Guest Editorial Wireless Transmission of Information and Power—Part II

Bruno Clerckx, *Senior Member, IEEE*, Rui Zhang, *Fellow, IEEE*, Robert Schober, *Fellow, IEEE*, Derrick Wing Kwan Ng, *Senior Member, IEEE*, Dong In Kim, *Senior Member, IEEE*, and H. Vincent Poor, *Fellow, IEEE*

THIS second of the two issues on wireless transmission of information and power starts with some works on Simultaneous Wireless Information and Power Transfer (SWIPT), then switches to Wirelessly Powered Communication Networks (WPCNs), and finishes with a few works on Wirelessly Powered Backscatter Communication (WPBC).

Zhou *et al.* formulate a secrecy rate maximization problem for amplify-and-forward (AF) relaying with SWIPT based on directional modulation. The optimization problem is not convex and hence is difficult to solve. The paper provides various solutions (some close to optimal) for this problem under various settings.

Deng *et al.* analyze the energy and rate meta distributions in a Wireless Information and Power Transfer (WIPT)-enabled device-to-device (D2D) network where D2D users are modeled by a Poisson bipolar network and ambient RF transmitters are modeled by a Poisson point process. The new performance measure is the meta distribution of the transferred energy, which is the distribution of the conditional energy outage probability given the locations of the RF transmitters. A new notion of transmission efficiency is also introduced and exploited to design such a WIPT-enabled D2D network.

This work was supported in part by EPSRC of U.K. under Grant EP/P003885/1, in part by the National University of Singapore under Grant R-263-000-D12-114, in part by the Australian Research Council's Discovery Early Career Researcher Award funding scheme under Grant DE170100137, in part by the National Research Foundation of Korea (NRF) Grant through the Korean Government under Grant 2014R1A5A1011478, and in part by the U.S. National Science Foundation under Grant CNS-1702808.

B. Clerckx is with the Electrical and Electronic Engineering Department, Imperial College London, London SW7 2AZ, U.K. (e-mail: b.clerckx@imperial.ac.uk).

R. Zhang is with the Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117583 (e-mail: elezhang@nus.edu.sg).

R. Schober is with the Institute of Digital Communications, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany (e-mail: robert.schober@fau.de).

D. W. K. Ng is with the School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, NSW 2052, Australia (e-mail: w.k.ng@unsw.edu.au).

D. I. Kim is with the Department of Electrical and Computer Engineering, Sungkyunkwan University, Suwon 16419, South Korea (e-mail: dikim@skku.ac.kr).

H. V. Poor is with the Department of Electrical Engineering, Princeton University, Princeton, NJ 08544 USA (e-mail: poor@princeton.edu).

Digital Object Identifier 10.1109/JSAC.2018.2872384

Li *et al.* present a stochastic network analysis to study the throughput maximization problem of a multiuser wireless powered communication (WPC) system under data buffer capacity constraints. It additionally considers finite energy storage capacity, nonlinear energy harvesting circuits, and stochastic data arrivals at the user terminals. The paper proposes an optimal time allocation algorithm for the downlink (DL) power transfer and the uplink (UL) information transfer of the users, where their minimum throughput is maximized. Further, it analytically derives the optimal transmit power in the DL and UL when the throughput is fixed.

Shan *et al.* study the problem of transmission delay minimization for a point-to-point WPC link, considering the arrival time of the data packets and the maximum storage capacity of the energy harvester. The paper first obtains the optimal transmission rate that minimizes the transmission delay for the offline case where packet information is known prior to transmission. This rate is then used for solving the problem for the online case where packets arrive dynamically without prior information, enabling the system to achieve near-optimal performance.

Zewde *et al.* study optimal resource allocation for WPCNs in the presence of delay-limited sources. To this end, they first study the throughput maximization for a single user and multiple users, respectively. Then the energy efficiency optimization is studied for both Time-Division Multiple Access (TDMA) and non-orthogonal transmissions. Given that throughput, delay, and energy are the three fundamental metrics in wireless networks, this paper addresses them in the context of WPCNs, so as to overcome their double near-far problem.

Zhang *et al.* propose a resource allocation scheme to support WIPT over a relay-assisted full-duplex network, in which WIPT is performed via the DL and only information is transmitted via the UL. Power splitting (PS) is used to enable simultaneous WIPT. To maximize the minimal sum of DL and UL rates, the proposed schemes optimize the subcarrier and power allocation, relay selection and PS ratio. To solve the non-convex max-min optimization problem, the paper develops an asymptotically optimal algorithm and a suboptimal algorithm after transforming the problem into a convex one.

