GUEST EDITORIAL

Internet of Things (IoT) in 5G Wireless Communications

During the past decade, the Internet of Things (IoT) has revolutionized the ubiquitous computing with multitude of applications built around various types of sensors. A vast amount of activity is seen in IoT based product-lines and this activity is expected to grow in years to come with projections as high as billions of devices with on average 6-7 devices per person by year 2020. With most of the issues at device and protocol levels solved during the past decade, there is now a growing trend in integration of sensors and sensor based systems with cyber physical systems and device-to-device (D2D) communications. 5th generation wireless systems (5G) are on the horizon and IoT is taking the center stage as devices are expected to form a major portion of this 5G network paradigm. IoT technologies such as machine to machine communication complemented with intelligent data analytics are expected to drastically change landscape of various industries. The emergence of cloud computing and its extension to fog paradigm with proliferation of intelligent 'smart' devices is expected to lead further innovation in IoT. These developments excite us and form a motivation to survey existing work, design new techniques, and identify new applications of IoT. Researchers, scientists, and engineers face emerging challenges in designing IoT based systems that can efficiently be integrated with the 5G wireless communications.

We received enthusiastic response to our special issue call for papers. A total of nine high quality papers were received out of which only seven were selected after a thorough review process. Invited articles were sought from two highly cited and accomplished researchers. Dr. Mischa Dohler (Fellow IEEE, Kings College London, UK) and Dr. Mung Chiang (Fellow IEEE, Princeton University, USA).

The first article "MIMO-NOMA design for small packet transmission in the Internet of Things", written by a collaborative team of researchers Ding et al.,, opportunistic serving mechanism is designed as part of the effort in the novel paradigm of Multiple Input Multiple Output Non-Orthogonal Multiple Access transmission scheme. Under the proposed method, one user is completely served with their quality of service requirements completely taken care of whereas second user is served opportunistically under the NOMA paradigm. The main contribution of this article is a design with two sets of system parameters, precoding and power allocation coefficients, in order to ensure that the potential of NOMA can be realized even if the users' channel conditions are similar. Two types of power allocation policies are developed in this paper. One is to meet first user's QoS requirements in the long term. For example, in order to satisfy its targeted outage probability. The other is in which to realize second user's QoS requirements instantaneously, e.g., the power allocation coefficients are designed to realize its targeted data rate for each channel realization.

Machine to machine communication has a significant role to play in emerging internet of things paradigm in years and decades to come. The emerging IoT-5G scenario extends sensor based IoT capabilities to robots, actuators and drones for distributed coordination and low-latency reliable execution of tasks at hand. In the invited work titled "Enabling the IoT machine age with 5G: Machine-type multicast services for innovative real-time applications" by Condoluci et al., core attention is focused on the end-to-end reliability, latency, and energy consumption comprising both up and downlinks for 5G-IoT communication. The authors propose the definition, design, and analysis of machine-type multicast service (MTMS). They recommend different procedures that need to be redesigned for MTMS and derive the most appropriate design drivers by analyzing different performance indicators, such as scalability, reliability, latency, and energy consumption. Overall, a very interesting read complemented by open problems and future research directions to pursue.

Security is one of the biggest challenges faced by Internet of Things. With devices becoming ubiquitous and pervasive in day to day lives necessitate reliable and secure algorithms. The third article, "Security enhancement for IoT communications exposed to eavesdroppers with uncertain locations" by Xu et al., develops a secure framework for eavesdroppers with Uncertain Locations in IoT. With the assumption that the locations of eavesdroppers change independently from hop to hop, authors derive an expression for the secrecy outage probability of the two-hop transmission, which is shown to be the upper bound of the outage probability when the locations of eavesdroppers remain unchanged. Following this expression, the end users formulate a secrecy rate maximization problem with the secrecy-outage probability constraint. The optimal rate design for codebooks and power allocation between the source and relay are derived. By studying the performance of the optimal scheme in some special cases, we obtain several insights concerning the setting of system parameters.

