NY, the University of Arizona, Tucson, AZ, and in New Zealand and Austria. Since 1993, he has been Director of the Center for Personkommunikation (CPK), Aalborg, Denmark, a research center dealing with modern wireless technologies. He has been active in European research programs, especially the COST activities on mobile communications. Apart from the communications aspects, he also has an interest in the biological aspects of electromagnetic radiation. His research interests have mainly been within the mobile channel, and its antenna and communication aspects. He is co-author of two monographs on these topics to appear in 2002.

Dr. Andersen is a former vice president of the International Scientific Radio Union (URSI).



Henry L. Bertoni (M'67–SM'79–F'87) received the B.S. degree in electrical engineering from Northwestern University, Evanston, IL, in 1960, the M.S. degree in electrical engineering, in 1962, and the Ph.D. degree in electrophysics, in 1967, both from the Polytechnic Institute, Brooklyn, NY (now the Polytechnic University).

After graduation he joined the faculty of Polytechnic University, eventually becoming Head of the Electrical Engineering Department from 1990 to 1995 and 2001, and serving as Vice Provost of Graduate Studies from 1995 to 1996. He has authored or co-authored over 120 journal and proceedings papers, of which four have received best paper awards. His current research deals with the theoretical prediction of UHF propagation characteristics in urban environments. Much of his work on cellular and other wireless systems is described in his recent book *Radio Propagation for Modern Wireless Systems* (Englewood Cliffs, NJ: Prentice-Hall PTR, 2000).

Dr. Bertoni was the first Chairman of the Technical Committee on Personal Communications of the IEEE Communications Society, and he recently completed an appointment as Distinguished

Lecturer of the IEEE Antennas and Propagation Society.



Shigeru Kozono (M'84) received the M.S. degree from Niigata University, Niigata, Japan, in 1972, and the Dr.Eng. degree from Kyoto University, Kyoto, Japan, in 1988.

In 1972, he joined the Electrical Communication Laboratories, NTT, Yokosuba, Japan. In April 1993, he joined the Chiba Institute of Technology, Chiba-ken, Japan, as Professor of Electronic Engineering. His research has included work on mobile radio propagation loss in urban and suburban areas and in tunnels, and on base station space and polarization diversity reception and co-channel interference measurement techniques for high capacity mobile and portable communication systems. He has also engaged in research on systems and system circuit designs. His research interests include propagation for microcell systems, wideband mobile radio channels, and bit-error rates for digital transmission.

Dr. Kozono is a member of the Institute of Electronics Information and Communication Engineers of Japan, the Information Processing Society of Japan, and the Research Institute of Signal Processing, Japan.



David G. Michelson (S'80–M'84–SM'99) received the B.A.Sc., M.A.Sc., and the Ph.D. degrees, in electrical engineering from the University of British Columbia (UBC), Vancouver, BC, Canada.

He currently holds an appointment as an Adjunct Professor at the UBC. From 1994 to 1996, he was a Postdoctoral Research Fellow in the MDA/NSERC Radar Remote Sensing Group at UBC. Since then, he has served as a Research Consultant in the area of propagation and channel modeling to various industry and government organizations, including AT&T Wireless Services, AT&T Labs-Research, Sierra Wireless, and the Government of Canada.

Dr. Michelson a member of the Applied Computational Electromagnetics Society. He serves as an Associate Editor of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, and as chair of the IEEE VT-S Technical Committee on Propagation and Channel Modeling.