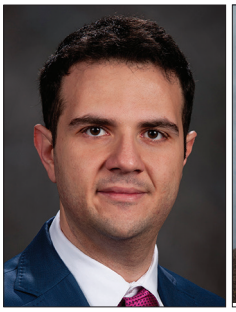
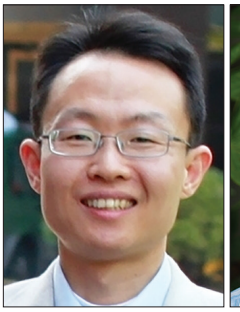
WIRELESS COMMUNICATIONS, NETWORKING, AND POSITIONING WITH UNMANNED AERIAL VEHICLES


Ismail Guvenc


Walid Saad


Mehdi Bennis


Christian Wietfeld


Ming Ding


Lee Pike

Enabled by the advances in computing, communication, and sensing as well as the miniaturization of devices, unmanned aerial vehicles (UAVs) such as balloons, quadcopters, and gliders have been receiving significant attention in the research community. Indeed, UAVs have become an integral component in several critical applications such as border surveillance, disaster response, traffic monitoring, and the transportation of goods, medicine, and first aid. More recently, new possibilities of UAVs for commercial applications and public service have emerged, with the potential to dramatically change the way in which we lead our daily lives. For instance, in 2013, Amazon announced a research and development initiative focused on its next-generation Prime Air delivery service. The goal of this service is to deliver packages into customers' hands in 30 minutes or less using small UAVs. The past couple of years have been pivotal in bringing UAV research to fruition as corroborated by an unprecedented proliferation of personal drones, such as the Phantom and Inspire from DJI, the AR and Bebop from Parrot, and the Solo from 3D Robotics.

Among the many technical challenges accompanying the aforementioned applications, leveraging the use of UAVs for delivering broadband connectivity will play a central role in the next generation of communication systems. Facebook announced in 2014 that they plan to use networks of drones that will circle in the stratosphere over specific population centers to deliver broadband connectivity. UAVs have also been proposed as an effective solution for delivering broadband data rates in emergency situations through low-altitude platforms. For example, the ABSOLUTE, ANCHORS, and AVIGLE projects in Europe have been investigating the use of aerial base stations to establish opportunistic links and ad hoc radio coverage during unexpected and temporary events. Such flying base stations can serve as a temporary, dynamic, and agile infrastructure for enabling broadband communications.

This *IEEE Communications Magazine* Feature Topic (FT) gathers articles from a wide range of perspectives that stem from different industrial and research communities. The primary goals of this FT are to advance the understanding of the challenges faced in UAV communications, networking, and positioning over the next decade, and provide further awareness in the communications and networking communities on these challenges, thus fostering future research. After a rigorous review process, six papers have been selected to be published in this May 2016 FT of *IEEE Communications Magazine*.

The first two articles provide a holistic perspective on the design, implementation, opportunities, and challenges of using UAVs for wireless communications applications. In particular, the article by Gomez *et al.*, "Designing and Implementing Future Aerial Communication Networks," which looks at the achievements and innovations harnessed by an aerial network composed of Helikite platforms. A trial phase of the system mounting LTE-A technology onboard Helikites serving ground users is interesting and offers a long-lasting solution, provided that efficient RF equipment in the Helikite is available. Subsequently, in "Wireless Communications with Unmanned Aerial Vehicles: Opportunities and Challenges," Zeng *et al.* provide an overview on architectural challenges of UAV deployment while also highlighting channel characteristics and operational constraints. The article concludes underscoring three key performance enhancing techniques using UAV controlled mobility, adaptive communication, relaying, and D2D-enhanced information dissemination.

The following two articles in this FT focus on propagation modeling and link characterization in UAV communications. In particular, in the article "LTE in the Sky: Trading Off Propagation Benefits with Interference Costs for Aerial Nodes" by Chiumento *et al.*, a study based on measurements and simulations has been conducted to investigate the impact of UAVs acting as either a base station or a user on a ground LTE network. In the article "On the Importance of Link Characterization for Aerial Wireless Sensor Networks," Ahmed *et al.* investigate the impact of environmental factors, antenna orientation, and multi-path fading on link-level performance of Zigbee-based UAV

communications, and recommend measures to improve communication performance considering such factors.