In the article, "Enabling massive IoT in 5G and beyond systems: PHY radio frame design considerations" by Ayesha Ijaz et al., the authors propose a flexible frame structure and design for massive Internet of Things (IoT) devices working in 5G wireless network. The authors also discussed

the interdependence of different frame design parameters, service requirements and characteristics of radio environment. Based on these interdependency, they provide guidelines for radio numerology design and elaborated on the frame design for IoT communications in 5G networks to support massive connection density of low-rate, low-power devices. The article concludes with some key research findings and challenges massive IoT in 5G wireless network.

It is estimated that in year 2020, 20 to 40 billion devices will be connected to the Internet as part of the Internet of Things. A critical bottleneck for realizing the efficient IoT is the pressure it puts on the existing communication infrastructures, requiring transfer of enormous data volumes. In the article ''CONDENSE: A reconfigurable knowledge acquisition architecture for future 5G IoT'', by Dejan Vukobratovic et al., the authors propose a architecture named 'Condense' which integrates the acquisition of IoT-generated data within the 3GPP MTC (machine type communications) systems. The proposed Condense architecture introduces a service within 3GPP MTC systems – computing linear and non-linear functions over the data generated by MTC devices This service brings about the possibility that the underlying communication infrastructure communicates only the desired function of the MTC- generated data (as required by the given application at hand), and not the raw data in its entirety. This transformational approach has the potential to dramatically reduce the pressure on the 3GPP MTC communication infrastructure. The article concludes by discussing challenges, provides insights, and identifies future research directions for implementing function computation and function decomposition within practical 3GPP MTC systems.

In the article, ''Frequency-domain oversampling for cognitive CDMA systems: Enabling robust and massive multiple access for Internet of Things'' by Su Hu et al., the authors utilize the concept of cognitive radio with dynamic non-continuous spectrum bands and code division multiple access to tackle the challenge of massive spectrum resource management in IoT. In order to suppress multiple access interference resulting from the non-orthogonality of partial available spectrum bins, carrier frequency offset, and spectrum sensing mismatch, the authors propose an enhanced receiver design that combines the frequency-domain oversampling scheme (FDO) and linear minimum mean square error (MMSE) method. The simulation results show that the cognitive-CDMA with FDO-MMSE receiver outperforms that with conventional per-user MMSE receiver in the presence of multipath fading channels, carrier frequency offset, and spectrum sensing mismatch.

In the invited article, ''A survey of client-controlled HetNets for 5G'' by Michael Wang et al., a comprehensive review is provided on spectrum of client-controlled HetNets for 5G networks: from the fully devolved distributed local control approach to the hybrid control approach where clients may make the decisions given some global information provided by the network. After giving a thorough review, the authors also provide future research directions

and recommendations for evolution of 5G heterogeneous networks as an enabler for next generation internet of things.

To conclude, the Editors would like to thank all authors who submitted their manuscripts against this Special issue. There had been some very exciting submissions though we could only accept best seven high quality submissions. The editorial staff also thanks the reviewers for their timely comments on the manuscript which helped us improve the presentation and quality of the content manifold. All the associate editors thank the Editor in Chief Dr. Michael Pecht for his assistance in making this special issue a reality. We would also like to thank the publications editor Ms. Kimberly Shumard for her continuous follow up on timelines and management of articles to ensure timely completion of the review process. We complete this note by letting the readers know to stay tuned with IEEE Access as we expect even more exciting issues in months to come.

WALEED EJAZ
Ryerson University,
Toronto, ON, Canada

ALAGAN ANPALAGAN
Ryerson University,
Toronto, ON, Canada

MUHAMMAD ALI IMRAN
University of Glasgow,
Glasgow, U.K.

MINHO JO
Korea University,
Sejong, South Korea

MUHAMMAD NAEEM
Ryerson University,
Toronto, ON, Canada

SAAD BIN QAISAR
National University of Sciences and Technology,
Islamabad, Pakistan

WEI WANG
Zhejiang University,
Hangzhou, China

WALEED EJAZ (S'12–M'14–SM'16) received the B.Sc. and M.Sc. degrees in computer engineering from the National University of Sciences and Technology, Islamabad, Pakistan, and the University of Engineering and Technology, Taxila, Pakistan, respectively, and the Ph.D. degree in information and communication engineering from Sejong University, South Korea, in 2014. He was with top engineering universities in Pakistan and Saudi Arabia as a Faculty Member. He was a Post-Doctoral Fellow with Queen's University, Kingston, Canada. He is currently a Senior Research Associate with the Department of Electrical and Computer Engineering, Ryerson University, Toronto, Canada. He also completed certificate courses on teaching and learning in higher education from the Chang School, Ryerson University. His current research interests include Internet of Things, energy harvesting, 5G cellular networks, and mobile cloud computing. He is currently serving as an Associate Editor of the *Canadian Journal of Electrical and Computer Engineering* and the IEEE Access. In addition, he is handling the special issues in *IET Communications*, the IEEE Access, and the *Journal of Internet Technology*.

