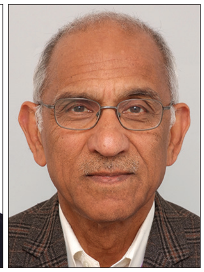
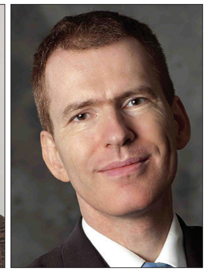
CHANNEL MODELS AND MEASUREMENTS FOR 5G

Jianhua Zhang



Mansoor Shafi



Andreas F. Molisch

Fredrik Tufvesson

Shangbin Wu

Koshiro Kitao

Some years ago, the late Larry Greenstein, known also as the father of radio propagation, published a beautiful article where he quotes Don Cox: "Before we can build a new radio system, we have to understand the propagation." In the 1970s, when AMPS was first introduced, Don Cox did pioneering studies in understanding of mobile radio propagation — mainly in the 850 MHz band. Since then, wireless mobile communication is well developed from first to fourth generation supported by plenty of channel studies in microwave bands (below about 6 GHz).

The fifth generation (5G) is expected to include new requirements, applications, and scenarios, and it will need massive and 3D multiple-input multiple output (MIMO), and increased spectrum via the use of millimeter-wave (mmWave) bands. The emerging techniques also pose new challenges to channel models. For example, 28 GHz is some 33 times higher in frequency relative to 850 MHz, and the channel bandwidth is 8000 times more than that of AMPS. These differences will increase even more when the operating frequency further increases. Reduced cell range, increased building penetration loss, human blocking, spatial consistency of some impulse response parameters, and so on are new properties that must be studied. Suffice it to say that propagation studies are time consuming and "not for the impatient as nature often reveals her secrets on a time table different from ours," as quoted by Larry in his article on 100 years of radio. It is therefore clear that more efforts are needed to understand propagation characteristics, especially in mmWave bands, and to demonstrate their impact on system design and deployment.

This main objective of this Feature Topic is to identify differences between propagation characteristics at microwave bands and at mmWave bands, summarize the current status of the 5G wireless channel modeling, and demonstrate the performance impact of channel models on system design and deployment. These considerations will enable simulation, evaluation, performance optimization, and network deployment of future 5G systems. We present eight articles that have been accepted after a rigorous peer review process.

The first contribution, "Microwave vs. Millimeter-Wave Propagation Channels: Key Differences and Impact on 5G Cellular Systems" by M. Shafi *et al.*, explains key differences in the propagation characteristics between the microwave and mmWave bands, including the large-scale propagation, bandwidth dependency of propagation parameters, the multipath cluster number differences, and spatial consistency, and also gives examples of how these differences impact 5G system design. The second article, "Recent Research on Massive MIMO Propagation Channels: A Survey" by P. Zhang *et al.*, summarizes the recent activities in massive MIMO channel research and identifies key propagation characteristics of the massive MIMO channel as well as their influence on massive MIMO systems. Several open issues for massive MIMO propagation modeling are also pointed out. The third article, "Millimeter-Wave Channel Measurement and Modeling: A NIST Perspective" by C. Gentile *et al.*, provides an overview of mmWave channel sounding through three types of systems: switched array, virtual array, and phased array at 28, 60, and 83 GHz, respectively. The authors describe how mmWave channel models — for path loss, dispersion, multipath tracking, Doppler spread, and blockage — differ from sub-6 GHz models.

The fourth article, "Spatial and Temporal Channel Characteristics of 5G 3D Channel Model with Beamforming for User Mobility Investigations" by U. Karabulut *et al.*, shows that a simplified and computationally efficient channel model is needed to evaluate when beamforming is applied to users connecting and switching between beams of the same or different cells. Most measurement campaigns measure the propagation channel between transmit and receive antennas that are (at least in the near field) free from surrounding obstacles. In reality, the UE is held by a person, which distorts the electromagnetic field and thus further changes the characteristics of the channel. The fifth article, "Spatio-Temporal Impact of Hand and Body Blockage for Millimeter-Wave User Equipment Design at 28 GHz" by V. Raghavan *et al.*, gives a description of the underlying effects, measurement results, and implications for the system design of this important aspect. Considering that high-gain narrow-beam antennas or beamformed antenna arrays will likely be used in mmWave bands, beamwidth, orientation, and shape of the narrow beam will impact channel properties. The sixth article, "Millimeter-Wave Radio Channels vs. Synthetic Beamwidth" by R.Y. Sun *et al.*, proposes a procedure to measure and model the channels vs. synthetic beamwidth and validate it by measure results.

