Matthias Pätzold, Alain Sibille,
KainamThomas Wong, and Alenka Zajić

The State of the Art in Propagation and Mobile Channel Modeling

In recent years, the ever-increasing demand for multimedia services, high mobility, and global connectivity has resulted in an explosion of new technologies for wireless communication systems. The design of all components of wireless communication systems, ranging from digital modulation schemes over channel coding techniques up to higher-layer protocols, is influenced by the propagation characteristics of the mobile channel. A thorough understanding of mobile channels is, therefore, crucial for the development, performance optimization, and testing of present as well as next-generation mobile communication systems. This is the reason why exploring the mobile channel has been a key research topic since the beginning of mobile communications. Currently, the research on propagation and mobile channel modeling involves a variety of challenging topics, such as the modeling of vehicle-to-vehicle channels; high-speed railway channels; power-line communication channels; multiple-input, multiple-output (MIMO) channels; air-to-ground channels for future unmanned aircraft systems; and indoor-to-outdoor channels, to name only a few. The objective of this special issue is first to capture the state of the art in the fascinating areas of propagation and mobile channel modeling and second to make recent research results readily comprehensible to a wide readership. To meet these objectives, this special issue is composed of seven articles providing an overview of the state-of-the-art research in propagation and mobile channel modeling.

The first article, "Power-Line Communication" by Pierre Degauque, Igor S. Stievano, Sergio A. Pignari, Virginie Degardin, Flavio Canavero, Flavia Grassi, and Francisco J. Cañete, is written in a tutorial style. Power-line communication for transportation systems is a technology that can provide high-speed data transmission by exploiting the existing power network with great benefits in terms of cost and weight reduction. The aim of this article is to present recent advances in the characterization and modeling of power-line communication channels in transportation systems. Special emphasis is given on the modeling and characterization of in-vehicle, spacecraft, and aircraft power-line communication channels. Starting from the typical topological features of the power networks used for these transportation systems, the article gives a comprehensive overview of the state-of-the-art channel modeling approaches that have been proposed in the literature.

The second article, "Over-the-Air Testing of MIMO-Capable Terminals" by Wei Fan, Xavier Carreño, Pekka Kyösti, Jesper Ødum Nielsen, and Gert Frølund Pedersen, outlines a new testing technology for evaluating multiple-antenna systems in realistic multipath propagation environments. As MIMO techniques continue to play a key role in upcoming wireless communication standards, there remains the need to emulate realistic multipath propagation environments for anechoic chamber testing of multiple antenna systems. To meet this need, the article proposes a multiprobe anechoic chamber setup that offers the user the capability to generate arbitrary multipath fading characteristics of a multiprobe spatiotemporal channel with arbitrary polarization characteristics. This contrasts with the mode-stirred reverberation chamber setup, which is capable of emulating only an isotropic multipath environment.

The third article, "Inside-Out Propagation" by Sanaa Hamid, Arafat Al-Dweik, Maysam Mirahmadi, Khaled Mubarak, and Abdallah Shami, discusses a generalized indoor-to-outdoor propagation model based on ray-tracing and exhaustive measurement campaigns. While there is a large body of knowledge on the characteristics of indoor, outdoor, and outdoor-to-indoor channels, very few papers have studied the indoor-to-outdoor channel characteristics. The goal of this article was to capture the complex effects of the architectural layout, fading, shadowing, and building materials and to develop a practical

Digital Object Identifier 10.1109/MVT.2015.2412192
Date of publication: 19 May 2015

nonsite-specific model to be used in the interference analysis and planning of next-generation femtocell systems. Femtocell systems are considered as an attractive solution for extending the coverage area and capacity for indoor users. One of the main technical challenges in designing femtocell systems is mitigating the radio-frequency interference. Therefore, studying the channel properties of residential femtocell systems as well as developing propagation models for interference characterization are of crucial importance for the development of future home-based communication systems.

The fourth article, "Vehicular Communications" by Wantanee Viriyasitavat, Mate Boban, Hsin-Mu Tsai, and Athanasios V. Vasilakos, presents a comprehensive survey on recent developments in the area of channel modeling for vehicular communications. Channels for vehicular communications differ from other types of wireless channels mainly by diverse and dynamic propagation environments, high mobility, and comparatively low antenna heights. The article describes and classifies the most relevant vehicle-to-vehicle channel models. The classification is made on the basis of the propagation scale, propagation environment, modeling approach, and the main properties of the channel models. Guidelines are provided for choosing a suitable vehicle-to-vehicle channel model for a given environment, such as a parking garage, tunnel, highway, and suburban area. Special attention is devoted to the usability of the channel models for the evaluation of protocols and applications for future cooperative intelligent transportation systems.

The fifth article, "Channel Characteristics in High-Speed Railway" by Binghao Chen, Zhangdui Zhong, Bo Ai, Ke Guan, Ruisi He, and David G. Michelson, offers an overview of research on high-speed railway channels. High-speed rail constructions are blooming in many parts of the world, especially in East Asia. For high-speed railway applications, this article overviews the radio channel's key characteristics of macro- and microscopic fading. Specifically, this survey summarizes empirical findings from over two dozen research papers, listing nine path loss models, six equations for the Rician factor, two types of Doppler spectra, and a wealth of numerical values on the root-mean-square delay spread as well as the maximum relative propagation delay. Special emphasis is placed on the viaduct scenario, where trains travel along an elevated bridge (which presents a largely unobstructed scenario), and the cutting scenario, which involves a semi-enclosed architecture in the railway track.

