5G WIRELESS COMMUNICATION SYSTEMS: PROSPECTS AND CHALLENGES


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In the last year or so, significant momentum has started to build around the idea of a fifth generation (5G) for wireless communications technology. New research projects have started internationally, and research centers devoted to 5G technology have begun to open. At the ICC 2013 conference in Budapest, there were a number of keynote talks and special invited sessions addressing some of the key concepts around 5G technology. This Special Issue was created by *IEEE Communications Magazine* to help readers understand the current perspectives on 5G technology from both industry and academic standpoints.

In the last five to ten years, the speed at which standards have developed has been breathtaking. The first release of the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) system was frozen in December 2008, with commercial deployments beginning a year or two after that. The first release of LTE-Advanced was in March 2011, which made LTE formally compliant with the International Telecommunication Union (ITU) definition of the fourth generation of wireless technology, called IMT-Advanced. LTE also met the requirements set out by the mobile-operator-led organization Next Generation Mobile Networks (NGMN). Further releases of LTE-Advanced still continue. However, the standards bodies and industry are now organizing a timeframe to standardize 5G technology, which is expected to be between 2016 and 2018, followed by initial deployments around 2020.

The development of 3G and 4G wireless technology was mainly driven by demand for data services over the Internet. However, the drivers for 5G systems are likely to be much more diverse. There is still a demand for higher-capacity networks, especially in Asia, where network operators face major challenges in meeting the demands of large populations. New traffic types and data services are emerging, notably machine-to-machine communications to support concepts such as the smart grid, smart homes and cities, and e-health. These applications have very diverse communications requirements, and providing a single unified wireless technology to support them seamlessly alongside existing voice and Internet services will be a major task. In addition, future networks should be much more energy-efficient than current networks in order to make 5G a sustainable network technology in the long term. Ultimately, if 5G technology cannot offer a new paradigm over and above what can be achieved with LTE-Advanced, the technology will not be commercialized successfully.

This Call for Papers was timed in order to appear in print for the Mobile World Congress 2014. In spite of the relatively short timescales, almost 70 independent submissions were received. After a rigorous review process, 18 manuscripts were finally selected for publication. In order to present all of these papers, this Feature Topic has been split into two. The first set of nine articles will appear in this issue, with the second part scheduled for publication in May 2014.

The first article, "Towards Green and Soft: A 5G Perspective" written by authors from China Mobile, presents an operator's perspective on 5G technology. They identify two major themes in their article relating to greener wireless networks and the wide adoption of software controlled networks from the radio base station through to the core network. In order to deliver this vision, they then point to five key approaches they believe will be adopted in 5G networks. The first of these is the design of radio networks taking into account both energy efficiency and spectral efficiency. The second approach is to abstract future cellular networks, where base station processing is moved to the Internet cloud: the so-called C-RAN approach. The third strand relates to the separation of data and control channels following the software defined networking (SDN) principles now being adopted in wired networks. Fourth, they see a move toward large antenna arrays or massive multiple-input multiple-output (MIMO) concepts in order to provide much higher data capacities. Finally, they predict the adoption of full duplex concepts in future radios so that they are capable of transmitting and receiving in the same frequencies simultaneously.

The second article, "Five Disruptive Technology Directions for 5G," is written by authors from an equipment manufacturer, Alcatel-Lucent Bell Labs, supported by academic colleagues. In response to the challenges of 5G, they also identify five major directions for future research and standardization. Their first point is to argue that network design should move away from being "cell-centric" toward being "device-centric" and focus on the needs of user terminals. They also argue that 5G should adopt higher-frequency millimeter wave bands where much more bandwidth is available, albeit signal propagation may be less favorable. Third, they also point toward large antenna arrays or massive MIMO as a key 5G technology. Fourth, they argue for more intelligent terminals that are capable of mitigating interference and communicating directly with other devices without network assistance. Finally, they point to the requirement for 5G to support machine-to-machine communications in an effective and integrated manner.

The third article, "Network Densification: The dominant theme for Wireless Evolution into 5G," is written by authors from Qualcomm. They argue that the network needs to densify in three ways: spatial densification, spectral aggregation, and backhaul densification. Spatial densification covers the move toward more heterogeneous network deployments of macrocells, picocells, relays, and small cells as well as direct device-to-device communication. Spectral aggregation implies that future devices are capable of communicating on multiple frequencies simultaneously, as well as adopting new portions of spectrum such as the millimeter-wave bands. Finally, backhaul aggregation identifies the requirement that the backhaul connection from different cells into the core network must also improve to meet the higher demands 5G networks will place on it.