Chang *et al.* investigate an energy efficient resource allocation problem for the wireless power transfer (WPT) enabled OFDMA multicell networks. Many antennas at the base stations deliver power in the downlink and the users can recycle and utilize the received energy for uplink data transmission. The paper proposes time, subcarrier and power allocation strategies with the objective of maximizing the energy efficiency under perfect and imperfect channel state information. Performance evaluations are conducted to demonstrate the advantages of the proposed schemes.

Nguyen *et al.* study one-way and two-way multi-pair AF relay networks in which the low-cost relays receive energy from the users for assisting data transmission. To guarantee fairness between user pairs, the max-min energy efficiency is maximized by jointly optimizing the data rates, users' transmit power, relays' processing coefficient, and energy harvesting time for such a network. The paper constructs a relatively realistic energy consumption model and proposes inner approximation based algorithms with low complexity to solve the max-min problems.

Malik *et al.* consider a wireless powered two-hop full-duplex MIMO relay channel. To keep the relay energy-neutral, they propose energy recycling as well as wireless energy transfer from the source. Under the energy-neutrality constraint, with the assumption that the relay uses power division to balance information and energy transfer, the paper develops a convex optimization framework to evaluate the fraction of power that each relay receive antenna requires to do harvesting, and the power allocation on each transmit antenna for the source and the relay.

Li *et al.* propose a joint power transfer, sensing, compression and transmission algorithm for a wirelessly powered crowd sensing (WPCS) application. An operator provides energy to multiple sensors, and each sensor gathers sensory information, compresses the information, and transmits the information to the operator. The sensors are incentivized to provide better data utility by receiving high power allocations from the operator. The paper formulates a joint optimization problem that maximizes the data utility of WPCS while minimizing the power consumption of the operator.

Du *et al.* present the problem of jointly optimizing node deployment, wireless energy transfer and sensor scheduling in a wireless powered sensor network (WPSN), driven by cost considerations (minimizing the number of nodes deployed) as well as quality-of-service requirements (supporting a required sampling rate). The paper decouples the problem into a deployment problem and a recharging and scheduling problem, which ensures the optimality of a greedy algorithm for node deployment, as well as the optimality of shortest lifetime recharging strategies and max energy sensor scheduling.

Psomas *et al.* consider a mmWave WPSN where the access point employs beamforming techniques to transfer energy to the sensors of a selected sector of the cell. This setting is investigated from a large-scale point-of-view where spatial randomness is considered with the aid of Poisson point processes. The network performance is evaluated in terms of the energy outage probability of a sensor in the DL as well as the beam outage probability in the UL. The paper also analyzes the effects of location awareness and event estimation in such a large-scale network.

Li *et al.* develop a novel wireless power transmission system, in which an unmanned aerial vehicle (UAV) equipped with RF energy transmitter charges IoT devices. The paper proposes a prediction-based dynamic charging policy, in which a machine learning framework of echo state networks is used to predict the energy consumption of each sensor node during the next period, and an improved k-means clustering algorithm is employed to implement the clustering for all the sensor nodes, aiming at maximizing the network utility and minimizing data packet losses.

Zhang *et al.* consider expectation maximization (EM)-based clustering methods for joint channel estimation and detection for ambient backscatter. Two detection algorithms are proposed to learn the backscatter symbols by using clustering methods that allow learning mixture parameters from data, without requiring channel state information. The paper models all unknowns relevant to backscatter as constants, and then, based on the complex Gaussian noise of the receiver, models the received signal as a mixture of Gaussians, with mean and covariance matrix estimated using the EM algorithm.

Vougioukas *et al.* deal with frequency shifting based ambient backscatter communications. Both analog and digital tag modulation schemes are considered, and the corresponding receivers are designed for ultra-low power and high performance. A prototype was implemented with low-cost tag, based on FM remodulation principles, demonstrating the transmission ranges up to 26 meters. Additionally, the paper shows that shifted-BPSK with short forward-error-correction coding offers tremendous performance gains with a modulated ambient signal, i.e., modulation of the ambient signal is helpful for the coded scheme.

This concludes the two special issues on wireless transmission of information and power. The breadth of the topics reported in these two issues demonstrates the interest of the community in this new and active research area. It is our hope that those two special issues will stimulate and encourage further research in the broad area of wireless transmission of information and power.