ALAGAN ANPALAGAN (S'98–M'01–SM'04) received the B.A.Sc., M.A.Sc., and Ph.D. degrees in electrical engineering from the University of Toronto. He is currently a Professor with the Department of Electrical and Computer Engineering, Ryerson University, where he directs the research group involved in radio resource management and radio access and networking areas within the WINCORE Lab. He served as an Editor of the IEEE Communications Surveys and Tutorials from 2012 to 2014, the IEEE Communications Letters from 2010 to 2013, the *Wireless Personal Communications* (Springer) from 2011 to 2013, and the EURASIP *Journal of Wireless Communications and Networking* from 2004 to 2009. He has co-authored three edited books, *Design and Deployment of Small Cell Networks* (Cambridge University Press, 2014), *Routing in Opportunistic Networks* (Springer, 2013), and *Handbook on Green Information and Communication Systems* (Academic Press, 2012).

Dr. Anpalagan is a registered Professional Engineer in ON, Canada, and a fellow of the Institution of Engineering and Technology. He served as the TPC Co-Chair of the IEEE Globecom'15: SAC Green Communication and Computing, the IEEE WPMC'12 Wireless Networks, the IEEE PIMRC'11 Cognitive Radio and Spectrum Management, and the IEEE CCECE'04/08. He served as the Vice Chair of the IEEE SIG on Green and Sustainable Networking and Computing with Cognition and Cooperation (2015–), the IEEE Canada Central Area Chair (2012–2014), the IEEE Toronto Section Chair (2006–2007), the ComSoc Toronto Chapter Chair (2004–2005), and the IEEE Canada Professional Activities Committee Chair (2009–2011). He was a recipient of the Dean's Teaching Award in 2011, the Faculty Scholastic, Research, and Creativity Award in 2010 and 2014, the Faculty Service Award in Ryerson University in 2011 and 2013. He also received the Exemplary Editor Award from the IEEE ComSoc in 2013 and an Editor-in-Chief Top10 Choice Award in the IEEE Transactions on Emerging Telecommunications Technology in 2012.

MUHAMMAD ALI IMRAN (M'03–SM'12) received the M.Sc. (Hons.) and Ph.D. degrees from the Imperial College London, U.K., in 2002 and 2007, respectively. He is currently a Professor in Communication Systems with the University of Glasgow, the Vice Dean of the Glasgow College UESTC, and the Program Director of Electrical and Electronics with Communications. From 2007 to 2016, he was an Adjunct Associate Professor with The University of Oklahoma, USA, and a Visiting Professor with the 5G Innovation Centre, University of Surrey, U.K.

He has led a number of multimillion-funded international research projects encompassing the areas of energy efficiency, fundamental performance limits, sensor networks, and self-organizing cellular networks. He also led the new physical layer work area for 5G Innovation center at Surrey. He has a global collaborative research network spanning both academia and key industrial players in the field of wireless communications. He has supervised 21 successful Ph.D. graduates and published over 200 peer-reviewed research papers, including over 20 IEEE Transaction papers. He secured first rank in his B.Sc. and a distinction in his M.Sc. degree along with an award of excellence in recognition of his academic achievements conferred by the President of Pakistan. He received the IEEE Comsoc's Fred Ellersick Award 2014, the Sentinel of Science Award 2016, and the FEPS Learning and Teaching Award 2014 and twice nominated for Tony Jean's Inspirational Teaching Award. He is a shortlisted finalist for The Wharton-QS Stars Awards 2014, the Reimagine Education Award for innovative teaching, and the VC's learning and teaching award in the University of Surrey. He is a Senior Fellow of the Higher Education Academy, U.K.