The sixth article, "Unmanned Aircraft Systems" by David W. Matolak and Ruoyu Sun, addresses the increasingly important use of unmanned aircraft systems, for which the radio channel toward a ground station has specific features that need to be quantitatively investigated and modeled for the proper design of wireless air–ground communication systems. Beyond the sole consideration of propagation path loss, the article details wideband characteristics, which involve multipath reflections resulting from the terrain shape and the presence of buildings. Based on measurement data, the authors model fading characteristics and other phenomena versus the link distance and arrive at an adequate agreement between measurement and model results.

The last article, "More Than the Eye Can See" by Ergin Dinc and Ozgur B. Akan, provides a review of the existing channel modeling techniques for troposcatter communications. This article also discusses the most important diversity techniques that can be employed in troposcatter communications to eliminate the effects of short-term fading. The term *troposcatter* refers to a method of communicating with radio signals over beyond-line-of-sight (b-LoS) communication links up to 300 km. This method uses the tropospheric scatter phenomenon, where radio waves are randomly scattered if they pass through the upper layers of the stratosphere. Troposcatter communication systems were developed in the 1950s for point-to-point communications b-LoS (over the horizon) between remote geographic areas, where microwave and cable links were not feasible. Since then, troposcatter communications have been extensively used for military operation, for offshore oil and gas operators, as well as for interisland civil telecommunication applications. With technological advancements, troposcatter communication systems have significantly reduced in size, allowing them to be carried in military or commercial trucks. Thus, troposcatter is a promising candidate for mobile b-LoS communication links as well.

Author Information

Matthias Pätzold (matthias.paetzold@uia.no) received his Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from Ruhr-University Bochum, Germany, in 1985 and 1989, respectively, and his habil. degree in communications engineering from the Technical University of Hamburg-Harburg, Germany, in 1998. From 1990 to 1992, he was with ANT Nachrichtentechnik GmbH, Backnang, Germany, where he was engaged in digital satellite communications. From 1992 to 2001, he was with the Department of Digital Networks at the Technical University of Hamburg-Harburg, Germany. Since 2001, he has been a full professor of mobile communications at the University of Agder, Grimstad, Norway. He is the author of several books and numerous technical articles. He has participated in numerous conferences, serving as a member and as a chair of technical program committees. He has received 13 Best Paper Awards. He is a Senior Member of the IEEE.

(continued on page 103)

 (continued from page 27)

Alain Sibille obtained the Ph.D./habilitation degree from the University of Paris 7 in 1985. He was with France-Telecom R&D and then moved to ENSTA-ParisTech, where he led the Electronics and Computer Engineering department until 2010. He is currently professor and vice chair for Research of the Communications & Electronics Department at Telecom-ParisTech. His main expertise lies in ultrawideband communications and systems, especially the interactions between antennas, channels, and signal processing. He chaired the European Wireless Conference 2007 in Paris and cochaired the TPC of PIMRC in 2008. He is a National delegate and steering committee member of the European Cooperation Action COST IC1004 "Cooperative Radio Communications for Green Smart Environments." He is also involved in URSI-France as secretary general and vice chair of Commission C "Radio communication and Signal Processing Systems."

KainamThomas Wong (ktwong@ieee.org) received the B.S.E. degree in chemical engineering from the University of California, Los Angeles, California; the B.S.E.E. degree from the University of Colorado, Boulder, Colorado; the M.S.E.E. degree from Michigan State University, East Lansing, Michigan; and the Ph.D. degree in electrical and computer engineering from Purdue University, West Lafayette, Indiana, in 1985, 1987, 1990, and 1996, respectively, all in the United States. He was a manufacturing engineer at the General Motors Technical Center from 1990 to 1991 and a senior professional staff member at the Johns Hopkins University Applied Physics Laboratory from 1996 to 1998. Between 1998 and 2006, he had been a regular member of the faculty at Nanyang Technological University, Singapore, the Chinese University of Hong Kong, Hong Kong, and the University of Waterloo, Ontario, Canada. Since 2006, he has been with the Hong Kong Polytechnic University as an associate professor. He has been on the editorial boards of several journals and is an elected member of the IEEE Signal Processing technical committee on sensor and multichannel processing from 2013 to 2015. His research interest includes sensor-array signal processing and signal processing for communications. He was conferred the Premier's Research Excellence Award by the Canadian province of Ontario in 2003. He is a Senior Member of the IEEE.

Alenka Zajić received the B.Sc. and M.Sc. degrees from the School of Electrical Engineering, University of Belgrade, Belgrade, Serbia, in 2001 and 2003, respectively. She received the Ph.D. degree in electrical and computer engineering from the Georgia Institute of Technology, Atlanta, Georgia, United States, in 2008. Currently, she is an assistant professor in the School of Electrical and Computer Engineering at Georgia Institute of Technology. Prior to that, she was visiting faculty in the School of Computer Science at Georgia Institute of Technology, a post-doctoral fellow in the Naval Research Laboratory, and a design engineer at Skyworks Solutions Inc. Her research interests include span areas of electromagnetics, wireless communications, signal processing, and computer engineering. She received the Neal Shepherd Memorial Best Propagation Paper Award in 2012, the Best Paper Award at ICT 2008, the Best Student Paper Award at WCNC 2007, and was the recipient of the Dan Noble Fellowship in 2004, awarded by Motorola Inc. and IEEE Vehicular Technology Society for quality impact in the area of vehicular technology. Currently, she is an editor for *IEEE Transactions on Wireless Communications* and the chair of the IEEE MTT/AP Atlanta Chapter.

VT