Bruno Clerckx (SM'17) received the M.S. and Ph.D. degrees in applied science from the Université Catholique de Louvain, Louvain-la-Neuve, Belgium, in 2000 and 2005, respectively. From 2006 to 2011, he was with Samsung Electronics, Suwon, South Korea, where he actively contributed to 3GPP LTE/LTE-A and IEEE 802.16m and acted as the Rapporteur for the 3GPP Coordinated Multi-Point (CoMP) Study Item. From 2014 to 2016, he was an Associate Professor with Korea University, Seoul, South Korea. He also held visiting research appointments at Stanford University, EURECOM, the National University of Singapore, and The University of Hong Kong. Since 2011, he has been with Imperial College London, first as a Lecturer from 2011 to 2015, then as a Senior Lecturer from 2015 to 2017, and now as a Reader. He is currently a Reader (Associate Professor) with the Electrical and Electronic Engineering Department, Imperial College London, London, U.K.

He has authored two books, 150 peer-reviewed international research papers, and 150 standards contributions, and is the inventor of 75 issued or pending patents among which 15 have been adopted in the specifications of 4G (3GPP LTE/LTE-A and IEEE 802.16m) standards. His research area is communication theory and signal processing for wireless networks. He has been a TPC member, a symposium chair, or a TPC chair of many symposia on communication theory, signal processing for communication and wireless communication for several leading international IEEE conferences. He is an Elected Member of the IEEE Signal Processing Society SPCOM Technical Committee. He served as an Editor for the IEEE TRANSACTIONS ON COMMUNICATIONS from 2011 to 2015 and is currently an Editor for the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS and the IEEE TRANSACTIONS ON SIGNAL PROCESSING. He has also been a (lead) guest editor for special issues of the *EURASIP Journal on Wireless Communications and Networking*, IEEE ACCESS and the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS. He was an Editor for the 3GPP LTE-Advanced Standard Technical Report on CoMP.

Rui Zhang (S'00–M'07–SM'15–F'17) received the B.Eng. (Hons.) and M.Eng. degrees from the National University of Singapore, Singapore, and the Ph.D. degree from Stanford University, Stanford, CA, USA, all in electrical engineering.

From 2007 to 2010, he was a Research Scientist with the Institute for Infocomm Research, ASTAR, Singapore. In 2010, he has joined the Department of Electrical and Computer Engineering, National University of Singapore, where he is currently a Dean's Chair Associate Professor with the Faculty of Engineering. He has authored over 300 papers. He has been listed as a Highly Cited Researcher (also known as the World's Most Influential Scientific Minds), by Thomson Reuters (Clarivate Analytics) since 2015. His research interests include wireless information and power transfer, drone communication, wireless eavesdropping and spoofing, energy-efficient and energy-harvesting-enabled wireless communication, multiuser MIMO, cognitive radio, and optimization methods.

He was an Elected Member of the IEEE Signal Processing Society SPCOM Technical Committee from 2012 to 2017 and SAM Technical Committee from 2013 to 2015. He serves as a member of the Steering Committee of the IEEE WIRELESS COMMUNICATIONS LETTERS. He was a recipient of the 6th IEEE Communications Society Asia-Pacific Region Best Young Researcher Award in 2011, and the Young Researcher Award of the National University of Singapore in 2015. He was a co-recipient of the IEEE Marconi Prize Paper Award in Wireless Communications in 2015, the IEEE Communications Society Asia-Pacific Region Best Paper Award in 2016, the IEEE Signal Processing Society Best Paper Award in 2016, the IEEE Communications Society Heinrich Hertz Prize Paper Award in 2017, the IEEE Signal Processing Society Donald G. Fink Overview Paper Award in 2017, and the IEEE Technical Committee on Green Communications and Computing Best Journal Paper Award in 2017. His co-authored paper received the IEEE Signal Processing Society Young Author Best Paper Award in 2017. He served as the Vice Chair of the IEEE Communications Society Asia-Pacific Board Technical Affairs Committee from 2014 to 2015. He served for over 30 international conferences as the TPC co-chair or an organizing committee member, and as the guest editor for three special issues of the IEEE JOURNAL OF SELECTED TOPICS IN SIGNAL PROCESSING and the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS. He served as an Editor for the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS from 2012 to 2016, the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS: Green Communications and Networking Series from 2015 to 2016, and the IEEE TRANSACTIONS ON SIGNAL PROCESSING from 2013 to 2017. He is currently an Editor for the IEEE TRANSACTIONS ON COMMUNICATIONS and the IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING.

Robert Schober (S'98–M'01–SM'08–F'10) received the Diploma (Univ.) and Ph.D. degrees in electrical engineering from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany, in 1997 and 2000, respectively. He was a Professor and a Canada Research Chair with The University of British Columbia (UBC), Vancouver, Canada, from 2002 to 2011. Since 2012, he has been an Alexander von Humboldt Professor and the Chair for Digital Communication, FAU. His research interests fall into the broad areas of communication theory, wireless communications, and statistical signal processing.