Dr. Imran has given an invited TEDx talk (2015) and over ten plenary talks, several tutorials and seminars in international conferences and other institutions. He has taught international short courses in USA and China. He is the Co-Founder of the IEEE Workshop BackNets 2015 and chaired several tracks/workshops of international conferences. He is an Associate Editor of the IEEE Communications Letters, the IEEE Access, and the *IET Communications* journal.

MINHO JO (SM'16) received the B.A. degree from the Department of Industrial Engineering, Chosun University, South Korea, in 1984, and the Ph.D. degree from the Department of Industrial and Systems Engineering, Lehigh University, USA, in 1994. He is currently a Professor with the Department of Computer Convergence Software, Korea University, Sejong, South Korea. He is one of the founders of the Samsung Electronics LCD Division. He was the Vice President of the Institute of Electronics and Information Engineers. He is currently the Vice President of the Korean Society for Internet Information. His current research interests include Internet of Things, AI/big data in Internet of Things, LET-Unlicensed, cognitive radio, mobile cloud computing, network security, heterogeneous networks in 5G, wireless energy harvesting, optimization in wireless communications, and massive MIMO. He is the Founder and an Editor-in-Chief of the *KSII Transactions on Internet and Information Systems* [SCI (ISI) and SCOPUS]. He served as an Editor of the IEEE Network. He is an Editor of the IEEE Wireless Communications, and an Associate Editor of the IEEE Internet of Things Journal, *Security and Communication Networks*, *Ad-Hoc & Sensor Wireless Networks*, and *Wireless Communications and Mobile Computing*.

MUHAMMAD NAEEM received the B.S. and M.S. degrees in electrical engineering from the University of Engineering and Technology, Taxila, Pakistan, in 2000 and 2005, respectively, and the Ph.D. degree from Simon Fraser University, BC, Canada, in 2011. From 2000 to 2005, he was a Senior Design Engineer with Comcept (pvt.) Ltd. At the design department of Comcept (pvt) Ltd., he participated in the design and development of smart card-based GSM and CDMA pay phones. From 2012 to 2013, he was a Post-Doctoral Research Associate with the WINCORE Laboratory, Ryerson University, Toronto, ON, Canada. Since 2013, he has been an Assistant Professor with the Department of Electrical Engineering, COMSATS Institute of IT, Wah Campus, Pakistan, and a Research Associate with the WINCORE Laboratory, Ryerson University. He is also a Microsoft Certified Solution Developer. His research interests include optimization of wireless communication systems, nonconvex optimization, resource allocation in cognitive radio networks, and approximation algorithms for mixed integer programming in communication systems. He was a recipient of NSERC CGS Scholarship.

SAAD BIN QAISAR (S'04–M'09–SM'14) received the master's and Ph.D. degrees in electrical engineering from Michigan State University, USA, in 2005 and 2009, respectively. He is currently serving as an Associate Professor with the National University of Sciences and Technology, Pakistan, and also leading Bitsym, an Internet of Things and data-analytics enterprise. He has authored over 60 publications, inventor of various patents, has completed multiple national and international projects and winner of various awards, including the University Best Researcher Award in 2012 and the UNIDO Cleantech Award in 2015, to name a few. His company, Bitsym, has been named among the 50 Most Promising Start-ups for 2012 by Global Entrepreneurship Week, globally.

WEI WANG (S'08–M'10–SM'15) received the B.S. and Ph.D. degrees from the Beijing University of Posts and Telecommunications, Beijing, China, in 2004 and 2009 respectively. From 2007 to 2008, he was a Visiting Student with the University of Michigan, Ann Arbor, USA. From 2013 to 2015, he was a Hong Kong Scholar with The Hong Kong University of Science and Technology, Hong Kong. He is currently an Associate Professor with the College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China. He has authored over 90 international journal and conference papers in the area of wireless communications and networks. His research interests mainly focus on cognitive radio networks, green communications, and radio resource allocation for wireless networks.

Dr. Wang is the Associate Secretary-General of the Zhejiang Institute of Communications. He is the Editor of the book *Cognitive Radio Systems* (Intech, 2009) and serves as an Editor of the IEEE Access, Transactions on Emerging Telecommunications Technologies, and the *KSII Transactions on Internet and Information Systems*. He also serves as the Co-Chair or a TPC Member for several international conferences.

• • •