Based on phased array transmitters and receivers operating at 60 GHz, the seventh article, "Empirical Effects of Dynamic Human-Body Blockage in Millimeter-Wave Communications" by C. Slezak *et al.*, presents a spatial dynamic channel sounding system, and the human-body statistical dynamic models are empirically studied by utilizing it. The last article, "A Channel Sounder for Massive MIMO and mmWave Channels" by J. Nielsen *et al.*, uses a setup with parallel receiver chains so that the device can measure in the sub-6 GHz range up to 128 antenna elements in 1.3 ms. Extending the frequency range through upconverters to the mmWave range, the > 6 GHz bands of interest in many 5G applications can also be measured.

We would like to thank all the authors for their excellent contributions and all the reviewers for their valuable comments. We also appreciate the strong and detailed support from Dr. Tarek El-Bawab, Editor-in-Chief of *IEEE Communication Magazine*, and the IEEE Communications Society publishing team.

BIOGRAPHIES

JIANHUA ZHANG (jhzhang@bupt.edu.cn) received her B.S. from North China University of Technology in 1994 and her Ph.D. degree from Beijing University of Posts and Telecommunications (BUPT) in 2003. Now she is a professor with the Information and Engineering College, BUPT. She continuously contributed to channel model standards from ITU-R M.2135 to 3GPP 36.873,900/901, and she was the Drafting Group (DG) Chairwoman of ITU-R IMT-2020 channel model. She has published more than 70 journal papers and received several best paper awards. Her research interests are massive MIMO and millimeter-wave channel modeling and transmission techniques, channel emulator, OTA test, and so on.

MANSOOR SHAFI (mansoor.shafi@spark.co.nz) received his B.S. and Ph.D. degrees in electrical engineering from the University of Engineering and Technology at Lahore and the University of Auckland in 1970 and 1979, respectively. He is currently employed at Spark NZ, and is a Telecom Fellow and an adjunct professor with the School of Engineering, Victoria University of Wellington. He has authored over 150 journal papers in wireless communications. He-shared the Best Tutorial Paper Award from the IEEE Communications Society in 2004 and the IEEE Donald G. Fink Award 2011. He was awarded membership in the New Zealand Order of Merit in the Queen's Birthday Honours 2013 for services to wireless communications.

ANDREAS F. MOLISCH [F] (molisch@usc.edu) is the Solomon Golomb — Andrew and Erna Viterbi Chair Professor at the University of Southern California. He previously was at TU Vienna, AT&T (Bell) Labs, Lund University, and Mitsubishi Electric Research Labs. His research interest is wireless communications, with emphasis on wireless propagation channels, multi-antenna systems, ultrawideband signaling, and localization. He is the author of 4 books, 19 book chapters, more than 220 journal papers, as well as 80 patents. He is a Fellow of the National Academy of Inventors, AAAS, and IET, as well as a member of the Austrian Academy of Sciences, and the recipient of numerous awards.

FREDRIK TUFVESSON (fredrik.tufvesson@eit.lth.se) received his Ph.D. in 2000 from Lund University, Sweden. After two years at a startup company, he joined the Department of Electrical and Information Technology at Lund University, where he is now a professor of radio systems. His main research interest is the interplay between the radio channel and the rest of the communication system with various applications in 5G systems such as massive MIMO, mmWave communication, vehicular communication, and radio-based positioning. He has authored around 80 journal papers and 140 conference papers, and recently received the Neal Shepherd Memorial Award ffrom *IEEE Transactions on Vehicular Technology* and the IEEE Communications Society Best Tutorial Paper Award.

SHANGBIN WU (shangbin.wu@samsung.com) received his B.S. degree in communication engineering from South China Normal University in 2009, his M.Sc. degree in wireless communications with distinction from the University of Southampton, United Kingdom in 2010, and his Ph.D. degree in electrical engineering from Heriot-Watt University, United Kingdom, in 2015. From 2010 to 2011, he worked as an LTE R&D engineer at New Postcom Equipment Ltd., China. From October 2011 to August 2012, he was with Nokia Siemens Network. He joined Samsung R&D Institute UK as a 5G researcher in November 2015.

KOSHIRO KITAO (kitao@nttdocomo.com) received B.S., M.S., and Ph. D. degrees from Tottori University, Japan, in 1994, 1996, and 2009, respectively. He joined the Wireless Systems Laboratories, Nippon Telegraph and Telephone Corporation, Kanagawa, Japan, in 1996. Since then, he has been engaged in research on radio propagation for mobile communications. He is now a research engineer at the 5G Laboratories, NTT DOCOMO, INC., Kanagawa, Japan. He is a member of the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan.