Future 5G Millimeter-Wave Systems and Termnals: Propagation Channel, Communication Techniques, Devices, and Measurements


Pablo Padilla


Jiro Hirokawac


Lars J. Foged


Juha Ala-Laurinahoo


Damir Senic


Astrid Algaba-Brazález


Ahmed Hussain


Juan F. Valenzuela-Valdés

The next generation (5G) of communication systems will face a complete set of significant challenges, such as ultra-high system capacity due to the traffic demand, massive device connectivity, ultra-low latency, reduction in energy consumption, and high quality of experience. In that context, 5G is called to produce a complete revolution in the way users can access content and services in their general activity across daily life. The evolution of communication systems has a direct and key role, offering major capacity and communication possibilities through the smart use of the available bandwidth and the propagation channel, and the deployment of higher frequencies at millimeter-wave (mmWave) frequency bands.

At the physical layer, the technical challenges are related to the development of RF devices and radiating elements, their proper characterization through appropriate measuring systems, the refinement of communication techniques, and the accurate wireless channel characterization for its smart usage.

The main objective of this Feature Topic is to present recent advances, technical aspects, and challenges surrounding mmWave 5G systems at the physical level so that the professionals involved in 5G definition and development can be aware of the technical challenges that arise in such systems. We present nine articles that have been accepted after a rigorous peer review process. These articles, devoted to mmWave 5G, are grouped into the following topics: manufacturing technology, antennas and RF devices, MIMO systems, channel measurements, and applications.

The first contribution, "Gap Waveguide Technology for Millimeter-Wave Antenna Systems" by E. Rajo-Iglesias *et al.*, is focused on manufacturing technology and presents an overview of a new type of family of low-loss antennas and components based on the recently developed gap waveguide technology, suitable for future mmWave 5G devices and antennas.

The next three articles are related to 5G mmWave antenna design and manufacturing. The article "Diffusion Bonding Manufacturing of High Gain W-band Antennas for 5G Applications" by E. Garcia-Marin *et al.* is devoted to illustrating the possibilities of the diffusion bonding technique applied to waveguide antennas operating in the W-band of 5G systems, including a circularly polarized cavity array prototype as a real example. The next article, "Low-Cost Millimeter-Wave Antenna with Simultaneous Sum and Difference Patterns for 5G Point-to-Point Communications" by A. Tamayo-Dominguez *et al.*, presents a low-cost solution for developing tracking antennas at mmWave bands. They provide the design of a radial line slot array (RLSA) antenna at W-band for 5G point-to-point communications, with 3D-printable gap waveguide technology for the feeding network. The third article related to 5G mmWave antennas, "Lens Antennas for 5G Communications Systems" by O. Quevedo-Teruel *et al.*, presents the principles of the operation of lens antennas and their potential application for 5G, highlighting the potential of two innovative techniques: transformation optics and metasurfaces.

The next two articles are related to mmWave MIMO techniques and devices. Y.J. Cho *et al.*, in their article "RF Lens-Embedded Antenna Array for mmWave MIMO: Design and Performance," propose the use of lens antennas for 5G mmWave beamforming systems as an alternative to beamforming without the heavy network of phase shifters. In the other article, "Feasible Transmission Strategies for Downlink MIMO in Sparse Millimeter Wave Channels," A. Vega-Delgado *et al.* discuss the use of reduced-size large antenna arrays for massive MIMO at mmWave frequencies, and point out the problem of high cost and power consumption required if signal mixers and analog-to-digital converters are used. They propose a possible cost-effective alternative based on the hybrid precoding transceiver architecture.

Regarding the propagation channel for mmWave 5G, two contributions are presented. In the first article, "Feasibility of Mobility for Millimeter-Wave Systems Based on Channel Measurements," S. Hur *et al.* identify and review the technical challenges that remain in 5G mmWave mobile networks. They present sample measurements of outdoor mmWave channels, emulate the mobile system operation in them, and discuss whether mmWave mobility is feasible. The next article, "Over-the-Air Radiated Testing of Millimeter-Wave Beam-steerable Devices in a Cost-Effective Measurement Setup" by W. Fan *et al.*, is devoted to reviewing radiated testing methods, with a focus on their principle and applicability for beam steerable mmWave devices. They propose a cost-effective simplified 3D sectored multi-probe anechoic chamber (MPAC) system with an OTA antenna selection scheme.