The fourth article, "Networks and Devices for the 5G Era," is co-authored by researchers from Intel and presents their vision for 5G. They draw attention to three major paradigm shifts related to the change in cellular network layout, changes in understanding mobile performance, and the growth in the number of radio technologies and devices. They bring attention to the growth of heterogeneous network architectures, such as combining macrocells, small cells, and relays with a variety of radio technologies including both cellular and wireless local area networks. They also envisage the adoption of new technologies such as massive MIMO, full duplex technology, and device-to-device communications. Future mobile terminals will have much improved context awareness, with knowledge of the user's requirements, the surrounding environment, and the network. The article also provides a helpful discussion on user terminal design and requirements, alongside radio spectrum issues.

The fifth article, "5GNOW: Non-Orthogonal, Asynchronous Waveforms for Future Mobile Applications," presents the perspective of a European 5G research project. Their focus is on how 5G will support machine-to-machine communications and the Internet of Things properly. They identify five major features that are required for this to happen. First, they propose a unified frame structure for the physical layer that can support both existing high data rate applications and machine-to-machine data traffic. Second, they support novel non-orthogonal waveforms that will provide better performance for the physical layer. Third, they propose the use of sparse signal processing that can decode bursty data traffic in an energy-efficient manner. Fourth, they highlight the importance of robust wireless systems that can perform well with real world limitations such as limited control channel bandwidth and imperfect channel knowledge. Finally, they highlight the importance of reducing the end-to-end delay of wireless links from tens of milliseconds to around 1 ms in order to meet the requirements of new machine-to-machine services.

The sixth article, "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," is written by authors from Samsung. This article describes their initial studies on the feasibility of using the 30 GHz band for data transmission. Their work shows that the use of antenna arrays can counteract the expected higher path loss at higher frequencies, enabling these bands to be used for cellular communications. They also describe a beamforming algorithm and discuss their initial field trial results of a practical 30 GHz antenna array system tested in Korea. Results show that good cellular coverage was achieved for both outdoor-outdoor and outdoor-indoor communication scenarios. These show the high potential of using millimetre-wave frequencies for 5G systems.

The seventh article, "Applications of Self-Interference Cancellation in 5G and Beyond," is written by authors from Kumu Networks. They are developing self-interference cancellation techniques for wireless receivers. This will enable full-duplex communications, where a radio can transmit and receive at the same time on the same frequency. Their article describes the basic self-interference cancellation radio architecture. It also shows how this approach can lead to more flexible spectrum use, including the concept of using the same frequencies for mobile terminals and backhaul links. Finally, they discuss how self-interference cancellation will affect future standardization.

The eighth article, "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks," is jointly co-authored by researchers from the United Kingdom and China. The article presents a future cellular network architecture using a combination of macrocells for outdoor coverage and relays, and small cells for indoor coverage. The article also identifies several key technologies for 5G systems. These include the use of massive MIMO and spatial modulation, which is a simple approach to increasing the capacity of antenna array systems. The article also discusses the use of cognitive radio as a means to use radio spectrum more effectively in the future. The mobile small cell concept is proposed where devices are installed on cars and trains along with the idea of promoting greener communications. The article concludes with some key research challenges to enable 5G.

The final article in this special issue is entitled "Cache in the Air: Enabling the Green Multimedia Caching and Delivery for 5G Systems" and is written by researchers at the University of British Columbia. It deals with data storage or caches through the mobile network, which can preemptively provide popular data requests, improving quality of service and reducing delay. The article describes different levels of caching that may be used in a mobile network. It also provides performance results to show the reduction in data delay that can be achieved and some examples of the potential savings in network costs due to caching.

Two of the Editors (Fettweis and Alamouti) have coauthored a separate article accepted through the magazine's open call route, entitled "5G: Personal Mobile Internet Beyond What Cellular Did to Telephony." This article appears alongside this Feature Topic. It discusses some key historical trends in wireless communications and looks forward to some of the major challenges that will necessitate new 5G standards. These include providing high bandwidth content with speeds in excess of 10 Gb/s. Furthermore, emerging monitoring and control applications should be integrated into 5G with very low wireless data rates combined with very low energy consumption. A third major trend is to develop new applications through the tactile wireless Internet, with total end-to-end delays of less than 1 ms.

In conclusion, the Editors would like to thank all authors who submitted manuscripts to this Feature Topic. Space constraints have meant that only nine of the 18 high-quality manuscripts accepted for this issue appear this month; the other nine will be published in the May 2014 issue. This will feature articles from new European research projects such as METIS and iJOIN, alongside contributions from Samsung, the Fraunhofer Heinrich Hertz Institute, the Chinese Academy of Sciences, and the University of Waterloo. The Editors wish to thank the reviewers who helped to review all of the papers in a very short timescale. They are grateful to the Editor-in-Chief, Sean Moore, for his encouragement and support to organize this special issue. They would also like to thank the publication staff, Joseph Milizzo and Jennifer Porcello, along with Richard Fritzsche of TU Dresden for their assistance. We finish this editorial by noting that two related Feature Topics on millimeter-wave technology and on end-to-end architectures for 5G are due to appear in the magazine in the second half of 2014.