Finally, the last two articles study some forward-looking communications applications with UAVs, including game theoretical communications and millimeter-wave communications. In "A Green Strategic Activity Scheduling for UAV Networks: A Sub-Modular Game Perspective," Koulali *et al.* investigate the scheduling of beacons (discovery signals) from an energy efficiency perspective and formulate a model based on a non-cooperative game theory for competing drones. Xiao *et al.* explore the potential of UAVs for millimeter-wave communications in "Enabling UAV Cellular with Millimeter-Wave Communication: Potentials and Approaches," and investigate several related challenges, including beamforming codebook design, spatial-division multiple access, and ways of dealing with signal blockage.

The Guest Editors would like to thank the large number of people who significantly contributed to this FT, including the authors, reviewers, and *IEEE Communications Magazine* publications staff. We hope that the readers enjoy this FT and that the selection of articles stimulate new research and innovations in future UAV based wireless networks.

BIOGRAPHIES

ISMAIL GUVENC [S'01, M'06, SM'10] (iguvenc@fiu.edu) is an assistant professor at FIU. His recent research interests include heterogeneous wireless networks and 5G wireless systems. He has published more than 130 conference/journal papers, three books, and close to 30 patents. He also served as an Editor for *IEEE Communications Letters* and *IEEE Wireless Communications Letters*, and as a Guest Editor for several other journals. He is a recipient of the 2015 NSF CAREER Award.

WALID SAAD [S'07, M'10, SM'15] (walids@vt.edu) received his Ph.D from the University of Oslo in 2010. He is an assistant professor and the Steven O. Lane Junior Faculty Fellow in the Department of Electrical and Computer Engineering at Virginia Tech. His research interests include wireless networks, game theory, cybersecurity, and cyber-physical systems. He received the NSF CAREER award in 2013, the ONR Young Investigator Award in 2015, the 2015 Fred W. Ellersick Prize, and several conference Best Paper Awards.

MEHDI BENNIS [SM] (bennis@ee.oulu.fi) received his M.Sc. degree in electrical engineering jointly from the EPFL and the Eurecom Institute in 2002. He obtained his Ph.D. in December 2009 on spectrum sharing for wireless cellular systems. His main research interests are in radio resource management and game theory for 5G networks. He recently received the prestigious 2015 Fred W. Ellersick Prize and the 2016 IEEE Communications Society Best Tutorial Paper Award He is an adjunct professor at the University of Oulu.

CHRISTIAN WIETFELD [M'05, SM'12] (christian.wietfeld@tu-dortmund.de) received his Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from RWTH Aachen University, Germany. He is currently a full professor and the head of the Communication Networks Institute, TU Dortmund University, Germany. Since 2008, he has been actively contributing to the research on wireless networking of unmanned aerial vehicles as coordinator of various research efforts (e.g., Airshield, AVIGLE, Anchors) and as co-founder of the IEEE GLOBECOM Wi-UAV Workshop.

MING DING [S'10, M'12] (ming.ding@nicta.com.au) is a researcher at Data61 (previously known as NICTA), Australia. He has been working in the wireless industry for 9+ years. He has authored more than 30 papers in IEEE journals and conferences, about 20 3GPP standardization contributions, and a Springer book, *Multi-Point Cooperative Communication Systems: Theory and Applications*. As the first inventor, he holds 15 CN, 7 JP, 3 US, 2 KR patents and co-authored another 100+ patent applications on 4G/5G technologies.

LEE PIKE [M] (leepike@galois.com) has a Ph.D degree in computer science from Indiana University, Bloomington. He is currently the Cyber-Physical Systems program director at Galois, Inc., Portland, Oregon. Before that, he was a staff scientist in the NASA Langley Formal Methods Group. He has a Best Paper Award from FMCAD, 2011.