Finally, regarding applications, M. Garcia-Fernandez *et al.*, in their article "On the Use of Unmanned Aerial Vehicles for Antenna and Coverage Diagnostics in Mobile Networks," propose an in-situ antenna measurement and diagnostics system using compact and low-cost unmanned aerial vehicles, discussing the extension of the system to allow measurements at mmWave frequencies.

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 support from Dr. Osman Gebizlioglu and Dr. Tarek El-Bawab, previous and current Editors-in-Chief of *IEEE Communications Magazine*, respectively, and the IEEE Communications Society publishing team.

BIOGRAPHIES

PABLO PADILLA (pablopadilla@ugr.es) received his Ph.D. from the Technical University of Madrid, Spain. In 2009, he joined the Signal Theory, Telematics and Communications Department at Universidad de Granada, Spain, where he is currently an associate professor. His research interests are related to communication topics on microwave and mmWave: device and antenna design and measurement, and wireless channel characterization. He is an author of more than 50 high-impact journal contributions and more than 40 contributions to international symposia.

JIRO HIROKAWA [F] (jiro@ee.e.titech.ac.jp) received his D.E. degree in electrical and electronic engineering from Tokyo Institute of Technology, Japan, in 1994. He is currently a professor there. He was with the antenna group of Chalmers University of Technology, Gothenburg, Sweden, as a postdoctoral fellow from 1994 to 1995. His research area has been in slotted waveguide array antennas and millimeter-wave antennas. He is a Fellow of IEICE.

LARS J. FOGED [SM] (foged@ieee.org) received his M.Sc. from California Institute of Technology and is scientific director of MVG. He has been Secretary of the IEEE Antenna Standards Committee since 2004 and was Chair of the APS Industry Initiatives Committee in 2016–2017. He is an AMTA Fellow and received the AMTA Best Technical Paper Award and the Distinguished Achievement Award in 2013 and 2017. He has contributed to 200 papers on antenna design and measurement topics.

JUHA ALA-LAURINAHO (juha.ala-laurinaho@aalto.fi) received his Doctor of Science in Technology degree from Helsinki University of Technology (currently Aalto University), Finland, in 2001. He works as a staff scientist responsible for the mmWave and sub-mmWave antenna measurement facilities in the Department of Electronics and Nanoengineering at Aalto University. In addition to the development of antenna measurement techniques, his research interests include the design and fabrication of mmWave antennas for various applications.

DAMIR SENIC (damir.senic@nist.gov) received his M.Sc. (2008) and Ph.D. degrees (2014) from the University of Split, Croatia. He is currently with the University of Colorado and National Institute of Standards and Technology (NIST), Boulder, Colorado. His research interests include millimeter-wave radiocommunications and over-the-air measurements in reverberation chambers. In 2013–2014 he was a guest researcher with NIST, Boulder, Colorado. He was elected as a distinguished reviewer of *IEEE Transactions on EMC* in 2016.

ASTRID ALGABA-BRAZÁLEZ (astrid.algaba.brazalez@ericsson.com) received her Ph.D. from Chalmers University of Technology in 2015. She has been working as a senior researcher at Ericsson Research, Ericsson AB, Gothenburg, Sweden, since November 2014. Her main research interests include millimeter-wave antenna systems, including antenna array design, filters, transitions, and metamaterials. She has been involved in the development of gap waveguide and glide symmetry technology for millimeter-wave and sub-millimeter-wave applications.

AHMED HUSSAIN (ah.hussain@samsung.com) received his Ph.D. from Chalmers University of Technology in 2014. He has been working as a senior engineer at Samsung Electronics, Suwon, South Korea, since 2015. His main research interests include 5G millimeter-wave antenna systems, including antenna array design, measurement systems, and channel propagation. He has been involved in the development of 5G millimeter-wave antenna arrays for Samsung's 5G modules.

JUAN F. VALENZUELA-VALDÉS (juanvalenzuela@ugr.es) received his Ph.D. from the Technical University of Cartagena. In 2009, he joined EMITE Ing. as head of research. In 2011, he joined Universidad de Extremadura, and in 2015, he joined Universidad de Granada, where he is currently an associate professor. His current research areas cover wireless communications and wireless channel characterization. His publication record is composed of more than 80 publications, including 40 JCR journal papers and seven book chapters.