BIOGRAPHIES

JOHN THOMPSON (john.thompson@ed.ac.uk) currently holds a personal Chair in Signal Processing and Communications at the School of Engineering in the University of Edinburgh. He specializes in antenna array processing, cooperative communications systems, and energy-efficient wireless communications. His work in these areas is highly cited, and his h-index is currently 18 according to the Web of Science. He is an elected Member-at-Large for the Board of Governors of the IEEE Communications Society from 2012–2014, the second largest IEEE Society. He was a Technical Program Co-Chair for the 2013 IEEE Vehicular Technology Spring Conference in Dresden, Germany, and serves as a track chair on Green Communications for the 2014 IEEE ICC in Sydney, Australia. He is lead Editor for this Feature Topic.

XIAOHU GE is currently a professor with the Department of Electronics and Information Engineering at Huazhong University of Science and Technology (HUST), China. He received his Ph.D. degree in communication and information engineering from HUST in 2003. He has worked at HUST since November 2005. His research interests are in the area of mobile communications, traffic modeling in wireless networks, green communications, and interference modeling in wireless communications. He has published about 80 papers in refereed journals and conference proceedings, and has been granted about 15 patents in China. He is leading several projects funded by NSFC, China MOST, and industry. He is taking part in several international joint projects, such as the RCUK funded UK-China Science Bridges: R&D on (B)4G Wireless Mobile Communications .

HSIAO-CHUN WU received his B.S.E.E. degree from National Cheng Kung University, Tainan, Taiwan, in 1990, and M.S. and Ph.D. degrees in electrical and computer engineering from the University of Florida, Gainesville, in 1993 and 1999, respectively. From March 1999 to January 2001, he was with Motorola Personal Communications Sector Research Laboratories as a senior electrical engineer. Since January 2001, he has been with the faculty of the School of Electrical Engineering and Computer Science, Louisiana State University, Baton Rouge. He has published more than 170 peer-refereed technical journal and conference articles in electrical and computer engineering. His current research interests include the areas of wireless communications and signal processing. He is an IEEE Distinguished Lecturer and is currently an Associate Editor for several IEEE journals.

RALF IRMER is currently leading Wireless Access Research in Vodafone Group R&D, United Kingdom. He received his Dr.-Ing. (Ph.D.) degree from Technische Universität Dresden in 2005 after studies in Dresden and Edinburgh. He joined Vodafone in 2005, where his major achievements were working with Verizon Wireless, China Mobile, and others to make LTE a global standard meeting operator requirements. He defined the Wi-Fi and small cell strategies and the future wireless network blueprint for Vodafone. He was also responsible for proving key strategies in pre-commercial trials, such as LTE TDD, LTE-Advanced, and 3G/LTE/WiFi small cells including backhaul. He currently leads the 5G activities in Vodafone. He holds several patents, and has published over 30 conference and journal publications, covering coordinated multipoint, multiuser MIMO, relaying, heterogeneous networks, and quality of user experience.

HONG JIANG is a researcher and project leader with Alcatel-Lucent Bell Labs in Murray Hill, New Jersey. He received his B.S. degree from Southwest Jiaotong University, Chengdu, China; M. Math. from the University of Waterloo, and Ph.D. from the University of Alberta, Canada. His research interests include signal processing, digital communications, and image and video compression. He invented key algorithms for VSB demodulation and HDTV video processing in the first generation ATSC system, which won a Technology and Engineering Emmy Award. He pioneered hierarchical modulation for satellite communication that resulted in commercialization of video transmission. He has published more than 50 articles in peer-reviewed scientific and engineering journals, and more than 40 U.S. patents in digital communications and video processing.

GERHARD FETTWEIS [F] earned his Ph.D. under H. Meyr's supervision from RWTH Aachen in 1990. After one year at IBM Research in San Jose, California, he moved to TCSI Inc., Berkeley, California. Since 1994 he is Vodafone Chair Professor at TU Dresden, Germany, with 20 companies from Asia, Europe, and the United States currently sponsoring his research on wireless transmission and chip design. He coordinates two DFG centers at TU Dresden, cfAED and HAEC. He is a member of acatech, has an honorary doctorate from TU Tampere, and has received multiple awards. In Dresden he has spun out 11 start-ups, and set up funded projects of close to €0.5 billion volume. He has helped organize IEEE conferences, most notably as TPC Chair of IEEE ICC 2009, IEEE TTM 2012, and General Chair of VTC Spring 2013 and DATE 2014.

SIAVASH ALAMOUTI received B.A.Sc. and M.A.Sc. degrees in electrical engineering from the University of British Columbia. He is currently an independent entrepreneur helping to build new companies with a focus on mobile personalization. He was Group R&D director for Vodafone from March 2010 until September 2013. Before that he was an Intel Fellow and CTO of the Mobile Wireless Group. Prior to joining Intel in 2004, he was the CTO of Vivato, and held various positions at Cadence, AT&T, and MPR Teltech. He is most well known for the invention of the Alamouti Code.