He is a fellow of the Canadian Academy of Engineering and the Engineering Institute of Canada. He received several awards for his work, including the 2007 Wilhelm Friedrich Bessel Research Award of the Alexander von Humboldt Foundation, the 2008 Charles McDowell Award for Excellence in Research from UBC, a 2011 Alexander von Humboldt Professorship, a 2012 NSERC E.W.R. Stacie Fellowship, and the 2017 Wireless Communication Technical Committee Recognition Award. In addition, he has received several best paper awards for his research and is listed as a 2017 Highly Cited Researcher by the Web of Science. From 2012 to 2015, he served as an Editor-in-Chief of the IEEE TRANSACTIONS ON COMMUNICATIONS. He serves on the Editorial Board of the PROCEEDINGS OF THE IEEE. Furthermore, he is a Member at Large of the Board of Governors, the Director of Journals, and a Distinguished Lecturer of the IEEE Communications Society.

Derrick Wing Kwan Ng (S'06–M'12–SM'17) received the bachelor's (Hons.) and M.Phil. degrees in electronic engineering from The Hong Kong University of Science and Technology in 2006 and 2008, respectively, and the Ph.D. degree from The University of British Columbia in 2012. He was a Senior Post-Doctoral Fellow with the Institute for Digital Communications, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany. He is currently a Senior Lecturer and an ARC DECRA Research Fellow with the University of New South Wales, Sydney, Australia. His research interests include convex and non-convex optimization, physical layer security, wireless information and power transfer, and green (energy-efficient) wireless communications.

Dr. Ng received the Best Paper Awards at the IEEE Third International Conference on Communications and Networking in China in 2008, the IEEE Global Telecommunication Conference in 2011, the IEEE Wireless Communications and Networking Conference in 2012, the IEEE International Conference on Computing, Networking and Communications in 2016, the IEEE Technical Committee on Green Communications and Computing Best Journal Paper Award 2018, INISCOM 2018, and the IEEE International Conference on Communications in 2018. He has been serving as an Editorial Assistant to the Editor-in-Chief of the IEEE TRANSACTIONS ON COMMUNICATIONS since 2012. In addition, he is listed as a 2018 Highly Cited Researcher by Clarivate Analytics.

Dong In Kim (S'89–M'91–SM'02) received the Ph.D. degree in electrical engineering from the University of Southern California, Los Angeles, CA, USA, in 1990. He was a Tenured Professor with the School of Engineering Science, Simon Fraser University, Burnaby, BC, Canada. Since 2007, he has been with Sungkyunkwan University, Suwon, South Korea, where he is currently a Professor with the College of Information and Communication Engineering. He was a first recipient of the NRF of Korea Engineering Research Center in Wireless Communications for RF Energy Harvesting from 2014 to 2021. From 2002 to 2011, he served as an Editor and a Founding Area Editor of Cross-Layer Design and Optimization for the IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS. From 2008 to 2011, he served as the Co-Editor-in-Chief of the IEEE/KICS JOURNAL OF COMMUNICATIONS AND NETWORKS. He served as the Founding Editor-in-Chief of the IEEE WIRELESS COMMUNICATIONS LETTERS from 2012 to 2015. From 2001 to 2014, he served as an Editor of Spread Spectrum Transmission and Access for the IEEE TRANSACTIONS ON COMMUNICATIONS. He is currently serving as an Editor-at-Large of Wireless Communication I for the IEEE TRANSACTIONS ON COMMUNICATIONS.

H. Vincent Poor (S'72–M'77–SM'82–F'87) received the Ph.D. degree in EECS from Princeton University in 1977. From 1977 to 1990, he was on the faculty of the University of Illinois at Urbana–Champaign. Since 1990, he has been on the faculty at Princeton, where he is currently the Michael Henry Strater University Professor of Electrical Engineering. From 2006 to 2016, he served as the Dean of Princeton's School of Engineering and Applied Science. He has also held visiting appointments at several other universities, including most recently at Berkeley and Cambridge. His research interests are in the areas of information theory and signal processing, and their applications in wireless networks, energy systems and related fields. Among his publications in these areas is the recent book *Information Theoretic Security and Privacy of Information Systems* (Cambridge University Press, 2017).

Dr. Poor is a member of the National Academy of Engineering and the National Academy of Sciences, and is a Foreign Member of the Chinese Academy of Sciences, the Royal Society, and other national and international academies. He received the Marconi and Armstrong Awards of the IEEE Communications Society in 2007 and 2009, respectively. Recent recognition of his work includes the 2017 IEEE Alexander Graham Bell Medal, Honorary Professorships at Peking University and Tsinghua University, both conferred in 2017, and a D.Sc. *honoris causa* from Syracuse University also awarded in 2017.